ANALYSIS OF AIR CARGO TRANSPORT SYSTEMS
USING STOCHASTIC SIMULATION

by

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CHAPTER I

INTRODUCTION

Statement of the Problem

A significant problem area related to air freight
transportation is the assignment of aircraft to routes that
encompass one or more transloading points. This problem is
complicated by the fact that shipping quantities fluctuate
at each transloading point, and there may be wide varia-
tions in freight demand over time. If cargo quantities
were to remain stable there would be no need to assign
vehicles with excess capacity, and load requirements along
any route could easily be computed. Such an approach is
taken by some land shippers with low priority goods who
simply wait for enough freight to form a full load before
transporting the merchandise. The air cargo industry, how-
ever, ships high priority goods requiring rapid delivery,
and thus cannot afford the luxury of freight consolidation.

The rapid delivery time expected by shippers using
air freight often precludes the possibility of allowing
cargo to accumulate until aircraft are loaded to capacity.
Consequently, most aircraft depart at scheduled intervals
with some unused capacity. In addition, many aircraft are

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scheduled to stop at one or more terminals where some shipments are delivered and different shipments are taken aboard. This exchange of cargo at transloading points either results in aircraft with unused capacity or forces some shipment to be left behind. Thus, there is clearly a tradeoff between the level of service obtainable and the desired capacity utilization of the aircraft.

In the air cargo industry, aircraft are generally assigned with sufficient capacity to accomodate peak loads likely to be encountered rather than normal loads. Thus, the usual practice is to allow a safety margin of excess capacity above forecasted demand and hope that the aircraft will not experience an excessive number of overloads (shipments which cannot be loaded aboard the aircraft). The stochastic nature of shipment quantities determines the extent of this safety margin and the probability that it will be exceeded. (Figure 1-1 illustrates the effects of forecasted changes or shifts in demand on aircraft load capacity.) Even with a safety margin, aircraft capacity is likely to be exceeded occasionally. An increase in the mean number of shipment units can result in an excessive number of overloads, while a decrease in the mean number of shipment units can result in an excess aircraft load capacity. Changes in the variance or spread of the shipment distribution will have a similar effect.
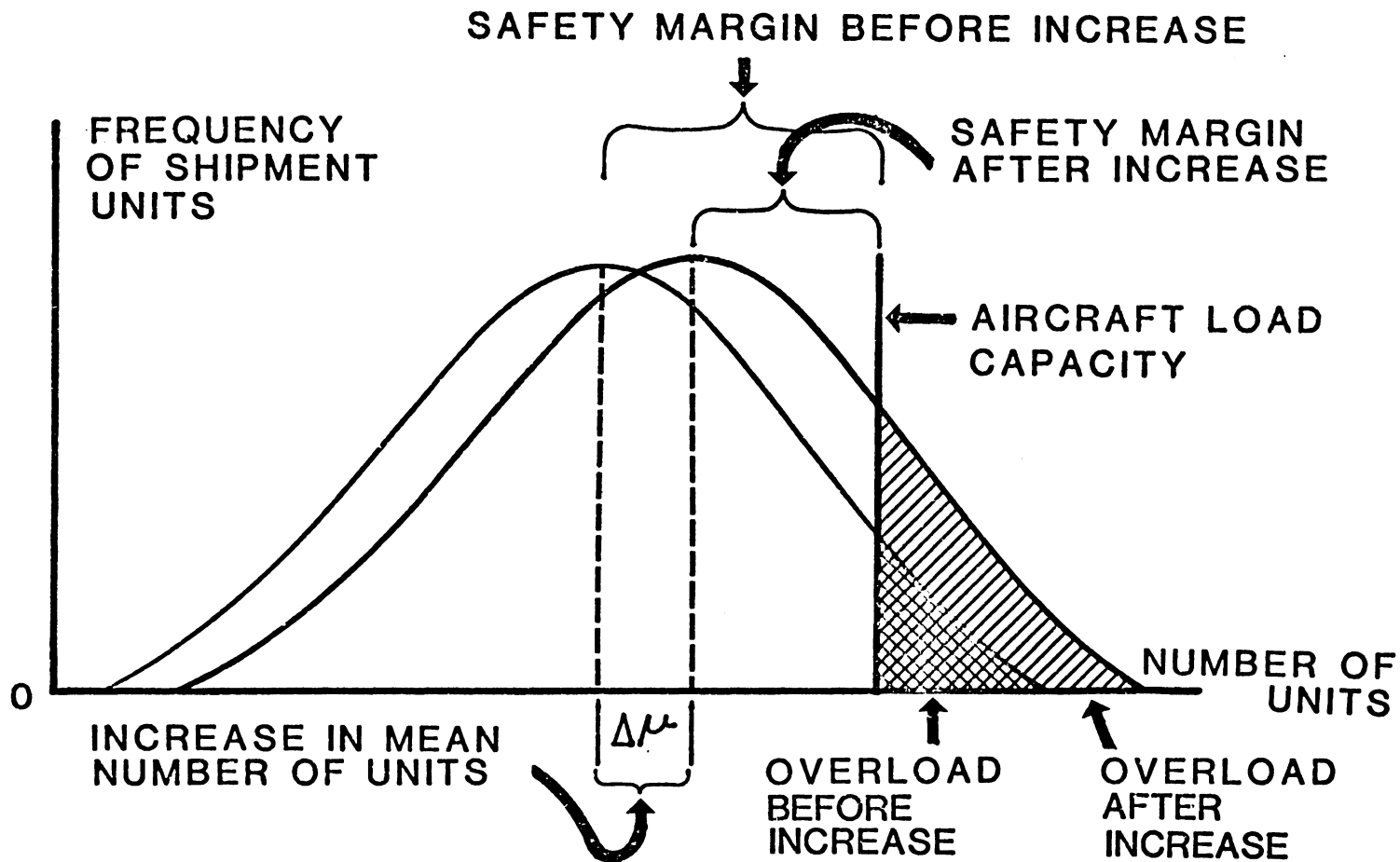
FIGURE 1-1: Effect of Increase in Mean Number of Shipment Units on Overload Condition. (Cross-hatched Areas Under Each Distribution Represent Proportion of Shipment Units That Will Not Fit Aboard Aircraft.)

The problem facing air transportation planners, in general, is that of evaluating aircraft and route pattern combinations so that appropriate vehicles are assigned and a desired level of service is maintained without creating excess capacity. Improved selection and assignment of aircraft could reduce the cost of operation while maintaining acceptable service levels. Both commercial and military air transport systems share similar problems when assigning aircraft to networks of varying degrees of complexity. (A list of terms associated with air cargo transportation is contained in Appendix A.)

Figure 1-1 illustrates the capacity problem when the nature of shipment distributions is known and the route is a simple one served by a single aircraft. When shipment quantities are represented by a distribution such as that shown in Figure 1-1, a slight increase in the mean number of units (μ) can result in a shift to the right which will lower the safety margin and dramatically increase the number of overloads. However, larger air transportation networks include transloading points where cargo is delivered and picked up before the aircraft reaches a final destination. Consequently, the aircraft carries a different load quantity on each leg of the flight, and the aggregate effect on load capacity must be taken into account. This situation can be shown using a "flight load profile" depicted in

Figure 1-2. This illustration shows a flight pattern consisting of five flight legs and six terminals identified by their three-letter codes. The horizontal scale represents miles traveled, while the vertical scale represents tons of cargo. The solid line near the top of the chart indicates the capacity of the aircraft. The profile is formed by line segments that represent the total tonnage carried from point to point. The profile will vary from flight to flight over the same five flight legs due to the variability of cargo quantities and their combined effects on aircraft load requirements.

Shipment arrivals at each terminal create a demand for aircraft services that is satisfied only when the shipments have been delivered to their destination. A particular aircraft can meet the demand for service only if the following conditions are met:

(1) The aircraft stops at the terminal where the cargo is to be loaded.

(2) The destination terminal for each shipment is on the aircraft's itinerary.

(3) The capacity of the aircraft is not exceeded.

In this context, a flight pattern may be regarded as a single-channel, multi-station queue problem in which the aircraft provides a channel for the service of goods arriving at various stations and departing at subsequent stations along the route. If more than one aircraft is used

Aircraft Capacity

Load in 1000's pounds

SUU   NZY   IND   NGU   CHS NIP

T=TCNS
C=CAPACITY

MILES
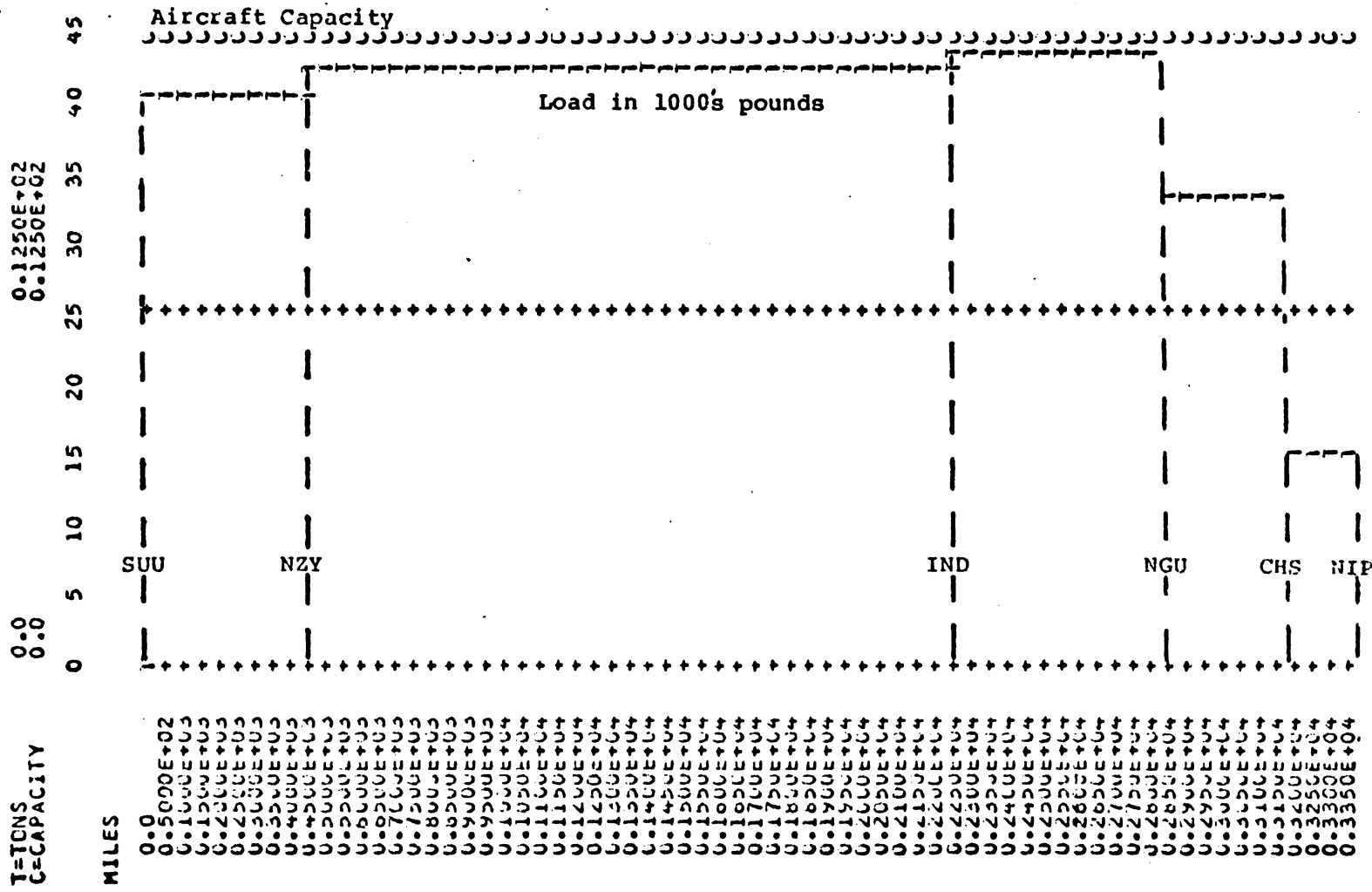
FIGURE 1-2: Flight Load Profile for Flight-132 (Six Terminals) Aircraft Capacity
21.75 Tons. (Data provided by Naval Material Transportation Office,
Norfolk, Virginia.)

to provide services, the flight pattern becomes a multi-channel, multi-station queueing network of some complexity, as illustrated in Figure 1-3.

The queueing features of an air cargo network are further complicated by the inability to regard shipments as homogeneous entities. Shipments can be in various sizes and shapes and require service over varying distances to any of a number of destinations. Different priorities and handling characteristics apply to various shipments; and these features affect the loading and unloading character-istics of the aircraft.

The complexity of aircraft operations creates some difficult problems for air transportation planners. For instance, what is the most appropriate sequence of terminals to include on an aircraft's itinerary? Which aircraft should be assigned to a given route? With what frequency should a given route pattern be flown? To physically ex-periment with the changes indicated in these questions would be time consuming and expensive. Alternatively, a computer simulation model representing an air cargo system would provide air cargo planners with a valuable analysis tool. In particular, an appropriately designed model can be used to evaluate aircraft and route pattern combinations so that appropriate vehicles are assigned and a desired level of service is maintained without creating excessive
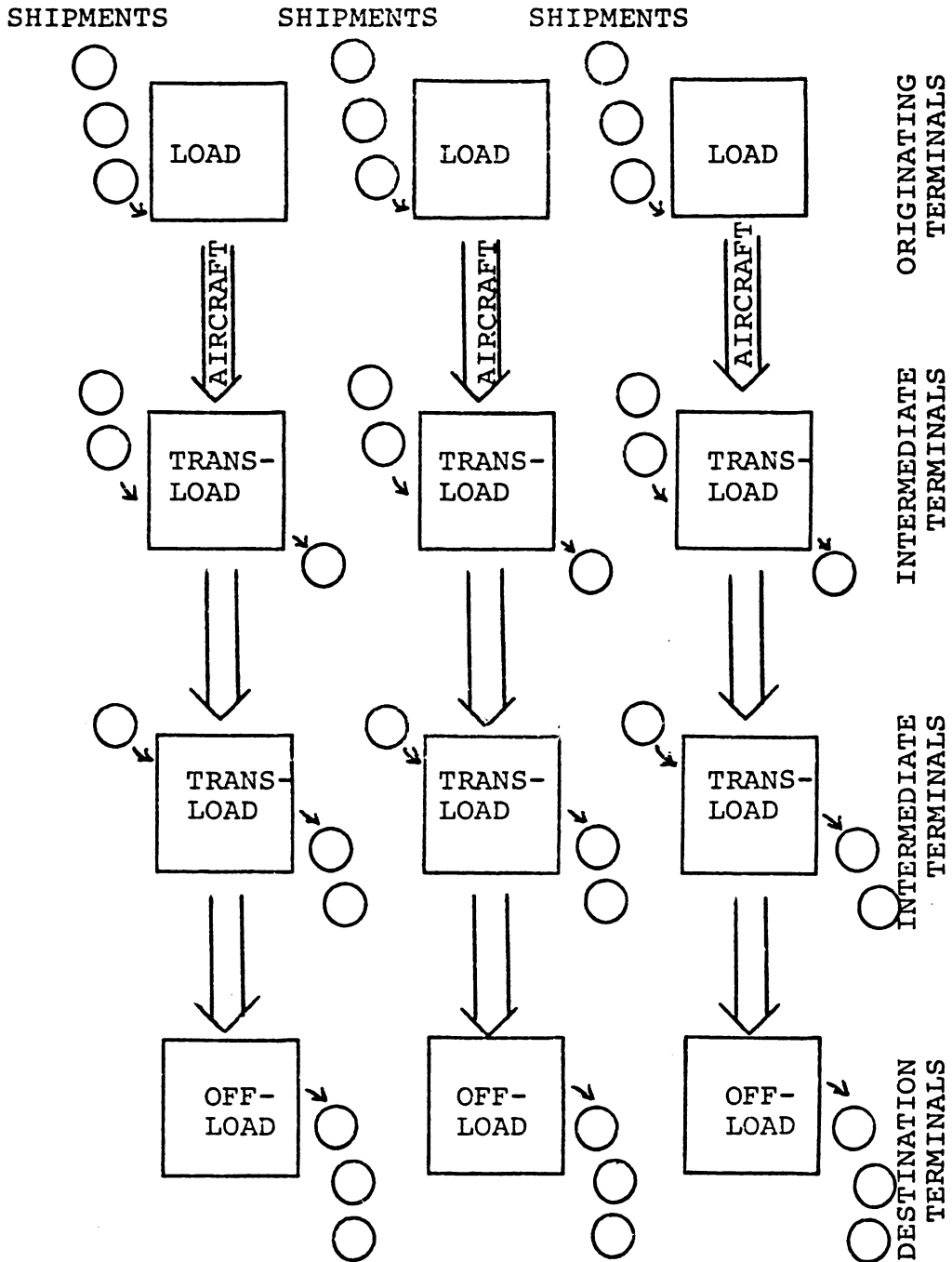
FIGURE 1-3: Air Transport System Depicted as a Multi-Channel, Multi-Station Queueing Network.

capacity. Better selection and use of aircraft can reduce the cost of operation without significant deterioration of service.[1]

Purpose of the Research

This research has been directed toward the development of a computer simulation model and a decision-making framework which will facilitate the selection of aircraft and route pattern combinations in an air transport system involving several aircraft and a number of transloading points. By representing the air cargo system as a dynamic, multi-channel, multi-station, queueing model, the stochastic nature of shipments will be taken into account. The simulation model, called CARGOSIM, has been specifically designed for air transport systems using the terminology and nomenclature appropriate for air cargo distribution networks. However, it is believed that the results of the research will have implications for freight transportation systems in general.

A cargo distribution system has characteristics in common regardless of the particular transportation mode. A network of depots or terminals at varying distances from

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[1]According to a source in the Navy's Material Transportation Office, improved selection of aircraft alone can save the organization over $1 million a year.

each other receive goods to be transported to other depots in the network. Vehicles of limited capacity are routed to the depots where freight or commodities are picked up and delivered according to the needs of the system. Distribution managers must assign the vehicles and schedule itineraries to insure the orderly flow of materials and maintain efficient use of resources. Consequently, the simulation approach developed through this research effort extends beyond the air transport application described herein. The value of this model with respect to other distribution systems is discussed in Chapter VI.

The model has been designed to produce statistics which will enable managers to evaluate proposed aircraft and route pattern combinations before resources (manpower, money and material) are committed to actual operations. Examples of the statistics are as follows:

(1) Load factor (i.e., utilization) of each aircraft over each route;

(2) Delayed shipments at each terminal where queues develop;

(3) Load profile and statistics reflecting the load carried over each leg of a flight itinerary;

(4) Total miles, ton miles, and aircraft landings for specified periods of time; and

(5) Total cost of operation including estimated

cost of service delays.

The simulation model developed in this research will
enable air cargo planners to view their air transport
system as a total system over time, and to estimate resource
requirements and operational capabilities for a given level
of activity. Air transportation planners are able to input
such characteristics as proposed aircraft and route itiner-
aries, and observe the resulting changes in the system.
For example, it may be suspected that a smaller aircraft
could serve a segment of the route structure without caus-
ing a deterioration of service. The simulation model will
indicate the likely effects of such a change. Another con-
sideration might be the addition or deletion of a terminal
from a service route. Again, the impact of the change can
be evaluated using the simulation model.

The research, however, is not complete without an
appropriate decision framework for evaluating the output
of various simulation runs. The simulation model can pro-
vide useful measures of performance, but its effectiveness
depends upon a well-designed decision structure that will
facilitate the selection of appropriate aircraft and route
pattern combinations. Consequently, a specific decision-
making framework has been developed for selecting the least
cost aircraft routing schedule that meets the requirements

of an air transportation network.

The development of a decision-making framework re-
quires a precise statement of the problem and a design
leading to a solution of that problem. For this reason,
the problem is restated as follows:

> From a set of available aircraft and possible
>
> route patterns, select a workable routing schedule
>
> which will minimize total operating cost subject
>
> to given time and service level constraints.

In the literature, this problem falls under the
general class of "vehicle scheduling" problems. According
to Kelly,

> No optimizing algorithms presently exist for deal-
> ing with general vehicle scheduling problems and
> it appears that even if such algorithms did exist,
> they would probably be computationally very com-
> plicated and impractical to use (41, p. 9).

However, it should not be construed from this statement
that good or efficient solutions cannot be found. There
are several techniques that may be employed in a decision-
making framework for this type of problem. These tech-
niques are discussed in greater detail in Chapter IV.

Significance of the Research

Transportation planners are often faced with the
problem of assigning carriers to transport cargo when the
exact size of shipments cannot be predicted in advance.

This problem may be further compounded by a requirement to pick up and deliver additional shipments at various points along the transportation route If some shipments cannot be accomodated, they must wait for available space on another carrier or be transported by an alternative method. These difficulties can cause delays or require special arrangements to be made in order to maintain the flow of materials. In either case, additional costs can be expected. Alternatively, assigning carriers with excess capacity results in inefficiencies and under-utilization, which also drives up costs.

The problem of balancing capacity and service is particularly notable in the air transport industry. Shippers employ air freight primarily for the delivery of products that must reach their destination in a short period of time. The air freight market consists primarily of such critical items as spare parts, medical items, film, high-priority documents, electronic components, chemicals, etc. By actual tonnage statistics, less than one percent of all intercity freight in the U.S. moves by air (72). However, the value of most air cargo is quite high, as this small volume makes up over 25 percent of the total value of domestic commerce (13).

The air freight industry has been cited as one of the fastest growing transportation industries in the nation.

Conservative long-range forecasts indicate that demand for domestic air cargo shipments will grow by 8 to 10 percent annually for at least the next decade (13). Thus, it is not surprising that a number of air freight companies have recently come into existence, and others are expected to appear on the scene in order to exploit this trend. During this period of growth, commercial scheduled airlines which previously received the bulk of the air freight business have experienced serious declines. Statistics published by the Air Transport Association (the scheduled airlines trade group) reveal that total freight tonnage was down 3.8 percent in 1979. One reason for this decline is a shift in forwarder tonnage (i.e., tonnage handled by air freight forwarding companies) to privately owned charter aircraft. In the past, air freight forwarding companies relied primarily on commercial scheduled airlines to transport cargo between major cities. Joseph N. Berg, President of Air Express International, states that the air forwarding industry is becoming increasingly independent of the airlines (52).

One of the most important statistics for air carriers is cargo load factor, which is the percentage of carrier capacity actually used. For passenger airlines, load factors of 80 percent are rarely achieved, and 65 percent is considered a reasonable goal (75). Statistics

published by the Air Transport Association for air car-
riers in 1979 revealed that for all-cargo carriers (air-
craft transporting cargo only), the load factor was 63.5
percent, and for combination (passenger and freight) air-
lines, the load factor was only 27.1 percent (52). Vambery
(75, p. 29), writing about the excess capacity problem in
air transportation, stated that the balancing of capacity
and service is "one of the most difficult tasks faced by
transportation management companies involved in common
carrier service."

The air freight industry is not the only transporta-
tion group facing the problem of balancing capacity and
service (54). For years, the Interstate Commerce Commission
published separate rate schedules for full truck loads (TL)
and less-than-truckloads (LTL). Part of the cost of unused
capacity was passed on to consumers. In other distribution
systems, the efficient use of specialized vehicles such as
mail trucks, delivery vans, tank trucks, and garbage trucks
requires careful scheduling and routing to use their respec-
tive capacities wisely. Virtually all transportation
activities call for some measure of tradeoff between capa-
city utilization and the provision of adequate service.

In air freight, and in many other distribution
systems, the cargo delivery requirements vary such that it
is impossible to predict with certainty the amount of cargo

to be picked up and delivered at each depot on a regular basis. Most facilities use average cargo figures when projecting their distribution needs, and hope that the highs and lows will "sort themselves out." The basis for this research is the assumption that cargo quantities cannot be treated in a simple and arbitrary way. Fluctuations in demand should be analyzed and incorporated into models used for distribution analysis. The stochastic simulation approach described in this document takes this essential feature into account.

The model developed in this research was applied to a specific air transport system in order to demonstrate its value within a realistic framework. The simulation model was used to analyze the distribution requirements of the U.S. Navy's QUICKTRANS network described in the next section.

The QUICKTRANS Air Network

Agencies of the U.S. Government frequently hire charter aircraft companies to provide air freight service on a contract basis. This is particularly true of the military services which consign a significant proportion of their airlift requirements to commercially owned and operated aircraft. The military organizations maintaining the most elaborate air transportation networks are: The

Military Air Lift Command (MAC), The U.S. Air Force
Logistics Command (LOGAIR), and the U.S. Navy's Domestic
Air Cargo Transportation System (QUICKTRANS).

QUICKTRANS (74) is the Navy air-truck transportation
network, designed to provide a controlled, flexible, and
responsive means of transporting urgently required cargo
between terminals of major Navy interest within the con-
tinental United States (CONUS). The goal of the QUICKTRANS
transport facility is to move high priority cargo between
any two QUICKTRANS terminals in a time interval no greater
than 48 hours. The QUICKTRANS transportation system uti-
lizes both air and truck transport units and operates daily
on predetermined time schedules and routes between commer-
cial and military terminals. Eight terminals in the network
are served primarily by air over established trunk lines.
The air service is supplemented by motor carrier freight
delivery to numerous additional points in the overall net-
work. The network is typical of several air distribution
networks incorporating major trunk lines and feeder route
channels (29). The research reported in this dissertation
is focused on the air transportation portion of the Navy
QUICKTRANS system.

The QUICKTRANS transportation system is operated by
the Navy Material Transportation Office (NAVMTO), head-
quartered in Norfolk, Virginia. Currently the information

required to develop the QUICKTRANS route structure is computed manually at considerable expense in manpower and time (47). Thus, a need exists for a more efficient and reliable method of determining QUICKTRANS route patterns and airlift requirements information for planning purposes (35).

This problem has existed for the Navy for quite some time. In 1976, a simulation model called QUAM (47) was developed for the Navy's QUICKTRANS system. The QUAM model, written in FORTRAN, used a static accumulation method to simulate the fixed route segment structure of QUICKTRANS (47). The program made use of historic cargo load data to determine aggregate cargo flow and assigned routes and vehicles according to available segment transport space and cargo space required. It was partially implemented and then abandoned for the following reasons:

(1) An insufficient data base to provide meaningful results;

(2) The program required manual reentry until a satisfactory solution was reached;

(3) It did not take into account fluctuating cargo quantities; and

(4) The output was difficult to read and interpret. The model did not account for day-to-day fluctuations in cargo quantities, nor did it measure the build-up of shipment queues at terminals likely to occur. QUAM required

the input of maximum allowable load factors for each route rather than allowing the aircraft to be loaded to capacity. Thus, load factors were constrained at the outset instead of being computed as a result of process simulation.

Although not recognized at the time, the a priori setting of load factors was a major weakness in this early simulation endeavor. Any solution under these constraints would be limited. Other problems encountered in the use of QUAM by staff members at the Navy Material Transportation Office included maintaining an adequate data base, providing appropriate input to the program, reading and interpreting the output, and accepting solutions which did not recognize loading restrictions, oversize cargo, etc. Experimentation with the computer program was eventually terminated.[2]

Discussion with NAVMTO personnel revealed that a satisfactory solution to the problem had yet to be developed.[3] Transportation planners in the organization indicated their desire to retain control over the route pattern and aircraft selection process. This enables them to insure

[2]Personal communication with A. A. Holloman, Director, Operations Management Department, Naval Material Transportation Office, Norfolk, Va., 1978.

[3]Personal communication with Harry Bordon, Operations Manager, Naval Material Transportation Office, Norfolk, Va., 1979.

that all important variables enter into the decision pro-
cess before a change in route pattern structure is pro-
posed. Since contracts with commercial air carriers are
let on a fiscal year basis, NAVMTO must live with whatever
changes are made for a period of one year before major
alterations can be made.

The NAVMTO planning staff developed several route
patterns and aircraft assignment strategies to be considered
for fiscal year 1979. The projected costs of the various
strategies were compared, and a somewhat laborious procedure
called arrival/departure load analysis was applied to test
the feasibility of each alternative. This procedure was
not always successful in detecting potential bottlenecks
in the system, and it failed to provide reliable measures
of performance efficiency. Thus, the need existed for a
more efficient and reliable method of determining the per-
formance of proposed operational strategies.

The problem confronting the Naval Material Trans-
portation Office had been described in part by a letter
from the Military Airlift Command to the Naval Supply
Systems Command. The letter, dated 2 February 1978, des-
cribed revised procurement requirements for domestic
military cargo air transportation services and the need to
consider alternative carriers in an emerging competitive
environment. Specifically, the Navy had been called upon

to provide the following information:

    (1)   Domestic cargo airlift requirements, including the number of aircraft and their characteristics;

    (2)   The route patterns accompanied with recommended types of aircraft to perform various patterns; and

    (3)   An evaluation of the ability of the various types of aircraft to meet air cargo requirements.

The third requirement was the most difficult to satisfy and constituted a major problem of concern to the Navy's transportation planners. The air transport planning personnel were able to assess the performance of current aircraft and route patterns using the manual procedure of arrival/departure load analysis. However, they were unable to evaluate the performance of proposed aircraft and route pattern combinations using the same process. The manual analysis procedure was too time consuming and did not provide results with sufficient accuracy to make adequate comparisons.

In evaluating the performance of untried aircraft over proposed routes, it was not known whether the aircraft could accomodate the cargo quantities at sequential transloading points (pick-up and delivery depots). At that time, only monthly cargo statistics were available. The aggregate

statistics tended to blur the actual cargo quantities and leave one guessing as to how well the aircraft would perform on a day-to-day basis. It was suspected that unacceptable queues might develop at various depots if insufficient aircraft capacity was assigned. Alternatively, over-assignment of aircraft capacity could lead to under-utilization and inefficiency.

The Navy acknowledged that meaningful cost reductions were possible if appropriate aircraft assignments and flight frequencies could be determined. The air portion of the QUICKTRANS network costs over $20 million annually and efficient changes in route schedules of aircraft assignments could result in savings of more than $1 million a year. Because of this potential, the Naval Material Transportation Office provided a special series of computer runs for use in this research consisting of 90 days of detailed shipping information that included total tonnage to and from all origin-destination points in the air network.

Thus, the NAVMTO planners needed a means to evaluate proposed combinations of aircraft and route schedules, taking into account the frequency of flights and the stochastic nature of shipping quantities. The daily shipment figures provided by the Material Transportation Office were intended for this purpose. The simulation model and decision framework developed as a result of this research effort is adaptable enough to be utilized by other air transport systems

with minor modifications. The availability of a general

simulation model for air transport evaluation provides a

means of system analysis that has not been previously

available. The model has the potential to satisfy a

demand for management information required by other air

transportation services, commercial as well as military.

Scope and Limitations

This research effort has been directed primarily at

developing a dynamic queueing simulation model and decision

heuristic to be used by air transport managers for the effi-

cient selection and assignment of aircraft and route itin-

eraries. The identification of cargo distribution patterns,

development of the simulation model, and the writing of a

decision heuristic constituted the bulk of this research

effort. The simulation model and its associated heuristic

are general enough to allow for the testing of alternative

strategies not specifically identified by NAVMTO for use

in QUICKTRANS.

The most crucial aspects of the research are the

development of a simulation model which takes into account

the stochastic nature of shipping quantities, and a deci-

sion heuristic which leads to a least cost aircraft and

route schedule combination. The simulation model can be

used to represent flight patterns consisting of up to nine

flights in a network of ten depots with as many as five
different types of aircraft included in the aircraft mix.
(With additional dimensioning, the number of flights,
depots and aircraft represented in a single run can be
increased.) Alternative flight patterns can be represented
by subsequent simulation runs in order to observe the
effects of:

(1)   Substituting different types of aircraft;

(2)   Altering the frequency of one or more flights;
and

(3)   Adding or deleting terminals from the network.
Each run results in a number of performance statistics en-
abling managers to review and evaluate the various alter-
natives.

The simulation model provides information on system
performance and service. The formulation and testing of
alternative flight pattern combinations is directed toward
selecting aircraft of appropriate capacity and maintain-
ing a desired level of service. The primary response
variable is the cargo load factor which is used to evalu-
ate the performance of proposed aircraft over various route
patterns. Service is measured by the number and percent of
delayed shipments at different terminals. The model is
used to identify the effects of various flight pattern
combinations on system performance.

Even though the simulation is primarily a perform-
ance evaluation model, it includes the option of producing
cost statistics for each of the alternatives tested. The
model output includes the costs for total miles traveled,
terminal fees for the total number of landings, and total
operating costs. These costs are compared to the cost of
the current system as part of the evaluation procedure.
Examples of model output from the Navy's QUICKTRANS opera-
tion are presented in Chapters III and V.

The simulation model provides transportation managers
with information suggesting the consequences of implementing
different flight patterns. From the output produced by
testing different alternatives, they are able to discard
inefficient selections and select an appropriate strategy.[4]
The computer simulation model provides the requisite infor-
mation. However, a decision-making framework is essential
for the efficient use of the simulation program. The design
and development of a decision framework led to the construc-
tion of a heuristic which facilitates the process of select-
ing a least-cost solution.

The heuristic accepts mean values from several iter-
ations of the simulation model, evaluates the feasibility
of an initial solution, and determines whether or not

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[4]Naval Material Transportation Office, Norfolk, Va.,
personal communication and correspondence, 1979.

improvement is possible. If so, the heuristic changes one or more inputs to the simulation model, accepts mean values from several more iterations, and evaluates the feasibility again. This process continues until a feasible least-cost solution is found. The primary response variable is total operating cost (including a service reduction penalty). The primary control variables are aircraft type and frequency of service for each flight.

By using the simulation model and decision-making heuristic, a large number of aircraft and route schedule combinations can be analyzed. A logical search technique insures that good solutions are not overlooked and that both the cost of operation and the cost of delayed service to various terminals are taken into account. This tandem approach to the analysis of the Navy's QUICKTRANS operation results in an improved aircraft routing schedule and significant cost reduction.

One embellishment of the decision-making heuristic was not tested in this research application. The heuristic was used to consider only one type of aircraft while searching for the best combination of flight frequencies. When a least-cost solution was reached for one type of aircraft assigned to all flights, another type of aircraft was assigned and tested by the same process. Any number of aircraft could be tested in this fashion, and so could a

mix of aircraft (i.e., different aircraft assigned to
different flights within a given flight pattern). However,
the number of possible combinations increases exponentially
when aircraft mixes are considered. The amount of computer
time rises correspondingly and can only be justified if the
nature of the problem requires a thorough evaluation of all
aircraft-flight combinations. Accordingly, an exhaustive
analysis of all possible aircraft mixes was deemed to be
beyond the scope of this research effort.

The primary thrust of the research was to develop a
combination of procedures for analyzing, evaluating, and
selecting appropriate aircraft and flight frequency combi-
nations within an existing network. For this reason, the
problem of optimal route selection (which has been treated
extensively in the literature) was not a major concern.
The Naval Material Transportation Office has only a small
subset of flight paths to consider when making changes in
the routing of aircraft since many routes are governed by
regulation, strategic requirements, and the need to main-
tain a basic defense logistics capability (74). Further
restraints on large scale route changes are determined by
cargo load requirements between major depots. Some flights
must be able to accomodate and transport oversized and out-
sized cargo even when smaller aircraft may appear to serve
a route more economically. These restrictions tend to

reduce the number of practical routing alternatives to a manageable few. Even though the current problem did not necessitate the application of a route finding algorithm, the simulation model is sufficiently flexible to allow for the testing of alternative flight paths in which depots may be added or deleted. To this extent, the model may be of value to organizations evaluating a reasonable subset of alternative flight patterns.

A major limitation encountered by others involved in this field of research has been the lack of available data (78). Department of Transportation statistics aggregate all freight data, losing the all-important mode and origin-destination information essential for statistical analysis. Intercarrier competition in the private sector precludes access to information about many specific companies. Without data on which to base intercity freight demand forecasting, commercial air cargo routes cannot be evaluated effectively (19).

The data for this research project was collected from the U.S. Navy Material Transportation Office (NAVMTO), in Norfolk, Virginia. As indicated previously, this organization operates a domestic air cargo transportation service that covers the continental United States and includes eight terminals in the network served primarily by air.

Some of the findings of this research study are limited to the NAVMTO network in terms of applicability and implementation. There are aspects of a military system that are not duplicated in the private sector enterprise. Even so, there are sufficient similarities to expect that some of the findings may be applicable to other transportation networks. The changes required for implementation in the private sector are discussed in Chapter VI.

Prior Research Related to This Study

The transportation of air freight has been studied by a number of organizations including government, military, commercial, and academic institutions. Government agencies or institutions involved in this research include the Civil Aeronautics Board (CAB), the Department of Transportation (DOT), and the American Enterprise Institute (AEI). Each of these organizations was queried with regard to air cargo studies, and a total of 47 documents were identified.

Military organizations involved in air cargo transportation research are the Military Airlift Command (MAC), the U.S. Air Force Logistics Command (LOGAIR), and the U.S. Navy's Domestic Air Cargo Transportation Service (QUICK-TRANS). Inquiries directed toward the appropriate department in these organizations resulted in the identification of another 112 publications related to air cargo. Commercial

sources include various airlines and air cargo companies, of which the primary all-cargo carriers are Emery Air Freight, Flying Tiger Airlines, and Federal Express Corporation. These companies were willing to make available information not considered proprietary, and another 52 documents were identified. Academic sources are quite numerous and include institutions in Canada and the United Kingdom as well as in the United States. Collectively, another 152 references related to air cargo were identified.

The search for related literature was not limited to references involving air freight alone. A considerable body of knowledge has been developed in the field of logistics and transportation planning. This field includes related studies in network analysis, vehicle scheduling, load planning, distribution, and simulation. Since it was considered likely that computer models developed for systems other than air freight transport might be applicable to air cargo distribution, research efforts in these topics were reviewed as well.

Vehicle scheduling models and algorithms are abundant in the literature. Ever since Clark and Wright (15) developed a "petal" expansion model for scheduling vehicles from a central depot in 1963, many variations and improvements have been reported. Vehicle scheduling techniques generally employ either integer programming or heuristic

programming to produce efficient solutions for problems
which are essentially deterministic. Researchers generally
attempt to improve the applicability of their models by
introducing a wider range of variables, such as multiple
vehicles, variable capacities, and daily alterations in the
number of delivery points (60). Some of the more success-
ful models handle real-life constraints by taking time,
distance, fuel consumption, personnel, and geographic fea-
tures into account. A primary shortcoming of most of these
models is their failure to respond to the fluctuating demand
inherent in the vast majority of distribution systems.

The literature search revealed a number of computer
models designed to solve problems in transportation planning.
However, none of these models considered the stochastic
nature of shipping quantities in a transportation network
involving delivery and pick-up at numerous transloading
points. In almost all cases involving load planning or
vehicle scheduling, fixed cargo quantities were assumed.
A few computer models took variable delivery times into
account, but did not provide for variable shipment quanti-
ties (5, 12, 20). When delivery volume varies, these models
project different solutions for each load and vehicles are
rescheduled accordingly (41, 65). Such models are useful
in vehicle dispatching when an organization has sufficient
flexibility to reassign vehicles on a daily basis, but this

arrangement cannot be applied to systems in which vehicle assignments and route schedules are fixed for periods of time.

Some research has been applied to the problem of fluctuating demand. Baumol and Vinod (5) applied a theoretical model with the assumption that the stochastic elements of the problem satisfy a Poisson distribution. Cook and Russell (20) considered stochastic demand and travel times in a vehicle routing model applied to a refuse collection problem. GPSS simulation was used to analyze travel times and develop frequency distributions of pick-up time error and travel time error. Other logistic simulation models give some consideration to stochastic cargo quantities, but most attention is directed toward stochastic lead times and delivery times (9, 10, 17). The cumulative effect of uncertain pick-up and delivery quantities on various routes can frustrate a seemingly manageable solution. None of the above models address the problem of multiple transloading points.

Transloading provides for the delivery and pick-up of merchandise by a single vehicle at several points along a route; whereas, transhipping provides for the transfer of goods from one vehicle to another at an intermediate point, such as a warehouse or a depot. Transloading is preferred by shippers to avoid excess cargo handling and loss of

accompanying paperwork (27). Some vehicle scheduling models have been developed to consider delivery and pick-up at various depots. Agin and Cullin (3) describe a transportation routing and vehicle loading model called TRAVEL which has been applied to aircraft routing. The model aids the planner by developing movement plans on a period-by-period basis using a time phased network formulation. Kelly (41) developed an algorithm for routing a vehicle with limited capacity such that its available capacity increases and decreases by various amounts along a tour. This algorithm accounts for pick-up and delivery activities, but only when load sizes are known in advance. Hersh and Ladany (33) constructed a mathematical model for assigning passenger seats aboard aircraft with one intermediate stop. A distribution of reservations and cancellations is included in the model, and a Bayesian reassessment of probabilities is incorporated in a sequential decision procedure. The authors suggest that the model may be extended to include multiple intermediate stops. Jansson (38) developed a computational procedure for optimizing service frequency and vehicle size on passenger bus routes. His approach seeks to identify total social cost to passengers as a measure of service level, and then minimize this cost. Jansson's approach may be extended to air cargo if a service cost comparable to social cost could be formulated.

At any rate, bus stops are transloading points, and the
model is applicable in that respect. Each of the models
described above is deterministic, except for the Hersh-
Ladeny model which is designed for operational use in con-
junction with a passenger reservation system. Other
heuristics and optimization models under study are strictly
deterministic and address the assignment of existing or
proposed aircraft to a predetermined network (40).

Simulation has also been used as a modeling approach
for the analysis of air transportation. An early attempt
at simulating air cargo transport was reported by D'Esopo,
Dixon, and Lefkowitz in 1960 (22). This analysis dealt with
a transitory situation in which the start-up phase of an
airlift was simulated for a network containing transloading
points. The model was able to select the number of trans-
port aircraft of each type required when exact cargo quanti-
ties were known at all depots. The analysis was considered
to be complete when the subsequent flow of cargo to the
final destinations could be approximated by a rate of
delivery. The model was deterministic and not designed to
handle uncertain demand or fluctuating cargo quantities.

A more recent simulation effort undertaken in 1976
resulted in the development of a computer model called QUAM,
which used a static accumulation method to simulate the
fixed route segment structure of the Navy's domestic air

cargo system (47). As mentioned previously, the model used historic cargo load data to determine aggregate cargo flow, and it assigned routes and vehicles according to available segment transport space and cargo space required. The model did not account for day-to-day fluctuations in cargo quantities, nor did it detect delays in shipments likely to occur.

A number of dynamic simulation models have been successful at representing and analyzing stochastic systems in physical distribution (9, 10). Dynamic system simulation has become a widely used technique for solving complex problems involving stochastic variables and the analysis of queues (26). Many of the problems in air transportation and logistics have been recognized as queueing problems. Recent articles have suggested that GERT, a network-oriented language, and Q-GERT, a queueing simulation language, could be used more extensively to help analyze problems in logistics (49, 70). Smith (66) conducted two major simulation studies in air transportation which were identified essentially as queueing applications. Several examples of the use of Q-GERT in air transportation have been published in the literature (2, 16, 34, 59). It is expected that other applications will be forthcoming.

A survey of private companies currently engaged in air cargo transport reveal considerable activity with regard

to computer applications and operations research techniques.
A survey of 12 airline companies revealed that systems
analysis and modeling techniques were being applied pri-
marily in five functional areas: regulation, finance,
marketing, traffic forecasting, and operations (14). The
area receiving the most attention is operations, which
includes scheduling of flights and crews, airport opera-
tions, reservations, maintenance, and inventory planning.
Some of the more advanced techniques have been adopted by
air freight companies as their computer facilities reach
the degree of sophistication required to implement various
route-finding algorithms and simulation packages. Federal
Express Corporation uses a computer model based upon the
Clark and Wright (15) vehicle scheduling algorithm to
develop the route structure for a monthly airline schedule.
The model incorporates load factors and demand projections
in order to build an optimized route structure to pick up
and deliver packages expected to be in the system. Another
computer model creates output files that produce flight
plans, traffic control reports, and crew assignment sched-
ules (13). Similar management tools are currently being
used by Flying Tiger Airlines and Emery Air Freight. How-
ever, there is no evidence that simulation models are being
used to analyze aircraft and route pattern combinations in
these companies.

Large-scale efforts to improve air cargo distribution are being conducted by the U.S. Government and the three military services. The Management Science Office of the U.S. Air Force uses operations research and network analysis to optimize logistics airlift systems (23). The Military Airlift Command has applied similar studies to aircraft scheduling and airlift requirements forecasting. The U.S. Army developed a network simulation model for an air cargo terminal to analyze the flow of cargo from sorting to staging and loading for a mission (46). Other simulation projects using origin-destination matrices for both trucks and aircraft were developed by the David W. Taylor Naval Research Center in Washington, D.C. (47). In most cases, the models applied to these systems are tailored to the specific requirements of the organization. None of the studies took into account stochastic shipping quantities in the analysis of transport aircraft and route pattern combinations, even though it was acknowledged that demand fluctuation constitutes a major consideration that cannot be ignored (19, 37, 75). Gunn described the problem as follows:

> Cargo as a payload... has been handled in a very simple and arbitrary way because (1) time and budget have not permitted a more sophisticated treatment, and (2) the data available on an origin-destination basis are regarded as inadequate (31, p. 219).

This review of prior research revealed a number of
air cargo considerations that have implications for this
study. Many of the research reports indicate that cargo
load factor is an important measure of aircraft capacity
utilization. Several studies address the problem of im-
proving cargo load factors while maintaining adequate levels
of service.[5] Accordingly, this study will provide for an
evaluation of cargo load factors as a primary measure of
aircraft utilization.

Prior research studies have also been helpful to the
extent that a number of convenient data formats have been
devised to facilitate the representation of essential infor-
mation for computer analysis. Examples include origin-des-
tination matrices, network diagrams, transport code names,
and city-pair distance tables. Some of these features sug-
gested by previous studies are used in this study to stream-
line data input and output representation.

A number of research studies also address the prob-
lem of fluctuating demand for air cargo service. Several
recommendations have emerged from such studies in an attempt
to accomodate fluctuations in demand. An air cargo system
is effective only if freight can be delivered on time in a
consistent manner. In addition, there is considerable

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[5]An extensive discussion of this problem is included
in Vambery (75).

evidence that prior research studies have suffered from a
lack of available data pertaining to air cargo shipment.
This may explain why many air transport studies regard
shipment quantities as fixed entities despite the fact that
load demand is rarely constant. Very little research has
been directed toward identification of actual air cargo
demand distributions.[6] Since such distributions apparently
were not identifiable, prior researchers did not undertake
the development of queueing models requiring stochastic
input. Consequently, this study may well be the first to
treat air shipments as arrivals in a dynamic queueing
framework.

Plan of Presentation

Chapter II is entitled Description of an Air Trans-
port System. A complete description of the U.S. Navy's
domestic air transportation service is included along with
a brief illustration showing how commercial air freight
service compares with the Navy system. Evaluation consid-
erations are listed and explained along with the performance
measures used to assess the efficiency of flights and air-
craft assignments. Some of the specific problems of air

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[6]Keaton (40) suggests that better utilization of air-
craft might result from a more even distribution of total
demand; however, the true nature of air cargo demand is
highly speculative.

flight scheduling are illustrated and the method of arrival-departure load analysis is explained. The air cargo system is described and analyzed as a queueing problem in which shipments are regarded as "arrivals" to be serviced by the aircraft. The complexity of the system is examined and the need for identifying the stochastic behavior of shipment distributions is discussed.

Chapter III, entitled Construction of the Simulation Model, provides a general discussion of simulation and simulation languages, followed by a clarification of the reasons for the selection of an alternative modeling package called SLAM. The process of identifying stochastic shipment distributions from actual data is described and the nature of these distributions is examined. Distribution parameters are identified and organized for input into the simulation model. The model itself is described in detail with specifications for input, variable names, file names, and output statistics. Examples of input and output are illustrated. The logic of the simulation model is explained in terms of the use of subroutines and files to represent air cargo transactions and events. The chapter concludes with a description of the verificiation and validation process and the results of statistical hypothesis tests used to compare model output with flight performance records.

In Chapter IV, entitled A Decision Framework for the Simulation Model, the model is refined to improve its value as a tool for estimating performance measures within acceptable limits. Statistical concerns are discussed, and a total-cost response function is defined and tested for sensitivity. Its margin of error is determined, and the development of a decision framework is discussed. The decision process includes three iterative steps calling for successive simulation runs within a logical framework. The programming of a heuristic and the search procedure for a least-cost solution is detailed in the latter portion of the chapter.

In Chapter V, entitled Model Application Within A Decision Framework, the simulation and its associated heuristic are demonstrated by using the model for flight pattern analysis and selection of a least-cost solution. A six-flight pattern is tested with five different aircraft until a least-cost schedule is obtained. The same is done with a four-flight pattern. The search process is illustrated by reducing flight frequencies until an efficient solution for each aircraft is found. Computer results are tabulated and output is evaluated from the standpoint of problem constraints and final selection procedure.

In Chapter IV, entitled Summary and Recommendations, the results of the research are summarized and certain

features of combined simulation and search procedure are
noted. The model is presented as a generalized air trans-
port simulation model with potential application in both
military and commercial air transport. Prospective uses
of the model are discussed and wider industry implications
are addressed. The extent to which this research resulted
in improved methodology is considered and avenues for
further research are suggested.

CHAPTER II

DESCRIPTION OF AN AIR TRANSPORT SYSTEM

The QUICKTRANS Air Cargo Network

The domestic air cargo network (QUICKTRANS) maintained
by the U.S. Navy Material Transportation Office consists of
eight terminals served primarily by air. These terminals
are listed below:

Terminal	Code
Norfolk, Virginia	NGU
Indianapolis, Indiana	IND
San Diego, California	NZY
Travis AFB, California	SUU
Charleston, South Carolina	CHS
Jacksonville, Florida	NIP
Dover, Delaware	DOV
McChord AFB, Washington	TCM

A ninth terminal at Pensacola, Florida (Code NPA), currently
served by truck, is under consideration to be served by air.

Three additional terminals in Florida (Patrick,
MacDill, and Key West) and one in Texas (Kelly) are served
by the U.S. Air Force and are not under the operational con-
trol of the Navy. With the exception of Pensacola, there

are no current plans to include any other terminals in the air network. Additional depots are served by motor carrier.

In order for air freight delivery service to be maintained at an acceptable level, the following shipment delivery times are applicable:

Transportation Priority	Delivery Time	Percent Shipped by Air
TP 1	2 days	55%
TP 2	7 days	45%
TP 3	30 days	(negligible)

A complete description of the QUICKTRANS network with route patterns, aircraft, and flight frequencies is given in Table 2-1 and illustrated by the network diagram in Figure 2-1.

System Operation and Evaluation Considerations

The QUICKTRANS air network differs from commercial air freight networks in several important aspects. Commercial air freight companies rarely include as many transloading points in their flight patterns. The "hub and spoke" network developed by Federal Express uses a design which has flights radiating out from central processing points where all air cargo is sorted and assigned to appropriate destinations (13). Aircraft depart at night from the central processing facility to various outlier points, deliver their cargo, pick up additional freight, and return to the central processing point. Changes are made to various route patterns on a daily basis,

TABLE 2-1:   Route Pattern for L-100-30

Patterns Flown and Frequency of Service:

Item: 46,000 pound capacity aircraft, able to carry
        eight 88 x 108 inch pallets

	Great Circle Statute Miles
Flight 172, 7 flights per week	
Originate Travis AFB, CA	
To NAS North Island, CA	467
To Indianapolis, IN (Weir Cook Airport)	1785
To NAS Norfolk, VA	576
To Charleston AFB, SC	350
To NAS Jacksonville, FL	207
TOTAL	3385
Flight 672, 7 flights per week	
Originate NAS Jacksonville, FL	
To Charleston AFB, SC	207
To NAS Norfolk, VA	350
To Dover AFB, DE	158
TOTAL	715
Flight 171, 7 flights per week	
Originate Dover AFB, DE	
To NAS Norfolk, VA	158
To Indianapolis, IN (Weir Cook Airport)	576
To NAS North Island, CA	1785
To Travis AFB, CA	467
TOTAL	2986
Flight 252, 5 flights per week	
Originate Travis AFB, CA	
To McChord AFB, VA	614
To Travis AFB, CA	614
TOTAL	1228

THIS IS QUICKTRANS FY79

WHIDBEY
BREMERTCN
McCHORD
BOSTON
LAKEHURST
MCGUIRE
DAVISVILLE
PQF PHL
NEW LONDON
NSY PHL
WASH
PATUXENT
DOVER
INDIANAPOLIS
INDIANHEAD
DAHLGREN
5
TRAVIS
NORFOLK
EXPANSION TRK/AIR CONTAINER
OAKLAND
(NSC)
CHERRY PT.
PORT HUENEME
7
7 7
PT. MUGU
EXPANSION TRK/AIR CONTAINER
LEMOORE
LONG BEACH
CHARLESTON
EL TORO
LOGAIR
SAN DIEGO
DALLAS
JACKSONVILLE
LOGAIR
PENSACOLA
KELLY
AIR
PATRICK
CORPUS
CHRISTI
MacDILL
LOG 5

AIR TERMINAL
L-100-30 AIR ROUTES
SCHEDULED TRUCK TERMINALS
DEDICATED TRUCK ROUTES
5 FLIGHTS PER WEEK
FREQUENT EXPANSION TRK ROUTES

KEY WEST

FIGURE 2-1: U.S. Navy QUICKTRANS Domestic Air-Truck Cargo Transport System.
(Naval Material Transportation Office, Norfolk, Virginia.)

and a vehicle scheduling algorithm is used to assign air-
craft and destination points. Emery Air Freight and Flying
Tiger Airlines use similar aircraft scheduling techniques.

The QUICKTRANS air system is not reevaluated on a
daily basis. All flights are prescheduled and remain basic-
ally unchanged for at least a year. Another unique charac-
teristic of the Navy's air cargo system is the assignment of
extended flights, particularly on transcontinental routes,
which include a number of transloading points. A substan-
tial amount of air cargo is bound for destinations on the
opposite coast. This situation requires a high degree of
air transport activity on east-west routes as indicated in
the route pattern description in Table 2-1. Furthermore,
air cargo may be destined for any one of a number of termi-
nals, all of which must be served in order to meet the re-
quirements of the system. The quantity of air cargo fluc-
tuates considerably over time, and in any given month there
is likely to be some cargo shipped between every point in
the network. An example of one month's cargo generation is
given in the origin-destination matrix shown in Table 2-2.
It should be noted that there is not a single empty cell in
the origin-destination matrix.

The Navy does not own the aircraft assigned to the
QUICKTRANS network. Each fiscal year, a new contrast is let
to a charter aircraft company which provides the aircraft

TABLE 2-2: Origin-Destination Matrix, Fiscal Year 1979, First Quarter

Origin	Destination								Total
	DOV	NGU	IND	CHS	NIP	NZY	SUU	TCH	
DOV		155.6	10.2	75.2	36.2	55.2	67.1	41.5	441.0
NGU	157.4		4.8	129.7	173.2	199.7	142.4	50.1	857.3
IND	10.5	19.3		10.8	4.6	17.0	16.1	9.2	87.5
CHS	48.4	97.5	9.9		29.9	17.0	34.0	14.3	251.0
NIP	34.3	167.9	5.2	27.1		53.4	58.2	17.8	363.9
NZY	32.4	145.5	5.2	20.2	50.8		217.7	62.3	534.1
SUU	57.2	158.7	11.9	45.2	64.6	255.4		167.0	760.0
TCM	31.2	39.9	10.7	14.5	7.2	42.6	120.4		266.5
Total	371.4	784.4	57.9	322.7	366.5	640.3	655.9	362.2	3561.3

NOTE: All figures represent average tons per month.

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and crews to fly route patterns and schedules assigned by
the Navy. The contracts are specific as to types of air-
craft and frequency of flights, and changes must be renego-
tiated by both parties. The current contract is held by
TIA, a charter aircraft company providing Lockheed L-100-30
air transport service for the U.S. Navy.

There are a number of considerations to be taken into
account when assigning aircraft and route patterns. These
include the following:

·Cargo quantities between origin-destination points;

·Air cargo density;

·Number of terminals in the network;

·Frequency of service;

·Capacity of different aircraft types;

·Aircraft loading characteristics;

·Crew changes and refueling points; and

·Origin and destination of aircraft.

A number of these considerations are of an operational
nature which are, in some respects, unique to the QUICKTRANS
system. For instance, most air cargo is secured on pallets
or half-pallets which are standard throughout the system
(88" X 108" and 88" X 54", respectively). However, some
items extend beyond the dimensions of the pallet and cannot
be loaded as conveniently as others. There are large items,
such as propeller shafts or blades, which must be mounted on
pallet trains before being loaded aboard an aircraft. Pallet

trains consist of two or more pallets joined together to accomodate a particularly bulky load. Shipments of these types are fairly common along some routes.

Consequently, the loading characteristics of each aircraft must be taken into account. These combinations include cargo loading door height and width, side loading or rear loading capability, and cargo compartment cross-sectional curvature and dimensions. These specifications must be considered when assigning aircraft to particular route segments.

Another consideration is air cargo density, which is the weight-to-volume ratio of air shipments. Most shipments are measured by weight, but a number of large volume shipments could cause the aircraft to "cube out" during loading before the weight capacity is reached. If this happens with any regularity, utilization statistics based on weight alone will tend to indicate that an aircraft is operating at less than full capacity, when in fact it may be loaded to full volume capacity. To account for average cargo density, the Navy uses a simple formula that matches air cargo load (ACL) in tons with volume capacity and average cargo density to come up with maximum "cubed out" capacity for each aircraft. This figure is a more realistic measure of the true capacity of each aircraft. Table 1-3 contains a list of capacity figures for the aircraft under consideration.

TABLE 2-3: Capacity of Selected Aircraft Considered for Use in the QUICKTRANS System

Aircraft	Maximum "Cubed Out" Capacity in Pounds	Maximum "Cubed Out" Capacity in Tons	Contract Air Cargo Load (ACL)*
L-100	43,500	21.75	23.0
L-188	30,430	15.215	17.3
DC-9	30,220	15.11	17.4
B-727	35,790	17.895	17.9
DC-8-33F	46,540	23.27	26.0

*ACL is determined by the contractor after taking into account the length of flight segments and the amount of fuel required. For instance, if the full load capacity of an aircraft is 24.5 tons and the fuel requirement at take-off is 1.5 tons, then the air cargo load (ACL) would be 23.0 tons.

Important considerations in determining flight itineraries include fuel stops, crew changes, total flight times, and the location of aircraft. The system must be balanced in the sense that an aircraft must be available at the originating terminal for each assigned flight, and end up at a terminal where it will be available for a subsequent flight. A study of the route pattern presented in Table 2-1 reveals that few of the flights originate and terminate at the same terminal. The actual schedules are arranged so that Flight 172 originates at Travis Air Force Base and arrives at Naval Air Station, Jacksonville, during the early morning hours. Flight 672 uses the same aircraft to fly to Dover Air Force Base. From there, Flight 171 employs the aircraft to return to Travis. A pool of back-up aircraft and maintenance facilities may be maintained at any one or more of these terminals. This decision is normally left to the contractor, but the schedule is designed to facilitate such considerations. A typical schedule is given in Table 2-4.

The flight schedule format in Table 2-4 is familiar to most air transportation managers. The schedule is arranged so that the terminals, listed by code name in the center column, are matched by arrivals and departures with "A" for arrive and "L" for leave in adjacent columns. Flight schedules are shown in remaining columns, with

TABLE 2-4: QUICKTRANS Flight Schedule (All times and days given in Greenwich Mean Time, effective 9 March 1978)

252	171		Trip Identity		172	672
L-100	L-100		Equipment		L-100	L-100
Sun & Tue-Fri	Daily	Oper Days	Terminal	Oper Days	Daily	Daily
	Orig					Term
	0950	L	DOV	A		0720
	1045	A		L		0630
	1200	L	NGU	A		0515
		A		L		0355
		L	CHS	A		0255
		A		L	Term	0200
		L	NIP	A	0030	Orig
		A		L	2330	
		L	CHS	A	2230	
		A		L	2055	
		L	NGU	A	1940	
	1420	A		L	1740	
	1520	L	IND	A	1640	
	2140	A		L	1105	
	2255	L	NZY	A	0950	
Orig	0050	A		L	0800	
0450	Term	L	SUU	A	Orig	
0710		A		L		
0840		L	TCM	A		
1050		A		L		
Term		L	SUU	A		

TABLE 2-4--Continued

L5Q		Trip Identity*		L5Q	73Q
L-188		Equipment		L-188	Truck
Mon-Fri	Oper Days	Terminal	Cper Days	Mon-Fri	Tues-Sat
1925	A		L		Term
2010	L	NIP	A		1200
2050	A		L		
2135	L	COF	A		
	A		L		0340
	L	MCF	A	0140	Orig
2355	A		L	0040	
	L	NQX	A		

*L5Q flights are under the operational control of the U.S. Air Force.

flight number, aircraft type, days operational, and times
of arrival and departure at each terminal. Flight times in
columns to the left should be read from the top down;
flight times in columns to the right should be read from
the bottom up. By using this flight schedule format,
arrival and departure activity at any terminal can be seen
at a glance.

The various factors associated with aircraft selec-
tion just described are typical of the real-life constraints
which often complicate a process to the extent that simple
mathematical models cannot be applied. The scheduling and
assignment of various aircraft to particular route patterns
is currently a trial-and-error procedure built upon experi-
ence and lengthy manual computations. The process does not
lend itself to computer analysis as easily as one might
imagine for a relatively small network.

Under the current arrival-departure load analysis
procedure, an existing (or proposed) aircraft and flight
pattern combination is decomposed into flight segments.
Monthly load figures (such as those contained in Table 2-2)
are then used to develop total tonnage per flight segment.
Ton-miles per segment are computed by multiplying monthly
load figures by segment distances. These ton-miles are
divided by ton-miles available (based on the capacity of the
aircraft) to yield cargo load factors. Cargo load factors

are then used to analyze a flight pattern segment-by-segment
to determine if aircraft are properly utilized and whether
or not changes in the route structure or flight frequency
are necessary.

The problem is further compounded by the stochastic
nature of shipping quantities to and from each of the
terminals. Although monthly or quarterly figures may be
used as averages, the exact size and quantity of shipments
cannot be predicted on a daily basis. The build-up of
shipments at one terminal or another sometimes results in
unacceptable queues or delayed shipments where the aircraft
assigned cannot accomodate all cargo. In this event, ship-
ments must await subsequent aircraft or be rerouted by
truck. In either case, delays occur which force agencies
served by the QUICKTRANS system to seek alternative trans-
port service or complain about a system which is not meet-
ing their needs.

The only flexibility the Navy has when this situation
is encountered is to divert cargo by truck. If the destin-
ation is not too distant, delivery by truck may be an
acceptable alterntive. Consequently, the Navy has been ex-
perimenting with a system by which shippers are asked if
their cargo could be diverted to truck without undue hard-
ship resulting from slower delivery. If so, the shipment
is designated as cargo which may be diverted if it cannot

fit aboard scheduled aircraft. In essence, this is a
priority system within the overall priority system by which
most TP1 cargo is brought into the air network. Monthly
cargo reports are now reflecting this "diversion" designa-
tion by listing separately the tonnage to be shipped by air
and the tonnage which may be diverted to truck.

The use of a diversion strategy may be seen largely
as a stop-gap measure which could conceivably be alleviated
with better scheduling or improved assignment of aircraft.
More aircraft capacity could be allocated to specific route
segments either by increasing the frequency of service or
by increasing the size of the aircraft. Of course, this
action may result in excess unused capacity in other seg-
ments of the route pattern and under-utilization of the air-
craft. The route pattern must be such that it strikes a
balance between the occasional build-up of a queue, with
some diversion of cargo, and efficient utilization of air-
craft over all route segments.

Problem Analysis

An evaluation of alternative route pattern and air-
craft combinations calls for an understanding of basic
system performance. The underlying system is, in fact, a
queueing system in which cargo quantities to be shipped may
be regarded as arrivals, while the aircraft in the system

provide service by transporting the cargo. A queueing system includes entities which come into the system as arrivals to be serviced. Each entity has attributes which may have a bearing on the type of service it receives. The servicing mechanism must accomodate each entity according to a service discipline. Since queues are likely to occur, rules are applied which may limit their size and provide a queue discipline for handling priorities.

In the QUICKTRANS air transport system, cargo shipments are entities with the following attributes:

(1)   Size: length, width, height, volume;

(2)   Weight in pounds or tons;

(3)   Originating terminal;

(4)   Destination terminal; and

(5)   Transportation priority.

Entities come into the system when they arrive at a terminal for transhipment to another terminal in the air network. They depart the system when they reach the destination terminal or are rerouted to transportation facilities outside of the air network.

There are a number of useful measures which enable managers to evaluate the performance of aircraft and route pattern combinations. These include such measures as tons carried per mile, tons carried from point-to-point, total tons delivered on time, total tons delayed, percent

delivered on time, percent delayed, time distribution of
delayed shipments, total ton-miles carried, total ton-miles
available, and utilization of aircraft (load factor). Some
of these measures are equivalent to results obtained from
queueing analysis, such as average queue length, average
waiting time, average time in system, server utilization,
etc. The two primary measures of performance in the air
transport system are:

(1) Load factor (utilization) of aircraft; and

(2) Number of tons and percent of cargo delivered
on time versus number of tons and percent of
cargo delayed.

The above measures make it possible to compare the effect
of alternative strategies with current system performance.
Furthermore, the two measures show clearly the tradeoff
resulting from changes in aircraft utilization and desired
service measured by on-time and delayed shipments. Load
factor is determined by dividing the number of ton-miles
carried by the number of ton-miles available. (Ton-miles
available is a hypothetical figure that would result if the
aircraft were fully loaded over all flight segments. It is
computed by multiplying maximum "cubed out" capacity by the
number of miles traveled.)

The air transport system can be regarded as a fairly
complex multi-channel, multi-station, queueing system. A

system of this complexity cannot be analyzed by using traditional queueing approaches. To do so, a number of simplifying assumptions would have to be made (assumptions such as homogeneous arrival entities, first-come, first-served queue discipline, no balking, no jockeying, etc.), and arrival distributions would have to fit theoretical distributions for which analytical formulas have been derived. Unless the problem lends itself to an analytical solution, extensive modification to fit an existing mathematical model would defeat the purpose for which this study is intended.

The number of origin-destination pairs in a directed (two-way) network is determined from the formula:

$$_nP_2 = n(n-1)$$

where n = number of nodes (terminals) in the network. Thus, a network consisting of eight nodes could have shipments between 56 origin-destination points, each of which must be accomodated by the transportation system. The addition of one node in the network increases the number of origin-destination shipment pairs to 72.

Shipments are generated at every node in the network and can be destined for any other node. Sizes and weights of shipments varied considerably and frequency distributions needed to be determined for each origin-destination pair. Initially, the probability distributions of shipment

arrivals were unknown. This exercise was a primary activity in the research effort, and a computer program called SIMFIT was used to facilitate the identification of shipment distributions.

Since the air transport system has been interpreted as a fairly complex queueing system, an appropriate vehicle for its analysis would be a discrete event simulation program. A simulation model is preferred for this analysis for several reasons:

(1) Actual cargo distributions can be simulated using random number generators. Distribution patterns may not meet the assumptions of theoretical models which generally reduce probability assessments to certainty formulations for computational purposes.

(2) Existing and proposed aircraft and route pattern combinations can be evaluated without the cost, risk, and expenditure of time involved in experimenting with the real process.

(3) A simulation model that successfully represents a real-world system can assist in identifying interactions and repercussions of various flight pattern combinations. Important variables can be identified with regard to their interaction and effect upon system performance.

(4) Successive simulation experiments used in con-
     junction with an appropriate decision heuristic
     can provide the information needed to develop
     improved solutions subject to realistic opera-
     tional constraints.

Summary

This chapter has included a description of the QUICK-
TRANS air cargo network and the means by which each of the
terminals is served. Some differences between commercial
and military operations were noted, and specific features
of the Navy's air cargo system were discussed. Also listed
were a number of considerations to be taken into account
when assigning aircraft and route patterns.

The chapter included an explanation of aircraft
loading characteristics, weight-to-volume ratios, and cargo
density. These features are taken into account when comput-
ing the capacity of aircraft. Some of the specific problems
of air flight scheduling were illustrated, and the method
of arrival/departure load analysis was explained. Cargo
load factor was identified as an important measure for the
assessment of flight and aircraft efficiency.

The air cargo system was described as a complex
queueing problem in which the number and size of shipments
vary from day to day and from terminal to terminal. The

need to identify the stochastic behavior of shipment dis-
tributions was discussed, and a simulation model was
suggested as an appropriate vehicle for analysis. Chapter
III presents a specific model for the simulation of the
air cargo system, and describes its construction.

CHAPTER III

CONSTRUCTION OF THE SIMULATION MODEL

System Modeling and Simulation Language

Simulation is a method for deriving solutions to a problem when analytic and numerical solution methods break down. Mize and Cox (50) state that analytical methods are simply not available for many complex system problems, such as large scale queueing problems; and numerical methods are too costly in many cases when the system being studied contains random variable components. Simulation has been found to be an extremely effective tool for dealing with queueing problems involving multiple channels in parallel or in series (51). Some computer simulation languages have been written for the express purpose of solving or providing insight into queueing type problems.

There are several programming languages which may be used for this class of problems. A general purpose language such as FORTRAN or ALGOL provides the analyst with considerable flexibility and the option of tailoring components of the program to meet the particular needs of the problem under study. There is less rigidity in the structure of these languages, and their program repertoires contain

numerous instructions and statements. Special purpose languages, on the other hand, have been written specifically for simulation applications. These include such languages as GPSS, SIMSCRIPT, GASP, DYNAMO, Q-GERT, SIMULA, TRANSIM and SLAM. These program packages have been developed to: provide a generalized structure for designing simulation models; facilitate the conversion of a model into a computer program; allow changes to be made without extensive reprogramming; and provide a number of useful outputs for statistical analysis. They permit an analyst to achieve considerable reductions in programming time and make use of pre-programmed characteristics common to most simulation models. The simulation language best suited for a particular study depends upon the nature of the system and the programming skill of the analyst.[1]

The selection of a simulation programming language was made quite easily with the emergence of SLAM (Simulation Language for Alternative Modeling) in 1979. SLAM provides a framework by which simulation models may be designed using network symbols, process statements, differential equations, or any combination cf the above. Network modeling is most appropriate when the system under study can be represented

_____

[1]A further discussion and comparison of simulation languages may be found in Naylor, et al. (51, Ch. 7) and Fishman (26, Ch. 4).

by the combined relationship of events and activities repre-
sented by symbols and the process statements that identify
them. Differential equations may be used to represent
system status variables over time when the rate of change
can be determined by specific functional relationships.
The behavior of a system may be categorized as discrete
when status variables change only at event times, or con-
tinuous when status variables change continuously over
simulated time. SLAM provides the capability for modeling
discrete, continuous, and combined interactions using net-
work, discrete event, or continuous simulation techniques
(57).

The air transport problem has already been described
as a complex queueing problem for which the simulation
approach offers considerable potential. Since the status
of the system changes when an aircraft loads, transloads,
or unloads at a terminal, these occurrences can be regarded
as events in simulation terminology. These events precipi-
tate changes in aircraft load, shipment queue lengths, and
other variables which tend to remain relatively fixed be-
tween event times. In addition, the arrival of shipments
as air freight at various depots also affects the queue of
waiting shipments. For the purpose of simulation modeling,
however, significant system chnges do not occur while the
aircraft is in flight. (Minor in-flight alterations, such

as fuel consumption and cost-per-mile considerations can be computed at event times, thus eliminating the need for continuous activity scanning.) Consequently, a simulation model for the air transport system can be developed using discrete simulation and a "next event" methodology. A complete dynamic portrayal of the state of the system can be obtained by advancing simulated time from one event to the next.

The discrete simulation features of SLAM are used to develop a model that can simulate the pick-up and delivery of shipments at various points, compile flight load and summary statistics, and produce output showing the effect of various strategies and options managers may wish to implement. Discrete-event simulation methodology is employed to represent the loading and unloading of aircraft over time and distance.

Another feature of SLAM which makes the language particularly desirable for this type of modeling is the extent to which user provided subroutines can be used in conjunction with SLAM functions and subroutines. A set of standard sub-programs is provided by SLAM for use by the modeler to perform common discrete event functions such as event scheduling, file manipulation, statistics collection, and random sample generation. All SLAM subroutines are written in FORTRAN, and the modeler can develop additional

subroutines in the same language for the purpose of defin-
ing events and changes that occur at event times. The SLAM
executive program controls the simulation by advancing time
and initiating calls to the appropriate event subroutines.
The power of the language and the flexibility afforded the
user make SLAM particularly suitable as the vehicle for
this simulation endeavor.

It should not be construed, however, that SLAM is the
only simulation package that could have been selected for
simulating an air cargo transport system. Other languages
and methodologies have been used to simulate air cargo and
related transportation/distribution systems (9, 17, 30, 66,
70). SLAM is only unique to the extent that it embodies
the capabilities of several other languages, such as GASP,
Q-GERT, and DYNAMO, and offers a number of additional
features as well. Furthermore, the language is readily
available and can be compiled on any sizeable system with
FORTRAN compiler capabilities.

Preparation of Stochastic Input

For a 91-day period from January 6 to April 1, 1979,
the Naval Material Transportation Office kept daily records
of the amount of shipping coming into the air system. These
records included the tonnage originating at each of the
QUICKTRANS flight points for transportation by air. In a

queueing sense, these shipments represented "arrivals" which
were to be served by the transport system. (Some could not
be accomodated by available aircraft and had to be diverted
to truck, usually after several days delay.) For each
origin-destination pair, this data contained a sample of 91
individual values measured in tons of cargo available for
shipment. There were a total of 56 such samples in this
application.

Each origin-destination (O-D) pair represents a pop-
ulation of shipments, past, present and future, for which
the underlying probability distribution had to be identi-
fied. In order to prepare this data for a simulation model,
each sample was subjected to frequency distribution analysis
using a program called SIMFIT. The SIMFIT program was
developed by the Air Force Institute of Technology to facili-
tate the application of curve-fitting techniques on samples
representative of total populations (28). The program pro-
vides for the fitting of data using any of the classical
distributions, and testing with the Chi-square and Kolmogorov-
Smirnov hypothesis tests. A sample histogram and test for
an Erlang distribution is illustrated in Figure 3-1 and
Table 3-1.

Each of the 56 samples was subjected to the curve-
fitting and hypothesis testing procedure. A 95 percent con-
fidence level was applied throughout. The results are

HISTOGRAM OF DATA AND CURVE APPROXIMATION

```
            LEGEND
               I     HISTOGRAM
               •     FITTED TO ERLANG
               *     HISTOGRAM AND FUNCTION

          0.0        2.5        5.0        7.5       10.0       12.5       15.0       17.5
           *          *          *          *          *          *          *          *
LT MIN*.
   0.5  *.I.IIIIII
   1.5  *.IIIIIIIIIIIII.III
   2.5  *.IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII.IIIIIIIIII
   3.5  *.IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII1
   4.5  *.IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII.II
   5.5  *.IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII.IIIIIIIIIIII
   6.5  *.IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
   7.5  *.IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
   8.5  *.IIIIIIIIIIIIIIIIIIIIIIIIIIIIIII.I
   9.5  *.IIII
  10.5  *.IIIIIIIIIIIIIII.IIIIIIIIIIIIIIIII
  11.5  *.IIIIIIIIII.IIIIIIIIIIIIIII
  12.5  *.IIIIII.II
  13.5  *.III.IIIIIIII
  14.5  *.    •
  15.5  *..
  16.5  *..
  17.5  *.
  18.5  *.
  19.5  *.
  20.5  *.
  21.5  *.
GT MAX*.
  22.5  *.
  23.5  *.
  24.5  *.
  25.5  *.
  26.5  *.
  27.5  *.
```

FIGURE 3-1:   Distribution of Tons of Cargo Shipped Daily From NZU to NZY, Second Quarter, FY80.

Table 3-1: An Example of SIMFIT Analysis Showing the Computed Value of Cells Generated for An Erlang Distribution (Variable X represents Tons of Cargo Shipped Daily from NZU to NZY, Second Quarter FY 80.)

Sample Ave   =   6.27
Sample Std   =   3.28

Max Error   =   0.076
Prob (0.05, Num 91)   =   0.143
If error is LE Prob Accept the Distribution

Cell No.	X	Probability CUM	Per Cell	Frequency Actual	Theory	Absolute Error	Chi Square
1	0.5	0.007	0.007	2	0.7	0.015	
2	1.5	0.045	0.038	4	3.5	0.021	
3	2.5	0.131	0.086	10	7.8	0.045	0.6178
4	3.5	0.255	0.124	7	11.3	0.002	1.6142
5	4.5	0.395	0.140	13	12.7	0.001	0.0058
6	5.5	0.531	0.136	15	12.4	0.030	0.5601
7	6.5	0.650	0.119	7	10.9	0.013	1.3703
8	7.5	0.747	0.097	7	6.8	0.033	0.3910
9	8.5	0.823	0.075	7	6.8	0.031	0.0034
10	9.5	0.878	0.056	1	5.1	0.076	3.2686
11	10.5	0.918	0.040	7	3.6	0.039	
12	11.5	0.946	0.028	6	2.5	0.001	
13	21.5	0.965	0.019	2	1.7	0.002	
14	13.5	0.978	0.013	3	1.1	0.022	
15	14.5	0.986	0.008	0	0.8	0.014	
16	15.5	0.991	0.005	0	0.5	0.009	
17	16.5	0.997	0.003	0	0.3	0.005	
18	17.5	0.997	0.002	0	0.2	0.003	
19	18.5	0.998	0.001	0	0.1	0.002	
20	19.5	0.999	0.001	0	0.1	0.001	
21	20.5	0.999	0.001	0	0.0	0.001	
22	21.5	1.00	0.000	0	0.0	0.000	

K=4   Chi Sq 11.0700   SUM   7.8310

summarized as follows:

    (1)   Exponential distributions - 21;

    (2)   Erlang distributions - 16;

    (3)   Mixed discrete-exponential distributions - 17;

            and

    (4)   Unidentified (empirical) distributions - 2.

In addition to identifying the nature of each origin-destination shipment distribution, various parameters were estimated by computing sample statistics. Each distribution can be identified by key parameters which become the input for the simulation model. Furthermore, each distribution (except for those that remain unidentified) can be represented by two parameters. The first parameter, named PARAMETER ONE, identifies the nature of the distribution, and is used by the simulation model to branch to whatever logic will generate an appropriate random value. The second parameter, named PARAMETER TWO, is a point estimate of the mean for each shipment population. This value is also used by the random number generator.

The most convenient method for preparing these parameters for simulation input was to use two matrices, one for PARAMETER ONE, and the other for PARAMETER TWO. The two matrices are illustrated as the second and third matrix in Table 3-2. The values in the PARAMETER ONE matrix require further explanation.

TABLE 3-2: Input Data For Route Pattern Simulation of
            Transport Network Consisting of 8 Terminals

DISTANCE MATRIX

Destination

Origin	TCM	SUU	NZY	IND	DOV	NGU	CMS	NIP
TCM	0.	614.	1035.	1873.	2402.	2440.	2420.	2458.
SUU	614.	0.	467.	1909.	2484.	2480.	2368.	2350.
NZY	1035.	467.	0.	1785.	2362.	2327.	2152.	2096.
IND	1873.	1909.	1785.	0.	590.	576.	585.	704.
DOV	2402.	2484.	2382.	590.	0.	0.	500.	707.
NGU	2440.	2480	2327.	578.	158.	350.	350.	556.
CMS	2420.	2368.	2152.	585.	500.	556.	0.	207.
NIP	2458.	2350.	2096.	704.	707.		207.	0.

STOCHASTIC SHIPMENT VALUES FOR PARAMETER ONE

	TCM	SUU	NZY	IND	DOV	NGU	CMS	NIP
TCM	0.0	2.0	1.0	99.0	1.0	1.0	29.0	46.0
SUU	2.0	0.0	2.0	33.0	1.0	2.0	1.0	1.0
NZY	2.0	4.0	0.0	41.0	1.0	3.0	14.0	1.0
IND	43.0	31.0	29.0	0.0	45.0	24.0	34.0	99.0
DOV	1.0	1.0	1.0	49.0	0.0	2.0	1.0	1.0
NGU	2.0	2.0	4.0	38.0	2.0	0.0	2.0	2.0
CMS	1.0	1.0	1.0	54.0	1.0	2.0	0.0	18.0
NIP	1.0	1.0	1.0	52.0	1.0	2.0	44.0	0.0

STOCHASTIC SHIPMENT VALUES FOR PARAMETER TWO

	TCM	SUU	NZY	IND	DOV	NGU	CMS	NIP
TCM	0.0	5.43	1.70	0.0	1.43	0.99	0.64	0.39
SUU	8.64	0.0	7.12	0.81	1.88	5.76	1.65	1.72
NZY	2.59	7.75	0.0	0.50	1.83	5.95	1.15	0.94
IND	0.42	0.52	0.59	0.0	0.43	0.76	0.42	0.0
DOV	1.36	2.44	1.89	0.35	0.0	5.32	2.29	0.91
NGU	2.28	4.83	6.27	0.50	5.91	0.0	4.09	3.66
CMS	0.59	1.23	0.78	0.39	1.71	3.39	0.0	0.68
NIP	0.54	1.31	0.74	0.32	1.24	4.13	0.47	0.0

Most of the shipments were identified (with 95 percent confidence) as being Erlang distributed or exponentially distributed. Since the Erlang distribution is a convolution of k exponential distributions and there is only one other parameter in the probability density function, the value of k (a positive integer) serves to distinguish between the two.[2] Consequently, a PARAMETER ONE value of 1 identifies an exponential distribution, while a PARAMETER ONE value of 2, 3, 4, or 5 identifies an Erlang distribution. (The example in Table 3-1 shows an Erlang distribution with a k value of 4.)

The third type of distribution identified using the SIMFIT program was a mixed distribution with a discrete endpoint. This type of distribution was associated with low volume O-D pairs containing a number of zero-shipment days. By counting the number of zero-shipment days and dividing by sample size, the probability of zero shipments is easily computed. This probability constitutes the discrete endpoint of the distribution. The remainder of each mixed distribution behaves exponentially, and a random number generator is included in the simulation model to generate appropriate random values. A PARAMETER ONE value representing the number of zero shipments in the sample (a number

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[2]For a further discussion of these distributions and their probability functions, see Naylor et al. (51, pp. 87-88).

between 5 and 99) signals the call to this generator.

There were only two very low volume O-D pairs which could not be associated with any classical distribution. These had to be treated as empirical discrete distributions with their probability values included in the simulation model. A call to these values (for the purpose of random number generation) is accomplished by a PARAMETER ONE value of 99.

The two matrices shown in Table 3-2 constitute the stochastic input for the simulation model. The large number of Erlang and exponential distributions obtained is not surprising since arrivals in many queueing applications tend to follow exponential (or a combination of exponential) distributions (50). Additional inputs for the simulation model are not stochastic and could be obtained through a relatively straightforward data collection effort. These inputs are specified in the next section of this chapter.

Model Specifications

All input for the air transport simulation model was encoded onto 80-column punch cards. The model is designed to accept this information and provide a recap of all input values. The input for the model was considered in two groups: input which remains relatively stable with regard to the air transport network, and input which changes from

run-to-run as a result of alternative flight pattern combination strategies to be tested. The first category of input data includes the following:

(1) The number of terminals in the air network and their transportation codes;

(2) The distance between each terminal (represented as a matrix); and

(3) The parameters associated with shipment arrival distributions for each origin-destination pair (represented by two matrices).

This category of input for the QUICKTRANS model is illustrated in Table 3-2. The distance matrix shows the distance in miles between each origin-destination pair. The stochastic shipment values in the other two matrices were described in the previous section of this chapter.

The second group of input values was provided by management for each aircraft and route pattern combination:

(1) Aircraft flight number and itinerary including origin, destination, and all transloading terminals;

(2) Frequency of service (days of the week) assigned for each flight;

(3) Aircraft type and maximum "cubed out" capacity in tons;

(4) Aircraft cruising speed in miles per hour;

(5) Contract cost and fuel adjustment cost per mile;

(6) Landing or terminal fee; and

(7) Flight number to which each aircraft type is assigned.

A recap of the input values for one QUICKTRANS flight pattern combination is illustrated in Table 3-3. The flight pattern description begins with a point number assigned to each terminal code. Point numbers are used to describe the flight path of each numbered flight. Using flight 172 as an example, the flight path is indicated in the third column and begins at point 2 (SUU or Travis). Shipments are loaded for points 3, 4, 5, 6, 7 and 8 as shown under SHIPMENT DESTINATIONS. Since point 5 (Dover) is not on the flight path, shipments destined for Dover are off-loaded at point 6 (NGU or Norfolk) for transhipment to Dover on a later flight. (Note the 5 under DESTINATIONS TO BE TRANSHIPPED in the same row as FLIGHT PATH point 6.) At each terminal, shipments destined for that point (or a later transhipping point) are off-loaded, and shipments destined for subsequent points are loaded. Flight 172 terminates at point 8 (NIP or Jacksonville) and no further shipments are loaded. Each of the four flight itineraries can be interpreted accordingly. A total of nine flights may be considered in one flight pattern combination.

TABLE 3-3: Flight Pattern Description

Terminal Code	TGM	SUU	MZY	IND	DOV	NGU	CHS	NIP
Assigned Point No.	1	2	3	4	5	6	7	8

Flight Number	Flights Per Week	Flight Path	Shipment Destinations										Destinations To Be Transhipped									
172	7	2	3	4	5	6	7	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		3	4	5	6	7	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		4	5	6	7	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		6	7	8	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
		7	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
672	7	8	7	6	4	3	2	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0
		7	6	4	3	2	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		6	5	0	0	0	0	0	0	0	0	0	4	3	2	1	0	0	0	0	0	0
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
171	7	5	6	7	8	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		6	4	3	2	1	0	0	0	0	0	0	7	8	0	0	0	0	0	0	0	0
		4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
252	5	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1	2	3	4	5	6	7	8	0	0	0	0	0	0	0	0	0	0	0	0	0
		2	0	0	0	0	0	0	0	0	0	0	3	4	5	6	7	8	0	0	0	0

TABLE 3-3: Continued

AIRCRAFT DATA

Aircraft Type	Capacity in Tons	Speed	Cost Per Mile	Cost Per Landing	Flight No. Assigned
L-100-30	21.750	245.	7.29980	250.00	172 672 171
L-188	15.220	240.	5.76000	250.00	252

The remaining input for the simulation model is il-
lustrated in Table 3-3 in AIRCRAFT DATA. Each of these
remaining entries is self-explanatory for the most part.
All costs are in dollars. The first type of aircraft, an
L-100-30 (Lockheed Hercules) is assigned to flights 172,
672, and 171. The second type of aircraft, an L-188 (Lock-
heed Electra) is assigned to flight 252. In this particular
example, the Electra was substituted for the Hercules
(which was normally assinged to all flights) for the purpose
of analyzing performance and cost with a smaller aircraft.
The simulation model can accept up to five different air-
craft types assigned to various flights.

Table 3-4 lists and defines the variables used in
the simulation model. There are five categories of vari-
ables listed. The first category consists of input varia-
bles which represents most of the values discussed earlier
in this section. The second category consists of attribute
variables which will be discussed further in connection
with particular files. The third category lists those
variables provided by SLAM for use in the simulation model.
The fourth category contains a list of intermediate or work-
ing variables used throughout the model logic for computa-
tion, temporary storage, or other purposes. The last cate-
gory lists the many variables used for statistical data
collection and output from the model.

TABLE 3-4:   Simulation Model Variables and Definitions

Input Variables	Definition
NPTS	Number of points in network
TCODE(I)	Terminal code
DIST(K,J)	Distance between origin-destination pairs
PAR1(I,J)	First shipment distribution parameter for O-D pairs
PAR2(I,J)	Second shipment distribution parameter for O-D pairs
IFLT(I)	Flight number
IFREQ(I)	Flight frequency
LOC(K,J)	Location or point on flight path
ID(I,J,K)	Shipment destination point
IT(I,J,K)	Transhipment point
TYPE(I)	
TYP1(I)	Aircraft types (alphanumeric)
TYP2(I)	
CAP(I)	Capacity of aircraft in tons
SPEED(I)	Speed of aircraft in miles per hours
CPM(I)	Cost per mile in flight
CPL(I)	Cost per landing
NFLT(I,J)	Flight number to which aircraft type is assigned

Attribute Array	Definition	Buffer Array
A(1)	Priority of shipment	B(1)
A(2)	Destination of shipment	B(2)
A(3)	Quantity of shipment in tons	B(3)
A(4)	Day shipment comes into air system	B(4)
A(5)	Capacity of aircraft	B(5)
A(6)	Speed of aircraft	B(6)
A(7)	Cost per mile of aircraft in flight	B(7)
A(8)	Cost per landing of aircraft	B(8)
A(9)	Flight number	B(9)
A(10)	Current location of aircraft	B(10)
A(31)	Event code (1-load, 2-trans-load, 3-off-load)	
A(32)	Day event takes place (TNOW)	

TABLE 3-4 --Continued

SLAM common Variables	Definition
ATRIB(I)	Attribute array equivalenced to A(I)
NCRDR	Card reader access number
NPRNT	Printer access number
NSET(I)	File array equivalenced to QSET(I)
TNOW	Current simulated time in days
XX(I)	Working variable array
NCLNR	File number of event file

Intermediate Variables	Definition
KKVNT(I,J)	Event code assigned during input
KEVNT	Event code assigned to event file
DTIME	Days until event takes place
KFLT	Flight number, used as argument
KFREQ	Flight frequency, used as argument
END	Working variable for load profile plot
RLAST	Working variable for load profile plot
SLOAD	Current load in tons
FCAP	Capacity of aircraft in tons
NSRCH	Starting entry in file to be searched
NRNK	Rank of entry in file to be searched
LF	File number of aircraft load file
DIFF	Difference between aircraft load and capacity
DELAY	Days shipment delayed
XLATE	Flag identifying shipments to be diverted
DAY(1)	Most recent time (in days) of diversion
IS,IR,IT	Random number streams
EMN	Distribution mean in tons
PZERO	Probability of no shipment
RN	Random number ($0 \leqslant RN \leqslant 1$)
CP1(I)	Cumulative probability (one of four arrays)
VAL(I)	Tonnage associated with cumulative probability

TABLE 3-4--Continued

Statistical Variables	Definition
FDIST	Distance traveled by flight
FTNMI	Ton miles carried by flight
FLND	Number of landings
TTNMI (I, J)	Total ton miles per flight
ATNMI (I, J)	Available ton miles per flight
TDIST (I, J)	Total distance per flight
TLND (I, J)	Total landings per flight
TNSDL (I, J)	Tons of cargo delayed (more than 2 days)
TNSOT (I, J)	Tons of cargo on time
FACTR	Load factor
DCOST	Distance cost
ACOST	Landing cost
TCOST	Total cost
TNMI (I)	Total ton miles per aircraft type
TDST (I)	Total distance per aircraft type
ALND (I)	Total landings per aircraft type
DCST (I)	Distance cost per aircraft type
ACST (I)	Landing cost per aircraft type
TCST (I)	Total cost per aircraft type
TONMI	Total ton miles carried
AVTMI	Total available ton miles
MILES	Total distance traveled
ALAND	Total number of landings
TOTOT (I)	Total cargo tonnage per O-D pair
PCTOT (I)	Percent of cargo on-time per O-D pair
PCTDL (I)	Percent of cargo delayed per O-D pair
TTTOT (I)	Total cargo on-time per destination depot
TOTAL (I)	Total cargo in system per destination depot
SVLEV (I)	Service rate per destination depot

Table 3-5 contains a list of the files used in the simulation model. The first eight files represent queues of waiting shipments at each of the terminals. The file entries represent shipments, and four attributes are associated with every shipment. These attributes include origin, destination, day originated, and weight in tons. These files vary in length and often represent bottlenecks when the number of waiting shipments becomes excessive.

The ninth file is used to represent the shipments aboard the aircraft as it proceeds along a flight path. Additional attributes maintain characteristics of the aircraft and flight. These attributes are stored in a file array QSET(I) until they are called upon by the model logic, at which time the attributes pass into an attribute array A(I). A buffer array B(I) is used similarly for the purpose of retaining earlier attributes drawn from a file entry. At each event, entries in the aircraft load file change to represent shipments aboard the aircraft as it proceeds from one terminal to the next. The sum of the weights of shipments in this file constitutes the aircraft load at a given point along the flight path.

The last file is designated by SLAM as the event or calendar file. SLAM automatically assigns a number to this file (NCLNR) which is one greater than the number of files designated by the user. This file is used to schedule

TABLE 3-5: File and Attribute Assignments

File #	File Name	Dest Point (2)	Shpmt Wt in Tons (3)	Day Shpmt Originated (4)	Orig Point (10)
1	Queue of Waiting Shipments at Point 1	X	X	X	X
2	Queue of Waiting Shipments at Point 2	X	X	X	X
3	Queue of Waiting Shipments at Point 3	X	X	X	X
4	Queue of Waiting Shipments at Point 4	X	X	X	X
5	Queue of Waiting Shipments at Point 5	X	X	X	X
6	Queue of Waiting Shipments at Point 6	X	X	X	X
7	Queue of Waiting Shipments at Point 7	X	X	X	X
8	Queue of Waiting Shipments at Point 8	X	X	X	X

(Above files ranked according to low value (LVF) of attribute (4).

		Additional Attributes				
		Aircraft Capacity (5)	Aircraft Speed (6)	Cost per Mile (7)	Cost per Landing (8)	Flight Number (9)
9	Aircraft Load File	X	X	X	X	X

File ranked last-in, first-out (LIFO).

10   Not used.

		Event Code* (31)	Day of Event (32)
11	Flight Path Event File	X	X

Ranked first-in, first-out (LIFO).

*Event Code	Flight Path Event
1	Load at origin
2	Transload at intermediate point
3	Off-load at destination
4	Generate shipments for new day
-1	End of simulation

events as the simulation proceeds from one event to the next. It is the first file loaded at the start of the simulation so that every flight may be scheduled for subsequent execution. Three event codes control the loading, transloading and off-loading of the aircraft as it proceeds along the flight path. Essential statistics are gathered at each event as well. A final entry in the event file terminates the simulation after a designated number of days.

Model Output

The simulation model provides a considerable amount of output and several options with information pertaining to aircraft, itineraries, schedules, service and costs. The output consists of the following:

(1) Recap of input values:

    (a) Distance matrix of origin-destination pairs

    (b) Shipment distribution parameters

    (c) Flight pattern description

    (d) Aircraft data;

(2) Notice of flights exceeding 10 hours (crew change may be required);

(3) Aircraft performance statistics by flight number, aircraft type, and all flights:

    (a) Distance traveled

    (b) Ton miles carried

      (c)   Ton-miles available

      (d)   Load factor;

(4)   Cost statistics by flight number, aircraft type and all flights:

      (a)   Miles traveled

      (b)   Distance cost

      (c)   Number of landings

      (d)   Landing cost

      (e)   Total operating cost for number of days simulated;

(5)   Origin-destination matrix of tons delivered on time and tons delivered late;

(6)   Origin-destination matrix of percent of cargo delivered on time and percent of cargo delivered late, with service level for each destination;

(7)   SLAM Summary Reports:

      (a)   Shipment delays at each terminal (days delayed)

      (b)   File statistics;

(8)   Histogram for each terminal showing queued shipments and number of days delayed;

(9)   (Optional) Aircraft load profile:

      (a)   Aircraft type and flight number

      (b)   Maximum "cubed out" capacity

      (c)   Load carried per flight segment plotted over distance.

Many of the output items listed above can be read quite easily from simulation printouts. Table 3-6 illustrates the aircraft performance statistics in a simulation run representing 120 operating days. All values listed are totals, with total cost for the operating period shown in the lower right. (In this particular run, the total cost over a four-month period using a smaller aircraft on one of the flights turned out to be $227,000 less than before with no significant reduction in service.)

Table 3-7 illustrates the output matrix showing tons delivered on time and tons delivered late. The upper figure in each row represents tons delivered on time while the lower figure represents tons delivered late. Table 3-8 shows a similar matrix, but here the upper figure represents percent of cargo delivered on time, and the lower figure shows percent of cargo delivered late. The "on-time" percentages are consolidated into service levels for each destination and are recorded in the bottom row. From the service levels in this particular run, it is apparent that TCM and SUU (Seattle and Travis) are receiving fewer on-time shipments than other destinations. This information is of considerable importance to air freight managers, and serves as the basis for computing the cost of service deterioration (presented in Chapter IV).

TABLE 3-6: Aircraft Performance Statistics By Aircraft Type - Simulation
For 120 Days

Aircraft Type	Distance Travelled	Ton-Miles Carried	Ton-Miles Available	Load Factor
L-100-30	850302.	16543392.	18494304.	89.45
L-188	147360.	1456655.	2242807.	64.95

Aircraft Type	Miles Travelled	Distance Cost	No. of Landings	Landing Cost	Total Cost
L-100-30	850320.	6207165.	1440.	360000.	6567165.
L-188	147360.	848794.	240.	60000.	908794.

AIRCRAFT PERFORMANCE STATISTICS: All Flights - Simulation for 120   Days

All Flights	Distance Travelled	Ton-Miles Carried	Ton-Miles Available	Load Factor
	997680.	18000032.	20737104.	86.80

All Flights	Miles Travelled	Distance Cost	No. of Landings	Landing Cost	Total Cost
	997680.	7055958.	1680.	420000.	7475958.

Table 3-7: Matrix of Tons Delivered on Time and Tons Delivered Late, Simulation for 120 Days

	Destination							
Origin	TCM	SUU	NZY	IND	DOV	NGU	CHS	NIP
TCM	0.0	580.4	173.9	18.5	148.4	85.6	39.6	12.7
	0.0	52.6	0.0	0.0	0.0	6.4	3.0	6.2
SOU	736.6	0.0	805.8	65.0	196.3	515.6	140.2	98.8
	32.9	0.0	0.0	0.0	0.0	155.4	37.7	74.3
NZY	234.2	569.3	0.0	30.5	189.2	378.9	93.8	82.6
	59.5	255.8	0.0	0.0	6.6	298.2	27.8	11.3
IND	7.9	11.9	27.2	0.0	23.6	48.0	26.4	10.3
	18.9	24.6	19.8	0.0	0.8	17.9	9.0	0.5
DOV	162.5	316.2	235.5	18.4	0.0	637.1	306.8	106.5
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NGU	18.0	176.1	751.7	28.2	738.7	0.0	512.7	419.2
	247.2	421.1	37.0	0.0	0.0	0.0	0.0	40.9
CHS	19.1	85.9	99.8	19.3	217.9	421.5	0.0	57.0
	40.8	62.5	0.0	0.0	0.0	0.0	0.0	0.0
NIP	20.8	106.7	85.8	11.4	181.3	513.3	36.1	0.0
	47.9	62.2	0.0	0.0	0.0	0.0	0.0	0.0

Late Shipments Are Those Exceeding Two Days Delivery

TABLE 3-8: Matrix of Percent of Cargo Delivered on Time and Delivered Late, Simulation for 120 Days

Origin	Destination							
	TCM	SUU	NZY	IND	DOV	NGU	CHS	NIP
TCM	0.0	91.69	100.0	100.0	100.0	93.02	92.93	67.06
	0.0	8.31	0.0	0.0	0.0	6.98	7.07	32.94
SUU	95.72	0.0	100.0	100.0	100.0	76.84	78.80	57.08
	4.28	0.0	0.0	0.0	0.0	23.16	21.20	42.92
NZY	79.74	69.00	0.0	100.0	96.63	55.96	77.14	87.98
	20.26	31.00	0.0	0.0	3.37	44.04	22.86	12.02
IND	29.52	32.59	57.81	0.0	98.67	72.84	74.53	95.35
	70.48	67.41	42.19	0.0	3.33	27.16	25.47	4.65
DOV	100.0	100.0	100.0	100.0	0.0	100.0	100.0	100.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NGU	6.78	29.48	91.15	100.0	100.0	0.0	100.0	91.10
	93.22	70.52	8.85	0.0	0.0	0.0	0.0	8.90
CHS	31.85	57.88	100.0	100.0	100.0	100.0	0.0	100.0
	68.15	42.12	0.0	0.0	0.0	0.0	0.0	0.0
NIP	30.30	63.17	100.0	100.0	100.0	100.0	100.0	0.0
	69.70	36.83	0.0	0.0	0.0	0.0	0.0	0.0
Service Level	72.83	67.75	95.92	100.0	99.56	84.47	93.71	85.52

Because the nature of delayed shipments is of im-
portance, the simulation model provides a histogram for
each terminal with the number and days delay of queued
shipments. Figure 3-2 illustrates the delay pattern at
SUU (Travis) and shows that most delays (first two rows)
are of only one or two days duration. A shipment is not
considered late unless it takes more than two days to
reach its destination. (Long delays of 3, 4, and 5 days
constituted only 5.2%, 3.3%, and 1.9% of delayed shipments,
as noted in 3rd, 4th, and 5th entries of the second column.)

The optional output provides for a flight load pro-
file of any flight or combination of flights desired by
management. This output uses the plot capabilities of SLAM
which graphically illustrates the load being carried along
flight segments. The profile includes the tonnage carried
and the tonnage capacity of an aircraft plotted over miles
traveled. An illustration of this output is presented in
Figure 1-2.

Model Logic

The simulation model uses a discrete event simulation
methodology to represent the pick-up and delivery of cargo
at various points. User-provided subroutines were written
to provide the logic for loading and unloading at each
terminal, selecting shipments according to destination,

HISTOGRAM NUMBER 2

SHPMTS DLAYD SUU

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT
1138	0.791	0.791	0.1000E+01
151	0.105	0.896	0.2000E+01
75	0.052	0.948	0.3000E+01
47	0.033	0.981	0.4000E+01
28	0.019	1.000	0.5000E+01
0	0.0	1.000	0.6000E+01
0	0.0	1.000	0.7000E+01
0	0.0	1.000	INF

1439			
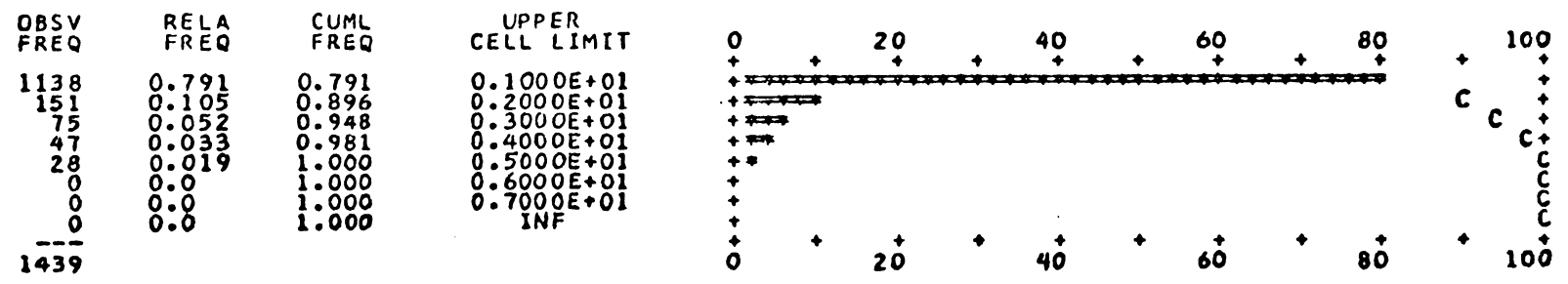
FIGURE 3-2: Distribution of Delayed Shipments at Travis Air Force Base. Each cell represents one day's delay.

testing to see if shipments can fit aboard the aircraft, queueing shipments that must be delayed, and maintaining statistics on all aircraft, flight segments, and shipment disposition. The next-event procedure does, in effect, simulate the movement of aircraft from terminal to terminal and update all files as shipments are loaded or unloaded at each terminal.

As noted in the previous section, files were created to represent the following:

(1) Aircraft load, shipments aboard each aircraft;

(2) Terminal shipment queue, shipments delayed at each terminal; and

(3) Event file, schedule of terminals on each aircraft's itinerary.

Each of these files play an essential role in the model logic.

The first file to receive entries is the event or calendar file. Each entry represents a point or terminal on an aircraft flight itinerary. All flights, flight paths, and flight frequencies are received and converted to file entries containing event codes and the days of the week each event takes place. The days of the week for each flight are computed automatically by a user-written subroutine according to the convention shown in Table 3-9. For example, a flight with a designated frequency of three

TABLE 3-9: Convention for Assigning Days of the Week to Flight According to Flight Frequency*

Flight Frequency (Flights per week)	Day Code (DTIME)	Day of the Week
1	6	Saturday
2	2	Tuesday
	5	Friday
3	1	Monday
	3	Wednesday
	5	Friday
4	1	Monday
	2	Tuesday
	4	Thursday
	6	Saturday
5	2	Tuesday
	3	Wednesday
	4	Thursday
	5	Friday
	7	Sunday
6	1	Monday
	2	Tuesday
	3	Wednesday
	4	Thursday
	5	Friday
	6	Saturday
7	1	Monday
	2	Tuesday
	3	Wednesday
	4	Thursday
	5	Friday
	6	Saturday
	7	Sunday

*Convention determined by NAVMTO personnel. (User retains the option of specifying days assigned if different from the above.)

flights per week will be scheduled on the event calendar
for Monday, Wednesday and Friday. (This convention can
be overridden if the user wishes to specify different
days.) The same user-written subroutine decomposes each
flight into events, one for each terminal on the flight
path. Thus a flight with six terminals on its itinerary
will generate six events for each day the flight is
scheduled. The first event represents departure (load
aircraft); the next four events represent stopover points
(transload); and the last event represents arrival at
aircraft destination (off-load). Once these events become
entries on the event file, the sequencing of events is
accomplished by an executive control subroutine provided
by the simulation language (SLAM).

The next files to receive entries are the terminal
shipment queue files. For the purpose of simulation, air
freight shipments are regarded as "entities" that come into
the network daily for the purpose of being transported
from one location to another. In effect, they are "ser-
viced" by the air transport system. These entities (ship-
ment arrivals) are generated by the simulation system using
the parameters developed during the stochastic input prepar-
ation procedure described earlier in this chapter. Ship-
ments are generated daily to represent the build-up of
shipment queues between flights. The shipments become

entries on the terminal shipment queue files. During the course of a simulation run, these queue files will become longer each time new shipments are generated and when shipments are delayed at a terminal for further transhipment. The queues become shorter when aircraft arrive to load and transport shipments and when shipments are diverted to truck after excessive delays at a terminal.

The key file for monitoring service is the aircraft load file. Although several aircraft and flights may be represented in a simulation run, only one file is needed since one flight is fully simulated before another one begins. As long as the flight pattern is handled chronologically, the system is represented with reasonable accuracy. The aircraft load file receives entries when the first event (load) takes place. Each entry represents a shipment removed from the terminal queue file. A service discipline is followed by simulating the loading of the most distant destinations first. Simultaneously, a queue discipline is being realized since the terminal queue files are ranked with the oldest shipments to be accessed first. When the simulation program can find no more shipments matching subsequent destinations on the flight path (or no more shipments will fit aborad the aircraft), statistics are recorded and the executive control subroutine advances to the next event.

The model logic is designed so that the above pro-
cess is repeated (with some modifications) as the simula-
tion proceeds from one event to the next. A general flow-
chart of model logic is illustrated in Figure 3-3. The
key to the logic of the simulation model is represented by
the central decision block where each subsequent event code
is checked. If the event code represents a new day, control
shifts to subroutines that remove aged shipments and place
new shipments in terminal queues. If the event code repre-
sents loading at the beginning of a flight, a terminal queue
is searched for shipments scheduled for destinations along
the flight path. All shipments that will fit are loaded
and the aircraft advances to the next destination. Subse-
quent event codes call for transloading at each intermediate
point with similar activities taking place after shipments
destined for that point are off-loaded. An event code for
off-loading occurs at the end of a flight where remaining
shipments are removed and a check is made to insure that
the aircraft is empty. At every point, statistics are
collected prior to advancing to the next event.

The total simulated time (in days) is determined by
the user. When all flights for the designated number of
days have been simulated, an event code representing end of
simulation passes control to various statistical subroutines
which compile and compute a number of summary statistics
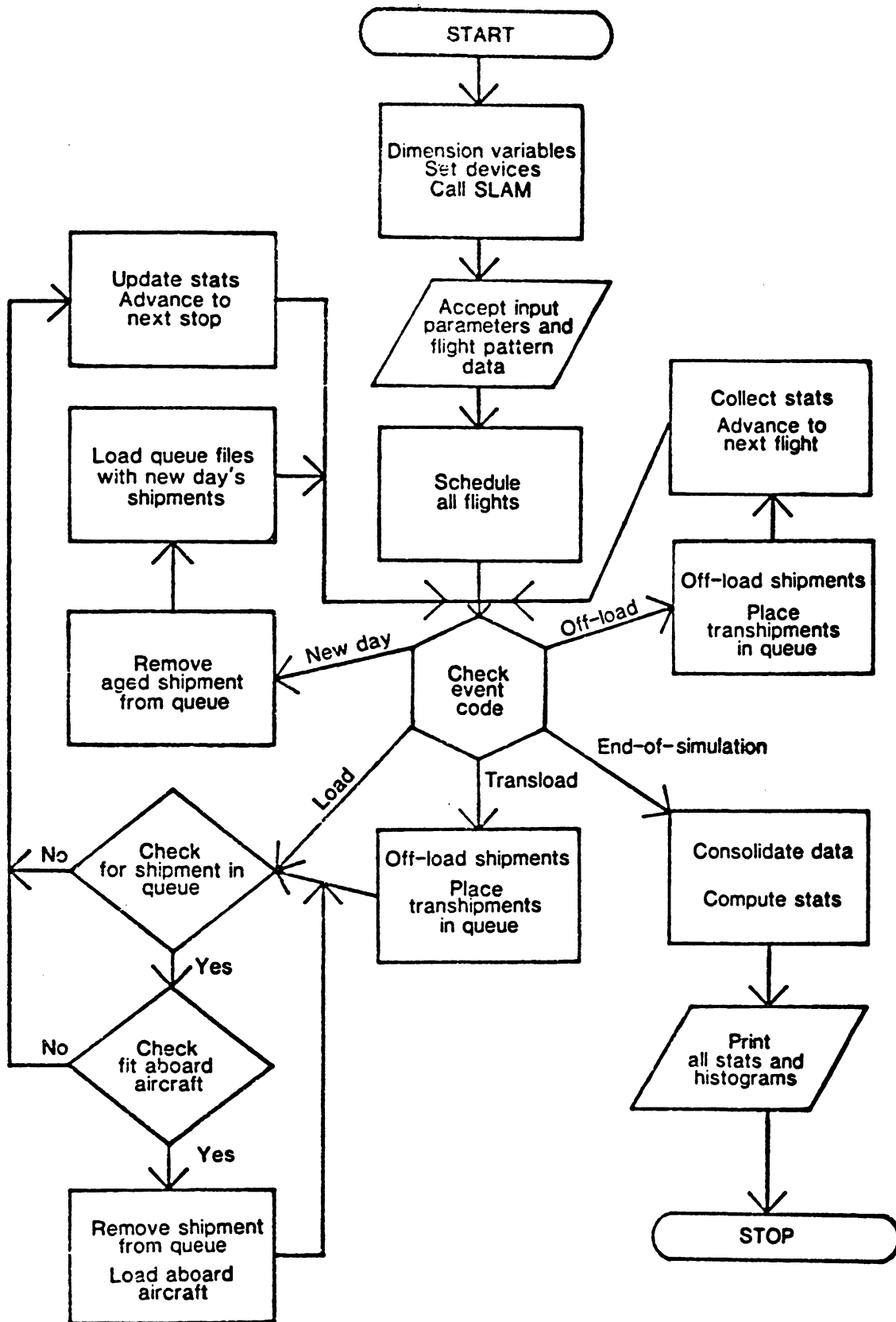
FIGURE 3-3:   General Flowchart of Air Transport Simulation Model

printed as output. This feature ordinarily terminates the
simulation run. A number of user-written subroutines are
designed to simulate the events described above and respond
to calls from the SLAM executive control program. These
subroutines are listed and described in Table 3-10. A
complete coded listing of all user-written subroutines is
contained in Appendix B. SLAM sub-programs are described
by Pritsker and Pegden (57, Appendix A).

Verification and Validation

Once the simulation model has been constructed,
credibility had to be attained through the two-step process
of verification and validation. Verification is the process
by which the model itself was analyzed to see if it was
working properly. This consisted largely of a reexamination
of the logic of the simulation with test runs to assure that
output values were reasonable in light of various input
parameters.

The model was developed and tested in several stages
so that each stage could be verified before proceeding
further. First, the input subroutine was written followed
by an output (ECHO) subroutine to see that all input was
being accepted by the model. Second, a subroutine was
written to convert input into file entries which were also
checked by printing the files. Third, additional subroutines

TABLE 3-10: User-Written Subroutine for Air Transport
Simulation Model

INTLC	Accept input data, initialize variables
ECHO	Print input data with headings
SETFL	Assign flights to days of the week and place events on event calendar
EVENT	Select appropriate load processing subroutines, initialize and collect flight statistics
GQUE	Accept new shipments and place in terminal shipment queues
OFFLD	Remove shipments from aircraft, place transhipments in terminal queues
LOAD	Test shipments for fit aboard aircraft, load aircraft
TQUE	Search queue for shipments to be loaded, locate and remove from queue, collect queue statistics
DIVRT	Search queues for aged shipments, remove and divert to truck, collect delay statistics
PROFL	Record aircraft load data at 50 mile intervals for flight load profile plot
FSTAT	Consolidate flight statistics, assign to appropriate arrays
LSTAT	Consolidate on-time and delayed load statistics in appropriate arrays
SHPMT	Function for generating new shipments using appropriate random number generators and probability distributions
OTPUT	Call statistical output subroutines
FLTOT	Compute and print flight load performance and cost statistics

TABLE 3-10-- Continued

TYPOT	Compute and print aircraft load performance and cost statistics, also summary statistics for all flights
DEPOT	Compute percentages and print on-time and delayed load statistics
SVLOT	Compute and print service levels for each destination

were written, tested separately, and then combined with SLAM to see if the model performed as an integrated combination. Fourth, non-stochastic values were introduced by making all shipments exactly one ton each. This strategy made it possible to compute and predict the outcome deterministically for comparison with simulation output. With some de-bugging, the simulation output matched the predicted outcome, and most of the model logic could be verified.

Schruber (62) describes validation as an attempt to demonstrate that the simulation behaves like the actual system. This usually involves statistical comparisons of aggregate measures of system performance with corresponding measures generated by simulation. The primary response variable in the air transport model is load factor, an aggregate measure of the proportion of aircraft capacity used over time. Since this figure is determined both by the amount of freight carried and aircraft capacity, it is an appropriate measure of system performance for comparison purposes. Sargent (61) discusses a number of additional validation techniques, including face validity and sensitivity analysis. The validation procedures that were used for the air transport model are as follows:

(1) Test of Hypotheses: If the underlying assumptions for a test of proportions are not

seriously violated, the load factor p can be

compared using

$$H_0: \quad Ps = Pc$$

$$H_1: \quad Ps \neq Pc$$

where Ps = simulated load factor, and

Pc = computed load factor based on

NAVMTO statistics.

(2) Face Validity: Face validity is a subjective

process by which knowledgeable people are asked

to examine the logic and flow within a model

to see if it "makes sense" and reflects what

they know about the real-world system.

(3) Sensitivity Analysis: This technique consists

of changing the input parameters of a model to

determine the effect upon the model and its

output. In particular, the effect of changing

shipment variability was supplied to the air

transport model. Reduced variability should

bring about greater stability with fewer de-

layed shipments and shipment queues.

The first approach toward validation required that

the existing flight pattern be simulated and evaluated in

comparison with actual performance statistics. The results

of this early simulation run are depicted in Table 3-11.

Mileage figures match up with actual miles traveled, and

TABLE 3-11: Comparison of Simulated and Computed Load
Factors, Samples From NAVMTO During FY1980

Aircraft Performance Statistics
By Flight Number - Simulation for 720. Days

Flight No.	Distance Traveled	Ton-Miles Carried	Ton-Miles Available	Simulated Load Factor	Computed Load Factor
172	2437200.	48055406.	53005120.	86.89	81.5
672	514800.	6845684.	11196737.	61.14	69.8
171	2149920.	44251152.	46759936.	94.63	84.8
252	631192.	9405496.	13728426.	68.51	66.7

Flight No.	Miles Traveled	Distance Cost	No. of Landings	Landing Cost
172	2437200.	17791072.	3600.	900000.
672	514800.	3757936.	2160.	540000.
171	2149920.	15693985.	2880.	720000.
252	631192.	4607575.	1028.	257000.

Aircraft Performance Statistics
All Flights - Simulation for 720. Days

All Flights	Distance Traveled	Ton-Miles Carried	Ton-Miles Available	Simulated Load Factor	Computed Load Factor
	5733112.	106557726.	124690208.	85.46	80.1

All Flights	Miles Traveled	Distance Cost	No. of Landings	Landing Cost
	5733112.	41850560.	9668.	2417000.

the ton-mile figures are very much in line with expectations. Overall load factor for the 720 day (103 week) simulation turned out to be slightly higher than expected. The computed load factors from NAVMTO records for Fiscal Year 1979 are also shown in Table 3-11.

A frequency histogram of load factors computed daily resulted in a skewed distribution. However, a frequency histogram of load factors computed weekly resulted in a near normal distribution. Since all flights are replicated weekly, and a normal distribution is assumed in most hypothesis tests, it was appropriate to proceed with a test of proportion. A two-sided statistical test for the difference between two population proportions may be conducted by restating the hypotheses and statistics as follows:

$$Ho: \quad Px - Pc = 0$$

$$H_1: \quad Ps - Pc \neq 0$$

and   ps = load factor from simulation sample

ns = simulated sample size (in weeks)

pc = load factors from NAVMTO records

nc = duration of NAVMTO sample (in weeks)

Using a risk of $\alpha = .10$, the rejection limits for a two-sided test are $\pm z(\alpha/2) = \pm 1.645$. (An α risk of .10 insures a higher power for the test than α risks of .05 or .01 that are commonly used.) The test statistic is determined as follows:

$$TS = d/S(d)$$

where $d = ps - pc$

$$p = \frac{(ns)(ps) + (nc)(pc)}{ns + nc}$$

$$s(d) = \sqrt{(p)(1-p)(1/ns + 1/nc)}$$

From Table 3-11, the sample values for a test of the load factor for all flights resulted in the following:

ps = .8546	d = .0536
ns = 103	p = .8366
pc = .801	s(d) = .0629
nc = 52	TS = .852

Since $TS < z(\alpha/2)$, there is insufficient evidence to reject Ho. The load factor represented by the simulation is within a statistically acceptable range of the load factor experienced by NAVMTO flights.

The above test used an aggregate measure which may have yielded promising results due to the combined effect of averaging several different load factors. A more convincing indication of simulation validity would be obtained by testing the individual load factors for each flight against the load factors computed by NAVMTO. The results at an α risk of .10 are summarized as follows:

Flight 172	z(.05) = 1.645
ps = .8689	TS = .889
pc = .8150	Accept Ho

Flight 672   z(.05) = 1.645

ps = .6114   TS =-1.06

pc = .698   Accept Ho

Flight 171   z(.05) = 1.645

ps = .9463   TS = 1.90

pc = .848   Reject Ho

Flight 252   z(.05) = 1.645

ps = .6851   TS = .228

pc = .667   Accept Ho

It is apparent that all flight load factors except
one are within statistically acceptable bounds. However,
load factors rarely exceed 90 percent in actual flight
operations, and Flight 171 simulated a load factor perform-
ance higher than the norm. A review of this outcome with
NAVMTO personnel revealed that Flight 171 travels a west-
bound route which from time to time requires a special
charter to carry cargo not loaded aboard the regular flight.
When the special charter was taken into account in a subse-
quent simulation run, all load factors fell well within
statistically acceptable bounds.

Face validity was determined by having NAVMTO per-
sonnel review the flight load profiles produced by the simu-
lation model and compare them to their own records of
flight load performance. The logic and flow within the
model was fully explained, and all assumptions were discussed

in detail. Minor improvements were suggested, and additional computer runs were made to test some slight modifications. Finally, the sensitivity of the model was put to the test by first reducing the variability of a number of shipment distributions which resulted in fewer delayed shipments and generally shorter queues. When the variability of shipment distributions was increased, the number of delayed shipments and queue lengths increased as well. Thus, the model appeared to be working satisfactorily and gave initial indications that the simulation was able to represent the QUICKTRANS system. The model was reviewed by the NAVMTO director and found to be both suitable and acceptable for application purposes.

Illustration of Model Value

The information contained in the output of each simulation run can be of considerable value to transportation planners. The usefulness of the model is best illustrated by an example. The flight pattern described in Table 2-1 uses L-100-30 aircraft on all four flights. Shipping records obtained over time revealed that Flight 252 (a round-trip flight between Travis and McChord 5 days a week) was carrying less cargo than other flights. It was suggested that a smaller aircraft might be able to handle the cargo load at less cost with minimal reduction of service.

To test this proposal, a simulation of the four-flight pattern was conducted with an L-188 aircraft assigned to Flight 252. The L-188 has a capacity which is five and one-half tons less than that of the L-100, but costs only $5.76 per mile to operate compared to the $7.30 per mile cost of the larger aircraft.

Table 3-6 illustrates the performance statistics obtained from a 120-day simulation run. The load factor for the L-188 turned out to be approximately 65 percent. This load factor is relatively low, suggesting that the smaller aircraft could perform the task without difficulty. Table 3-6 also includes the simulated distance traveled, ton-miles carried, ton-miles available, and the cost of operation. The total cost of operation for the 120-day simulated period was approximately $7,476,000, a savings of $227,000.

Aircraft performance measures, however, indicate only a portion of the total picture. To illustrate the level of service provided, the output matrix in Table 3-8 reveals that service from Travis (SUU) to McChord (TCM) was over 95 percent, while service from McChord to Travis was over 91 percent. These service levels are very favorable and further suggest the feasibility of substituting a smaller aircraft for the flight shuttling between the two terminals.

Another measure of service efficiency can be observed in Figure 3-2 where it is revealed that out of 1,439 shipments experiencing some delay at Travis Air Force Base, 1,138 experienced only a one-day delay and 151 were delayed only two days. These figures apply to shipments originating or being transloaded at Travis. Similar histograms are generated for all terminals in the network.

A summary of the performance measures used in this comparison are recapitulated below:

	L-100	L-188
Capacity in tons	21.75	15.215
Cost per mile	$7.30	$5.76
Load factor (%)	49.07	64.95
Service level (%)		
SUU to TCM	98.41	95.72
TCM to SUU	96.13	91.69
Shipments delayed at SUU		
One-day delay	1104	1138
Two-day delay	152	151
Cost of Flight 252	$1,135,699	$908,794
Cost of total operation	$7,702,864	$7,475,958

Savings with smaller aircraft. $226,906

People familiar with air cargo transportation generally agree that statistics similar to those illustrated in this computer simulation are extremely useful in the evaluation of aircraft and flight pattern combinations (35).

Even though the measures represent approximations or point estimates of actual performance (due to the effect of random error in stochastically generated shipment values), they provide valuable indications of likely performance when and if the simulated strategies are implemented. Further examples of air transport simulation output and interpretation are presented in Chapter V.

Summary

This chapter began with a general discussion of simulation and simulation languages, followed by a clarification of the reasons for selecting SLAM as the simulation modeling package used in this research. The SLAM language allows for a high level of user interaction and provides a number of useful subroutines for modeling a queueing process.

The preparation of stochastic input required a careful analysis of shipping data provided by the Naval Material Transportation Office. A program called SIMFIT was used for frequency distribution analysis. Parameters identifying shipment distributions were computed and organized for input into the simulation model. Specifications for the model were described in detail. They include input categories, variable names, file names, and output statistics.

The logic of the simulation model was explained in terms of the use of subroutines and files to represent air cargo transactions and events. A general flowchart of model logic was included to illustrate the interaction of various subroutines and steps in the simulation process. Verification and validation procedures were described with statistical hypotheses tests used to compare model output and flight performance records. The value of the simulation model was discussed with reference to the output information made available. Chapter IV presents a decision framework which enhances the value of the model by providing an efficient search procedure to develop least-cost solutions.

CHAPTER IV

A DECISION FRAMEWORK FOR THE SIMULATION MODEL

Statistical Considerations

A decision framework requires some criteria for selecting from alternatives generated by repeated applications of the simulation model. In order to establish this criteria, certain statistical considerations must be taken into account. A description of the decision framework follows the next two sections which explain the statistical basis for the decisions to be made.

Shannon (63) describes a number of actions which must be carried out before an experimentor can draw statistically significant inferences from the data generated by computer simulation. One of these pertains to the fact that the output of a model may be biased by a set of initial values until the model has warmed up or reached a steady state condition. McMillan and Gonzalez (45) define steady state as an arbitrarily close approximation to the system's equilibrium state.

The starting condition in many queueing simulation models is described by Fishman (26) as "empty and idle." This condition is frequently used when the analyst has little

or no a priori knowledge of starting conditions that would
minimize or shorten the warm-up period. Consequently, an
early portion of the output from a simulation run may have
to be deleted to eliminate the bias introduced. The ana-
lyst has to determine how much of the simulation will be
truncated so that the initial series of measurements will
not affect the final result.

To perform this task, the average queue lengths of
the four most active terminals were recorded and plotted
every 15 days in simulation runs of 720 days each. Seed
values for the random number generators were changed with
each run so that different stochastic values would be gen-
erated. The resulting plots were reviewed and analyzed for
the point at which the simulation appeared to settle into
equilibrium. A truncation point was selected from the plot
requiring the longest warm-up period, illustrated in Figure
4-1. It was determined that data generated during the
first 150 days of simulated time would be deleted so as not
to bias subsequent results. Figure 4-1 indicates that the
model reached and maintained a steady state condition after
the first 150 days.

In order to derive meaningful output from the simu-
lation model, it was recognized that each measure from a
simulation run could be regarded only as a single observa-
tion. Law (43) notes that one realization or replication

```
T=TRAVIS          0.0                          0.1250E+02
S=SDIEGO          0.0                          0.1250E+02
I=IND             0.0                          0.1250E+02
N=NORFOLK         0.0                          0.1250E+02

                  0    5   10   15   20   25   30   35   40
DAYS

   0.0            T                             +    T
   0.1500E+02     +      I S              N     +  T
   0.3000E+02     +          IS                 T    N
   0.4500E+02     +          I  S              T+       N
   0.6000E+02     +        I    S             T   +    N
   0.7500E+02     +        I     S           T    +    N
   0.9000E+02     +         I    S          T     +   N
   0.1050E+03     +        I     S         T T    +  N
   0.1200E+03     +        I     S              T +  N
   0.1350E+03     +        I     S              T +  N
   0.1500E+03     +        I      S             T +  N
  ─────────────────────────────────────────────────────────
   0.1650E+03     +        I      S             T  +N
   0.1800E+03     +        I      S             T  +N
   0.1950E+03     +        I      S             T+  N
   0.2100E+03     +        I      S             T+ N
   0.2250E+03     +        I      S             T+  N
   0.2400E+03     +        I      S             T + N
   0.2550E+03     +        I      S             T+ N
   0.2700E+03     +        I      S            T +N
   0.2850E+03     +        I      S            T +N
   0.3000E+03     +        I      S            T +N
   0.3150E+03     +        I      S            T + N
   0.3300E+03     +        I      S            T + N
   0.3450E+03     +        I      S            T + N
   0.3600E+03     +        I          S        T + N
   0.3750E+03     +        I      S            T + N
   0.3900E+03     +        I      S            T +N
   0.4050E+03     +        I      S            T+N
   0.4200E+03     +        I      S            T+N
   0.4350E+03     +        I      S            T+N
   0.4500E+03     +        I      S            T+  N
   0.4650E+03     +        I      S            T + N
   0.4800E+03     +        I      S            T+N
   0.4950E+03     +        I      S            T+N
   0.5100E+03     +        I      S            T+  N
   0.5250E+03     +        I      S            T+  N
   0.5400E+03     +        I      S            T+  N
   0.5550E+03     +        I      S            T+  N
   0.5700E+03     +        I      S            T+ N
   0.5850E+03     +        I      S            T+ N
   0.6000E+03     +        I      S            T+ N
   0.6150E+03     +        I      S            T+ N
   0.6300E+03     +        I      S            T+ N
   0.6450E+03     +        I      S            T+  N
   0.6600E+03     +        I      S             T N
   0.6750E+03     +        I      S             TN
   0.6900E+03     +        I      S             TN
   0.7050E+03     +        I      S             TN
   0.7200E+03     +        I      S             TN
```

FIGURE 4-1:   Plot of Cumulative Average Number of Shipments
              Waiting at Four Most Active Terminals.
              (Horizontal Line Marks Truncation of First 150
              Days Simulated.)

is generally not sufficient to obtain an acceptable esti-
mate of a measure of performance. Two approaches may be
used to gain additional measures for the purpose of sta-
tistical analysis. One approach calls for replicating a
number of simulation runs changing only the seed values
from one run to the next; while another approach calls for
a single experimental run to be subdivided into segments
so that a sequence of internal measures may be obtained.
Conway (18) and others seem to prefer the latter method.
Performance measures are based on an entire run (except
for a warm-up period), and the precision of the results may
be estimated using confidence intervals.

It is tempting under the latter alternative to create
runs of considerable length, but economy usually rules
against such a practice. Variances are reduced through
time, but at a cost that needs to be appraised in terms of
the precision gained. If a number of alternatives are
going to be tested, some tradeoff is necessary. The QUICK-
TRANS model had to be evaluated with these considerations
in mind.

A convenient segmentation for the air transport model
was selected by having simulation segment times correspond
with actual data collection periods used by the Navy. Since
statistics were aggregated on a monthly basis, simulation
runs were divided into 30-day segments with performance and

cost variables recorded at the end of each period. Thus, each simulation run yielded a sample of 19 monthly observations (720 days minus 150-day warm-up period, divided by 30). Whether or not this sample size would suffice depended upon the precision of the results. The approach used for assessing the accuracy of the estimates was to construct a confidence interval of the true measures.

Sensitivity of the Response Function

A primary consideration in the design of a decision-making process is the determination of a measure of effectiveness or response variable. In this particular application, total operating cost is an appropriate response variable. The key factors having an impact on total operating cost for the problem are listed as follows:

·Type of aircraft flown;

·Frequency of service to each point;

·Service level at each point;

·Total distance flown;

·Total number of landings.

The total operating cost identified as OCOST is expressed as a function of the factors listed above.

A sample of monthly OCOST values was generated from a simulation run and found to approximate a normal distribution. A 95 percent confidence interval for the mean

OCOST was constructed as follows:

n = 19

Std. deviation = 113,500

Std. error = 26,752

Degrees of freedom = 18

t(18,.05) = 2.101

Sampling error = $56,200

Mean OCOST interval estimate = $2,527,000 ± $56,200.

Before the response variable can be used for decision-making purposes, the sensitivity of the response function must be determined. A sensitivity analysis was performed using the predictor variable most affected by the stochastic input to the model. This predictor variable, identified as COD, is the cost of delay per day for each percent decrease in overall service level. The COD value is perhaps the most difficult figure to obtain. It requires some judgement as to the effect that each percentage decrease in the service level has on the cost of operations. In essence, this amounts to a "penalty" cost for reduction in service, and can only be estimated in the absence of hard data. The U.S. Navy did not maintain statistics on the cost of service delays. (COD was not included in earlier simulation runs but was incorporated as part of the total cost function for the decision-making model described in this chapter.)

The results of the sensitivity analysis are shown in Table 4-1. A series of simulation runs were made changing

TABLE 4-1: Sensitivity of Total Operating Cost to Changes
in Delay Penalty

Delay Penalty (COD)*	Mean Total Operating Cost (OCOST) From Samples of 19 Months Each
$ 0	$1,929,093
100	1,989,423
200	2,049,766
300	2,110,117
400	2,170,446
500	2,230,778
600	2,291,116
700	2,351,460
800	2,411,802
900	2,472,135
1000	2,532,464
1100	2,592,793
1200	2,653,128
1300	2,713,483
1400	2,773,822
1500	2,834,150

Average difference in OCOST response values - $60,337

*COD - Cost of delay per day for each percent decrease
in service level.

only the COD variable from one run to the next. The COD values ranged from zero to $1500 in $100 increments. OCOST output values were recorded for each change in COD input. Differences of over $60,000 per month resulted when mean OCOST values were recorded. The significance of these differences can be determined from the sampling error in the confidence interval estimate. Each $100 increase in COD resulted in a monthly OCOST increase of over $60,000 which was greater than the margin of error due to sampling ($56,200). Mean OCOST values derived from simulation runs could then be used as estimates of total monthly operating cost as long as differences in outcomes below $56,200 were not regarded as statistically significant.

Description of the Decision Framework

One of the purposes of this research project was to provide a specific decision-making framework for selecting the least-cost aircraft routing schedule that meets the requirements of the air transportation network described in Chapter I. In simulation modeling where many variables are involved, several techniques may be used appropriately in a decision framework. The procedure most commonly applied to vehicle scheduling problems are heuristic or search techniques, or a combination of the two. The technique chosen for this decision-making process is an

iterative improvement scheme which sequentially improves upon a starting solution until a minimum cost solution is found or a constraint is violated. To keep the problem within manageable bounds and demonstrate the usefulness of the model, some values remain fixed throughout the process while others are varied. These are indicated in Table 4-2. This table includes the objective function, constraints, exogenous and endogenous variables, and the control or predictor variables that are used in the decision framework.

The decision-making process consists of three iterative steps:

(1) Develop a routing itinerary which will serve all points in the network. Assign the largest aircraft;

(2) Set a maximum frequency of service to all points, then successively reduce service to low demand points until the minimum operating cost is reached.

(3) Assign the next largest aircraft and repeat Step (2). When all aircraft have been tested, record the least-cost solution and stop.

A general description of the methodology and its execution is delineated as follows:

Step 1 requires that an initial starting itinerary be developed. This may be accomplished by making arbitrary

TABLE 4-2: Summary of Pertinent Factors and Variables Used in the Decision Making Model

Objective Function (Response Variable)

OCOST = Total Operating Cost (expressed as a function of aircraft type, frequency of service, service level, distance flown, and number of landings).

Constraints

Service level (minimum 60% on-time at any terminal)

Daily operating time per air crew (maximum 10 hours)

Variables

Control (Predictor) Variables:

Capacity of aircraft (varies by type)
Speed of aircraft (varies by type)
Cost of operation (varies by type)
Service reduction penalty

Exogenous Variables:

Shipping quantities (in tons) at each terminal (stochastic)

Shipping priority, 48-hour requirement (fixed)

Endogenous Variables:

Number of flights
Number of terminals
Frequency of service
Distance between terminals
Route pattern

assignments or by using prior knowledge of a feasible routing schedule already demonstrated to be workable. Conway (18) notes that a _priori_ knowledge of the system is not unusual, and the selection of a "good" route pattern at the outset may shorten the evaluation procedure. (In the QUICKTRANS problem, a route pattern designed to serve the eight points in the network was readily obtained for this purpose.)

Step 2 allows for the evaluation of any aircraft type for which speed, capacity, and per-unit operating costs are known. Once the values for each variable are input into the system, the frequency reduction process begins. All points are set initially to receive flights seven times weekly. After each simulation run, frequency of service is reduced on any flight path in which service level constraints are not violated. Frequency may be reduced to as low as one flight per week if no constraints are violated. Frequency reductions are made simultaneously at terminals on the same flight path, and service level violations usually occur well before all combinations are exhausted. When a service level violation does occur, the flight frequency is reset at its earlier (non-violating) value. When no more frequency reductions can be made, a message to that effect is printed and total operating cost is recorded.

Step 3 repeats the above process for each aircraft

type beginning with the largest. The process stops when

all aircraft have been evaluated and a "best" solution has

been obtained for each aircraft type. The decision cri-

terion calls for the selection of the aircraft and frequency-

of service combination which results in the least total

operating cost.

Clearly, the decision framework described above

requires careful selection of representative values from

successive simulation runs. Conway recommends the following:

> ...a single experimental run should be made for
> each alternative tested. Variability should be
> reduced and replication provided by extending the
> length of the run rather than executing completely
> separate and independent runs. Performance measures
> will be based on the entire run (except for the
> "warm-up"... period at the beginning of the run),
> but the run must be subdivided and a sequence of
> interval measures obtained in order to estimate the
> precision of the results (18, p. 34).

The expanded output is then treated as a single sample to

provide the response values for each step in the decision

process.

Development of a Heuristic

In order to implement the decision framework des-

cribed in the previous section, a heuristic was developed

and included in the simulation model as a separate sub-

routine. The subroutine contains provisions for evaluating

the output of each simulation run, changing the frequency

of flights, re-running the simulation with changed values,
and stopping the simulation when no more improvements can
be made. A flowchart of the decision process is illustrat-
ed in Figure 4-2.

A major function of the heuristic is to carry out
the procedure described in Step 2 of the decision process.
This step calls for setting a maximum frequency of service
to all points, and then successively reducing service to
low demand points until a minimum operating cost is reached.
The heuristic incorporates several rules of thumb which
improve the efficiency of the search procedure and reduce
the number of simulation runs required to obtain an effi-
cient solution. Since it is theoretically possible to
reduce service at each terminal from seven to one flight
per week, 7^8 or 5,764,801 combinations are possible with
eight terminals in the network. Several techniques are
used to eliminate the necessity of exploring all combina-
tions. One technique is to make frequency reductions at
all terminals on the same flight path simultaneously.
Another is to reduce the frequency of all flights having
load factors less than 85 percent as long as no service
level constraints are violated. These features provide
for the rapid reduction of feasible alternatives to a small
region of alternatives having the greatest promise. This
remaining region is searched until the most efficient
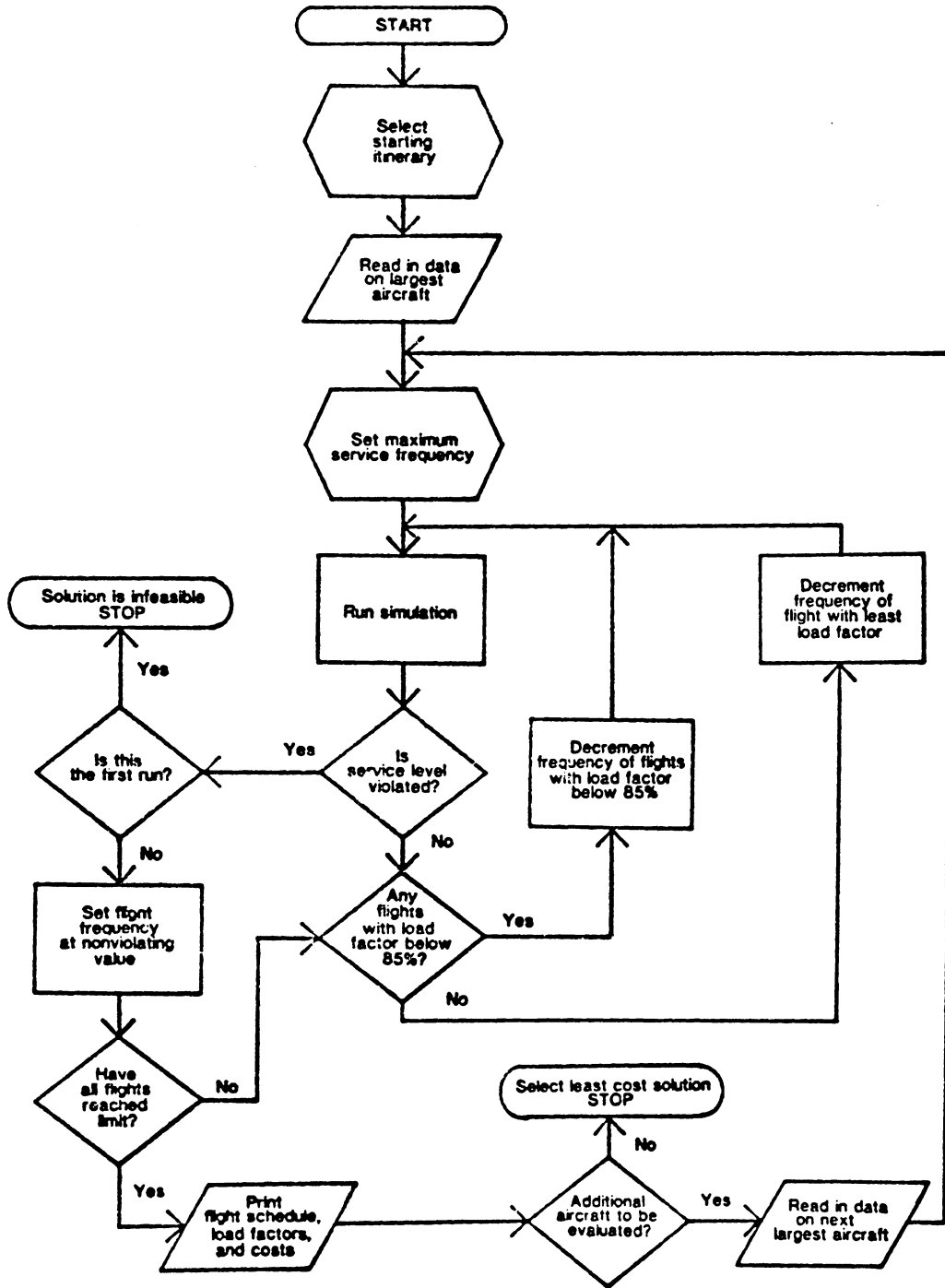
FIGURE 4-2: Flow Diagram of Decision Process

solution is found.

The program which performs the necessary logic is a
user written FORTRAN subroutine called EVAL. A coded list-
ing of this subroutine is contained in Appendix C. The
program reviews the results of a simulation run by first
checking to assure that the service level of on-time ship-
ments has not dropped below 60 percent at any terminal.
Next, the frequency of each flight with a load factor less
than 85 percent is reduced by one. The figure 85 percent
was chosen (after several experimental runs) to hold the
frequency constant for flights nearing the upper bound
until other flights with lower load factors could have their
flight frequencies decremented. When one or more flights
is reduced in frequency, summary statistics are recorded and
another simulation run is initiated with the altered flight
frequencies as input.

In the event that all flights have load factors
greater than or equal to 85 percent, and a service level
constraint is not violated, the program will reduce the
frequency of the flight with the least load factor (the one
with the greatest potential for improvement). Flight fre-
quencies are reduced one at a time until a service level
constraint is violated. When this happens, the previous
flight frequency is restored to the flight which caused
the constraint violation. An arbitrary load factor of 100

percent is assigned so that this flight cannot be decre-
mented again.

The program will attempt to reduce the frequency of
each remaining flight in turn until all have been given
dummy load factor values of 100 percent for constraint
violations. At this point, the simulation stops and a
message is printed stating the number of iterations com-
pleted. Since no further improvement is possible, the
least-cost solution can be selected from the printed
results of the last few iterations.

A summary printout of performance and cost statistics
is provided after each iteration. The information provided
consists of the following:

- Frequency of each flight (number of flights per
  week);
- Load factor for each flight (dummy load factors
  are not included);
- Average load factor for all flights;
- Monthly operating cost without delay penalty;
- Service level for each destination terminal;
- Overall service level; and
- Total monthly operating cost with delay penalty.

Summary

This chapter presented a decision framework for the simulation model which calls for successive simulation runs to find a least-cost solution. A heuristic subroutine designed to effect an efficient search was described as part of the decision procedure.

Statistical considerations were discussed with emphasis on output since stochastic simulation results are affected by random error. The margin of error was determined for the primary response variable. Demonstrations of the decision process and simulation results are presented in Chapter V.

CHAPTER V

MODEL APPLICATION WITHIN A DECISION FRAMEWORK

Flight Patterns and Aircraft Types

This chapter presents the results of the simulation
procedure applied to the U.S. Navy's QUICKTRANS air cargo
system. The first step in the simulation procedure was
to select one or more route patterns which could be tested
with a variety of aircraft and flight frequencies. The
selection of a route pattern may be accomplished by apply-
ing one or more of the route finding algorithms available
for this purpose (48), or by using the input of experienced
professionals in the transportation industry familiar with
the routing requirements of a particular network. Generally,
the number of feasible route patterns can be reduced to a
relatively small subset of flight path combinations worthy
of detailed evaluation.

A flight pattern selected for detailed evaluation and
demonstration purposes consists of six flights with the
following general orientation (flights assigned numbers 101
through 106 for reference purposes):

Flight 101: West to east, southern corridor, cross-
country;

Flight 102: East to west, southern corridor, cross-
country;

Flight 103:   West to east, middle corridor, cross-
              country;

Flight 104:   South to north, Atlantic coastal route;

Flight 105:   East to west, middle corridor, cross-
              country; and

Flight 106:   Round-trip, Pacific coastal route.

Table 5-1 contains a detailed itinerary of all flights, termi-
nals, and distances.

This flight pattern satisfies most of the requirements
for efficient service to all eight points in the QUICKTRANS
network, yet it affords greater flexibility than the current
four-flight pattern. By flying the southern corridor cross-
country, terminals such as North Island (San Diego) in the
west and Charleston and Jacksonville in the east would get
faster and more direct service on some flights. Furthermore,
if Pensacola were to be included in the air system, the
added stopover would require no major revision of the flight
pattern. Special flights to Pensacola would no longer be
required.

It should be noted also that the six-flight pattern is
balanced in the sense that the last terminal on each flight
path is the originating terminal on the next flight path.
This pattern facilitates the distribution of aircraft and
eliminates the need for unscheduled return flights. This
is a basic requirement for a transport system of this type.

TABLE 5-1   Six-Flight Route Pattern Selected for Evaluation

	Great Circle Statute Miles
FLIGHT 101	
Originate Travis AFB CA	
To NAS North Island CA	467
To NAS Jacksonville FL	2096
To Charleston AFB SC	207
To NAS Norfolk VA	350
To Dover AFB DE	158
	3278
FLIGHT 102	
Originate Dover AFB DE	
To NAS Norfolk VA	158
To Charleston AFB SC	350
To NAS Jacksonville FL	207
To NAS North Island CA	2096
To Travis AFB CA	467
	3278
FLIGHT 103	
Originate Travis AFB CA	
To NAS North Island CA	467
To Indianapolis IN (Weir Cook Airport)	1785
To NAS Norfolk VA	576
To Charleston AFB SC	350
To NAS Jacksonville FL	207
	3385
FLIGHT 104	
Originate NAS Jacksonville FL	
To Charleston AFB SC	207
To NAS Norfolk VA	350
To Dover AFB DE	158
	715
FLIGHT 105	
Originate Dover AFB DE	
To NAS Norfolk VA	158
To Indianapolis IN (Weir Cook Airport)	576
To NAS North Island CA	1785
To Travis AFB CA	467
	2986

TABLE 5-1--Continued

Great Circle
Statute Miles

FLIGHT 106

Originate Travis AFB CA
To McChord AFB WA   614
To Travis AFB CA   614
                                                    1228

Further input is required before a flight pattern can be evaluated using the simulation model. The total cost variable is a function of certain characteristics and costs associated with each aircraft type as well as the route pattern to be tested. Five aircraft are included in the evaluation procedure. Each of these aircraft types are eligible for inclusion in the QUICKTRANS air system and may be leased on a contract basis for annual service at the start of each fiscal year. The contract costs and other characteristics associated with each aircraft type are included in Table 5-2.

As a further demonstration of the simulation model and its associated heuristic, the current four-flight pattern is also evaluated and revised to effect a least-cost solution. This flight pattern has already been described in Chapter II and presented in Table 2-1. Both flight patterns are simulated using different combinations of aircraft and flight frequencies according to the decision framework outlined in the previous chapter. The demonstration of this procedure is described in the next section.

Demonstration of Model Application

A starting itinerary consisting of the six flights described in the previous section was prepared as input for the computer simulation. Matrices consisting of mileages

TABLE 5-2: Aircraft Performance Characteristics and Costs

Type	Capacity in Tons	Speed in Knots	Cost per Mile	Cost per Landing
DC-8	23.27	310	$8.60	$250
L-100	21.75	245	7.2998	250
B-727	17.90	345	6.24	250
L-188	15.22	240	5.76	250
DC-9	15.11	325	5.59	250

between all points and parameters identifying stochastic shipment distributions were also entered as input. Performance and cost data on the DC-8 (see Table 5-2) was prepared for entry in the first series of simulation runs. The service delay cost was estimated at $1000 per day for each percent below 100.

The computer simulation was performed using the SLAM simulation package on an IMB 370/158 with three megabytes of memory. The CPU time varied depending on the number of iterations in the search procedure. Each iteration used an average of 53.6 seconds of CPU time. A run of 18 iterations, therefore, required approximately 16 minutes.

When the data for a particular flight-pattern and aircraft combination was entered, no further human intervention was required. All flights were automatically assigned a flight frequency of seven days per week in the initial simulation. For the six-flight pattern, this meant that the total number of flights per week began at 42. The heuristic subroutine decremented this number according to the logic described in the previous chapter. As the number of flights per week was reduced, the simulation was repeated until there were no more feasible flight-pattern/frequency combinations to be evaluated in the least-cost region. This process required 18 iterations.

Figure 5-1 illustrates the output provided by the first three iterations, while Figure 5-2 illustrates the output from the last three iterations. Similar output is produced for all iterations in the simulation and search procedure. Both figures illustrate the output available from each iteration. Figure 5-1 shows how the frequency of each flight is decremented as the heuristic proceeds from one simulation to another. Output data for each iteration is separated by a horizontal dashed line. (The frequency of each flight in the first iteration is understood to be seven, and does not appear in the output.)

Figure 5-2 shows the output for iterations 16, 17 and 18. Iteration 16 represents a total of 22 flights per week (a reduction of 20 flights from the first iteration) at a total cost of $3,047,800. This solution is feasible since no service level drops below 60 percent. Iterations 17 and 18 show a total of 21 flights per week each; however, the service level constraint is violated at one or more terminals making these solutions unacceptable to the originator. The user is able to scan the output values and select an acceptable least-cost solution.

A summary of the results from all iterations in the first heuristic search trial is contained in Table 5-3. Iteration 11 yielded a least-total-cost solution of $3,013,000, but the difference between this solution and

AIRCRAFT DATA

AIRCRAFT TYPE	CAPACITY IN TONS	SPEED	COST PER MI.	COST PER LDG.	FLIGHT NO. ASSIGNED
DC-8	23.270	310.	8.60000	250.00	101
					102
					103
					104
					105
					106

```
     FLIGHT NUMBER 101      LOAD FACTOR 76.77
     FLIGHT NUMBER 102      LOAD FACTOR 72.77
     FLIGHT NUMBER 103      LOAD FACTOR 23.61
     FLIGHT NUMBER 104      LOAD FACTOR 14.02
     FLIGHT NUMBER 105      LOAD FACTOR 34.45
     FLIGHT NUMBER 106      LOAD FACTOR 52.42
     LOAD FACTOR FOR ALL FLIGHTS 50.26
     TOTAL COST    4023506
SERVICE
 LEVEL  98.66  97.71  98.58  99.85  99.64  99.07  99.48  99.96
     OVERALL SERVICE LEVEL  98.84
     TOTAL COST WITH DELAY PENALTY     4058217.
```

- -

```
     FLIGHT NUMBER 101      6 FLIGHTS PER WEEK
     FLIGHT NUMBER 102      6 FLIGHTS PER WEEK
     FLIGHT NUMBER 103      6 FLIGHTS PER WEEK
     FLIGHT NUMBER 104      6 FLIGHTS PER WEEK
     FLIGHT NUMBER 105      6 FLIGHTS PER WEEK
     FLIGHT NUMBER 106      6 FLIGHTS PER WEEK
     FLIGHT NUMBER 101      LOAD FACTOR 81.28
     FLIGHT NUMBER 102      LOAD FACTOR 74.20
     FLIGHT NUMBER 103      LOAD FACTOR 35.61
     FLIGHT NUMBER 104      LOAD FACTOR 20.37
     FLIGHT NUMBER 105      LOAD FACTOR 51.43
     FLIGHT NUMBER 106      LOAD FACTOR 61.40
     LOAD FACTOR FOR ALL FLIGHTS 58.76
     TOTAL COST    3452746.
SERVICE
 LEVEL  93.56  95.20  96.38  97.24  96.03  96.39  97.16  98.77
     OVERALL SERVICE LEVEL  96.00
     TOTAL COST WITH DELAY PENALTY     3572722.
```

- -

```
     FLIGHT NUMBER 101      5 FLIGHTS PER WEEK
     FLIGHT NUMBER 102      5 FLIGHTS PER WEEK
     FLIGHT NUMBER 103      5 FLIGHTS PER WEEK
     FLIGHT NUMBER 104      5 FLIGHTS PER WEEK
     FLIGHT NUMBER 105      5 FLIGHTS PER WEEK
     FLIGHT NUMBER 106      5 FLIGHTS PER WEEK
     FLIGHT NUMBER 101      LOAD FACTOR 84.85
     FLIGHT NUMBER 102      LOAD FACTOR 76.43
     FLIGHT NUMBER 103      LOAD FACTOR 51.21
     FLIGHT NUMBER 104      LOAD FACTOR 27.13
     FLIGHT NUMBER 105      LOAD FACTOR 70.51
     FLIGHT NUMBER 106      LOAD FACTOR 72.54
     LOAD FACTOR FOR ALL FLIGHTS 68.67
     TOTAL COST    2874939.
SERVICE
 LEVEL  77.69  89.55  88.45  93.96  91.88  90.27  94.77  96.51
     OVERALL SERVICE LEVEL  89.36
     TOTAL COST WITH DELAY PENALTY     3194217.
```

- -

FIGURE 5-1:   Illustration of Output - First Three Iterations of
              Six-Flight Pattern Evaluation With DC-8.

- -

```
        FLIGHT NUMBER 101      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 102      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 103      3 FLIGHTS PER WEEK
        FLIGHT NUMBER 104      1 FLIGHTS PER WEEK
        FLIGHT NUMBER 105      3 FLIGHTS PER WEEK
        FLIGHT NUMBER 106      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 101      LOAD FACTOR 88.70
        FLIGHT NUMBER 102      LOAD FACTOR 79.13
        FLIGHT NUMBER 103      LOAD FACTOR 69.86
        FLIGHT NUMBER 104      LOAD FACTOR 81.50
        FLIGHT NUMBER 105      LOAD FACTOR 87.23
        FLIGHT NUMBER 106      LOAD FACTOR 69.36
        LOAD FACTOR FOR ALL FLIGHTS 80.44
        TOTAL COST    2267218.
SERVICE
 LEVEL 68.96  71.99  80.04  64.42  64.42  67.89  92.42  90.78
        OVERALL SERVICE LEVEL   73.98
        TOTAL COST WITH DELAY PENALTY    3047801.
```

- -

```
        FLIGHT NUMBER 101      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 102      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 103      3 FLIGHTS PER WEEK
        FLIGHT NUMBER 104      1 FLIGHTS PER WEEK
        FLIGHT NUMBER 105      3 FLIGHTS PER WEEK
        FLIGHT NUMBER 106      4 FLIGHTS PER WEEK
        FLIGHT NUMBER 101      LOAD FACTOR 88.27
        FLIGHT NUMBER 102      LOAD FACTOR 77.73
        FLIGHT NUMBER 103      LOAD FACTOR 71.31
        FLIGHT NUMBER 104      LOAD FACTOR 77.50
        FLIGHT NUMBER 105      LOAD FACTOR 85.98
        FLIGHT NUMBER 106      LOAD FACTOR 81.90
        LOAD FACOTR FOR ALL FLIGHTS 81.24
        TOTAL COST    2219481.
SERVICE
 LEVEL 36.21  74.13  80.78  63.46  65.38  66.43  92.03  91.53
        OVERALL SERVICE LEVEL   70.35
        TOTAL COST WITH DELAY PENALTY    3109096.
```

- -

```
        FLIGHT NUMBER 101      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 102      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 103      3 FLIGHTS PER WEEK
        FLIGHT NUMBER 104      1 FLIGHTS PER WEEK
        FLIGHT NUMBER 105      2 FLIGHTS PER WEEK
        FLIGHT NUMBER 106      5 FLIGHTS PER WEEK
        FLIGHT NUMBER 101      LOAD FACTOR 88.46
        FLIGHT NUMBER 102      LOAD FACTOR 80.02
        FLIGHT NUMBER 103      LOAD FACTOR 68.92
        FLIGHT NUMBER 104      LOAD FACTOR 78.16
        FLIGHT NUMBER 105      LOAD FACTOR 88.36
        FLIGHT NUMBER 106      LOAD FACTOR 67.78
        LOAD FACTOR FOR ALL FLIGHTS 80.00
        TOTAL COST    2152074.
SERVICE
 LEVEL 69.63  68.35  72.80  58.52  65.36  67.53  92.43  90.88
        OVERALL SERVICE LEVEL   72.07
        TOTAL COST WITH DELAY PENALTY    2990112.
```

- -

```
        SOLUTION HAS VIOLATED SERVICE LEVEL CONSTRAINT
        SELECT PRIOR SOLUTION     HEURISTIC REQUIRED  18 ITERATIONS
```

FIGURE 5-2: Illustration of Output - Last Three Iterations of
            Six-Flight Pattern Evaluation With DC-8.

TABLE 5-3: Heuristic Search for Least-Cost Schedule Using Six-Flight Pattern Flown by DC-8, Capacity 23.27 Tons (All Costs in $1000)

Iteration	Total Number of Flights per Week	Mean Load Factor	Mean Service Level	Avg. Monthly Cost w/o Delay Penalty	Average Total Monthly Cost
1	42	50.26%	98.84%	4024	4058
2	36	58.76	96.00	3453	3573
3	30	68.67	89.36	2875	3194
4	24	– constraint violation		–	–
5	29	69.98	86.75	2845	3243
6	28	69.31	87.73	2816	3184
7	27	70.34	86.00	2786	3206
8	26	74.34	85.21	2655	3099
9	25	74.36	85.67	2626	3055
10	24	77.17	79.55	2496	3110
11	23	79.32	78.92	2381	3013*
12	22	– constraint violation		–	–
13	22	– constraint violation		–	–
14	22	– constraint violation		–	–
15	22	– constraint violation		–	–
16	22	80.44	73.98	2267	3048
17	21	– constraint violation		–	–
18	21	– constraint violation		–	STOP

*Least-cost value

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two other solutions (iteration 9 and iteration 16) is not statistically significant. This illustrates one of the problems associated with a stochastic response variable which is discussed in greater detail in Chapter VI. The best that can be expected, according to Biles, is that "we shall seek a solution which hopefully lies close to the true solution" (6, p. 11).

The simulation and search procedure was undertaken again using the six-flight pattern and a different aircraft, the L-100. The results of this process are summarized in Table 5-4. Again, 18 iterations were required, and a least-cost solution was found in the 11th iteration. Similarly, the heuristic search procedure was applied to the remaining three aircraft (B-727, L-188, and DC-9). The results are summarized in Tables 5-5, 5-6 and 5-7. An evaluation of these results which constitute the complete decision process for the six-flight pattern is included in the next section.

Evaluation of Output

Figure 5-3 contains a plot of each of the cost curves interpolated from the output of the heuristic search procedure using the six-flight pattern described in the previous section. A separate curve depicts the results obtained for each aircraft evaluated. The search procedure started

TABLE 5-4. Heuristic Search for Least-Cost Schedule Using Six-Flight Pattern
Flown by L-100, Capacity 21.75 Tons (All Costs in $1000)

Iteration	Total Number of Flights per Week	Mean Load Factor	Mean Service Level	Avg. Monthly Cost w/o Delay Penalty	Average Total Monthly Cost
1	42	53.57%	98.19%	3442	3497
2	36	62.26	94.04	2954	3133
3	30	72.25	85.76	2460	2887
4	25	— constraint violation		—	—
5	29	72.19	83.84	2434	2919
6	28	72.84	83.51	2409	2903
7	27	73.67	82.37	2383	2912
8	26	77.75	80.92	2271	2843
9	25	77.79	81.58	2245	2798
10	24	— constraint violation		—	—
11	24	80.02	78.89	2147	2780*
12	23	— constraint violation		—	—
13	23	— constraint violation		—	—
14	23	— constraint violation		—	—
15	23	— constraint violation		—	—
16	23	80.30	74.33	2050	2820
17	22	81.92	70.83	1939	2814
18	21	— constraint violation		—	STOP

*Least-cost value

TABLE 5-5 Heuristic Search for Least-Cost Schedule Using Six-Flight Pattern
Flown by B-727, Capacity 17.90 Tons (All Costs in $1000)

Iteration	Total Number of Flights per Week	Mean Load Factor	Mean Service Level	Avg. Monthly Cost w/o Delay Penalty	Average Total Monthly Cost
1	42	63.11%	93.72%	2969	3157
2	36	72.32	85.42	2548	2985
3	30	— constraint violation		—	—
4	35	72.51	85.57	2525	2958
5	34	73.27	84.26	2503	2975
6	33	73.33	83.62	2481	2972
7	32	74.31	81.43	2458	3015
8	31	76.72	79.88	2361	2965
9	30	77.18	79.34	2339	2959
10	29	— constraint violation		—	—
11	29	79.05	77.25	2243	2925
12	28	— constraint violation		—	—
13	28	— constraint violation		—	—
14	28	81.56	76.45	2149	2855
15	27	— constraint violation		—	—
16	27	— constraint violation		—	⌐
17	27	82.64	74.46	2055	2822*
18	26	— constraint violation		—	STOP

*Least-cost value

TABLE 5-6   Heuristic Search for Least-Cost Schedule Using Six-Flight Pattern
Flown by L-188, Capacity 15.22 Tons (All Costs in $1000)

Iteration	Total Number of Flights per Week	Mean Load Factor	Mean Service Level	Avg. Monthly Cost w/o Delay Penalty	Average Total Monthly Cost
1	42	70.54%	86.54%	2754	3158
2	36	– constraint violation		–	–
3	41	72.36	86.99	2734	3134
4	40	72.20	86.35	2713	3122
5	39	72.50	84.65	2692	3152
6	38	72.56	85.38	2671	3110
7	37	75.04	83.34	2582	3082
8	36	75.51	81.58	2561	3114
9	35	77.31	80.14	2472	3068
10	34	– constraint violation		–	–
11	34	78.29	76.93	2382	3075
12	33	– constraint violation		–	–
13	33	– constraint violation		–	–
14	33	– constraint violation		–	–
15	33	79.84	75.47	2305	3041
16	32	– constraint violation		–	–
17	32	80.62	73.68	2219	3008*
18	31	– constraint violation		–	STOP

*Least-cost value

TABLE 5-7 Heuristic Search for Least-Cost Schedule Using Six-Flight Pattern
Flown by DC-9, Capacity 15.11 Tons (All Costs in $1000)

| Iteration	Total Number of Flights per Week	Mean Load Factor	Mean Service Level	Avg. Monthly Cost w/o Delay Penalty	Average Total Monthly Cost
1	42	70.77%	86.05%	2678	3097
2	36	– constraint violation		–	–
3	41	72.71	86.64	2658	3059
4	40	72.42	86.05	2638	3056
5	39	72.75	84.25	2617	3090
6	38	72.84	84.70	2597	3056
7	37	75.37	82.57	2511	3034
8	36	75.84	81.05	2490	3059
9	35	77.66	79.64	2403	3014
10	34	– constraint violation		–	–
11	34	78.65	76.05	2316	3035
12	33	– constraint violation		–	–
13	33	– constraint violation		–	–
14	33	80.69	76.24	2233	2946
15	32	– constraint violation		–	–
16	32	– constraint violation		–	–
17	32	81.85	74.96	2148	2900*
18	31	– constraint violation		–	STOP

*Least-cost value

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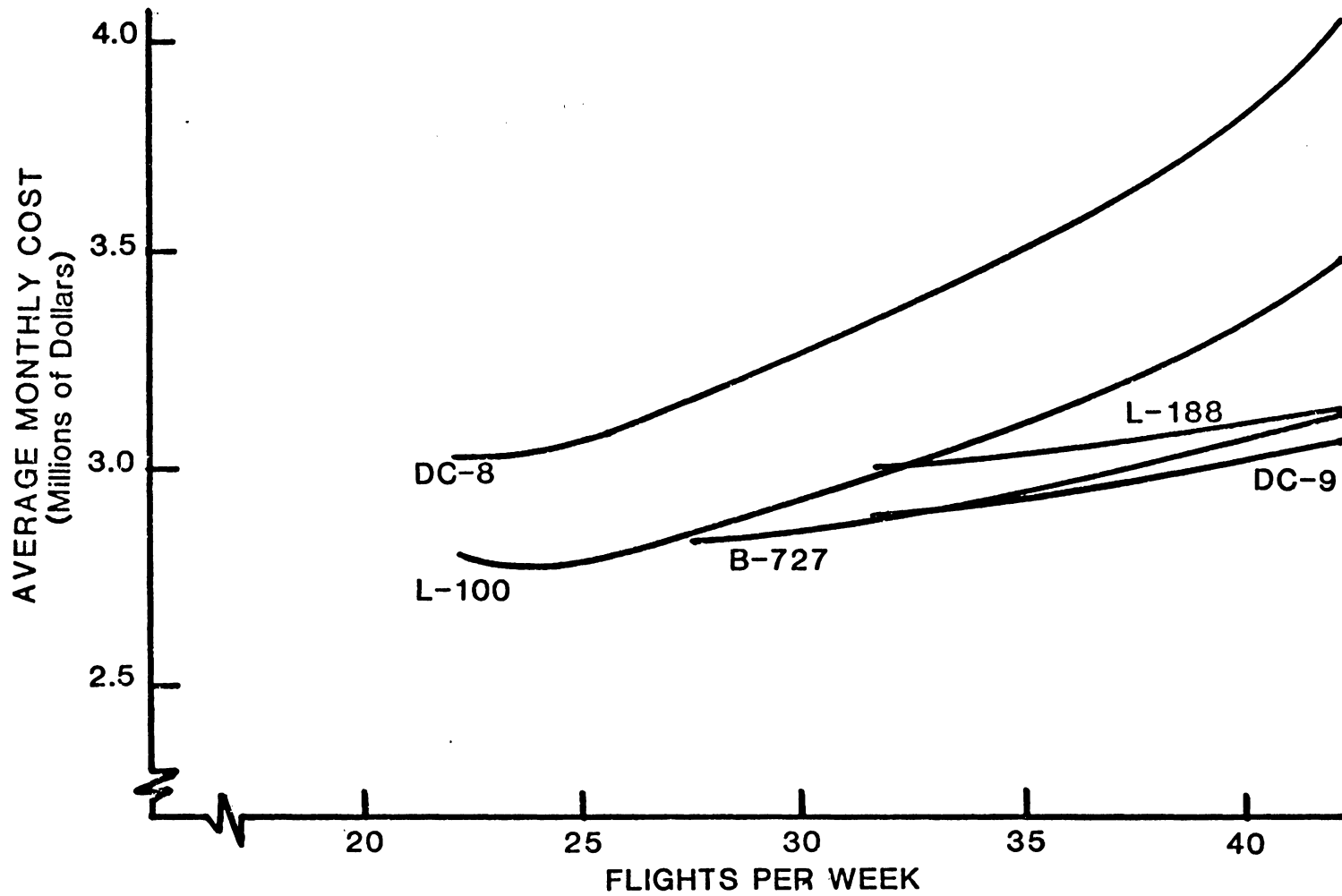
FIGURE 5-3:   Average Monthly Cost Curves by Number of Flights per Week.
Six-Flight Pattern, Five Aircraft Evaluated.

with a maximum of 42 flights per week with successive re-
ductions until one or more constraints were violated. The
consequent reduction in average total monthly cost may be
seen in Figure 5-3 by following each curve from the right
to the point where it stops (due to constraint violations)
or the slope flattens out to zero. The minimum cost for
each aircraft evaluated may be approximated from the graph.
Furthermore, the least-cost solution for any feasible
schedule specifying the number of flights per week may be
determined from the graph.

As expected, the larger aircraft (DC-8 and L-100)
yielded larger costs at the high end of the scale of flights
per week. However, some costs diminished more rapidly than
others as the number of flights per week decreased. As a
result, the L-100 becomes a more economical choice than the
L-188 below 32 flights per week. Also, the B-727 becomes
a more economical choice than the DC-9 below 33 flights per
week. The cost curve for the L-100 dropped lower than all
others with a least-cost solution of 24 flights per week.

Table 5-8 contains a summary of heuristic search
results using the six-flight pattern for each aircraft type
evaluated. As noted, the L-100 turned out to be the most
economical choice for this flight pattern. A schedule of
24 flights per week would be expected to cost an average of
$2,780,000 per month. The next economical choice would be

TABLE 5-8   Summary of Heuristic Search Results Using Six-Flight Pattern,
             Five Aircraft Evaluated (All Costs in $1000)

Aircraft	Capacity (Tons)	Flights per Week	Mean Load Factor(%)	Mean Service Level (%)	Avg. Monthly Cost w/o Delay Penalty	Least Average Total Monthly Cost
DC-8	23.27	23	79.32	78.92	2381	3048
L-100	21.75	24	80.02	78.89	2147	2780*
B-727	17.90	27	82.64	74.46	2055	2822
L-188	15.22	32	80.62	73.68	2219	2008
DC-9	15.11	32	81.85	74.96	2148	2900

*The L-100 aircraft yields a least-cost solution flying 24 flights per week
for a total average monthly cost of $2,780,000.

a B-727 flying 27 flights per week at a monthly average
cost of $2,822,000, a difference of $42,000. This differ-
ence does not exceed the sampling error ($56,200) at 95
percent confidence, thus there is no statistical assurance
that the L-100 produces the best (or optimal) solution.
When the confidence interval of one solution overlaps the
confidence interval of another, there is always some prob-
ability that the true means may not differ to the extent
that one solution will be preferred over another. The
L-100 solution differs sufficiently from the remaining three
aircraft solutions to be significant, and therefore accept-
able as a preferred solution. The schedule for the six-
flight pattern at the L-100 solution point is as follows:

Flight Number	Flights per Week	Days Flown
101	5	T,W,Th,F,Su
102	5	T,W,Th,F,Su
103	4	M,T,Th,Sa
104	1	Sa
105	4	M,T,Th,Sa
106	5	T,W,Th,F,Su

Table 5-8 reveals additional information that may be
of value to transportation managers evaluating two or more
alternatives that are very close in cost. For instance, the
L-100 shows a simulated mean load factor of 80.02 percent
and a mean service level of 78.89 percent. The B-727 shows

a slightly higher mean load factor of 82.64 percent, suggesting better utilization, and a lower mean service level of 74.46 percent, suggesting reduced on-time delivery. Of course, these percentages are subject to random error and can only be regarded as point estimates in much the same manner as costs. (Disregarding the delay penalty, the B-727 reveals a lower operating cost.) These ancillary features may persuade a manager to select an alternative based on considerationsother than a strict least-cost criterion.

Table 5-9 contains the results of the heuristic search procedure using a four-flight pattern for each aircraft type. Fewer iterations were required to arrive at a least-cost solution. Only two aircraft types produced feasible solutions for this alternative. The DC-8 produced a least-cost solution of $2,733,000 while the L-100 produced a least-cost solution of $2,532,000, a difference of over $200,000. This difference is substantial and proves to be statistically significant. Therefore, the L-100 alternative may be selected with 28 flights per week (each of the four flights flown daily). This least-cost solution is almost identical to the schedule described in Table 2-1. The solution produced a simulated mean load factor of 91.98 percent and a mean service level of 79.89 percent. No improvement is possible without disregarding the delay penalty, in which case, an L-100 solution of 25 flights per

TABLE 5-9   Heuristic Search for Least-Cost Schedule Using Four-Flight Pattern
(All Costs in $1000)

Iteration	Total Number of Flights Per Week	Mean Load Factor	Mean Service Level	Avg. Monthly Cost w/o Delay Penalty	Average Total Monthly Cost
AIRCRAFT:	DC-8, Capacity 23.27 Tons				
1	28	80.45%	84.02%	2254	2733
2	26	84.04	81.07	2177	2745
3	24	86.31	76.88	2100	2793
4	22	–	constraint violation	–	–
5	23	–	constraint violation	–	–
6	23	–	constraint violation	–	–
7	23	–	constraint violation	–	–
8	23	–	constraint violation	–	STOP
AIRCRAFT:	L-100, Capacity 21.75 Tons				
1	28	81.98%	79.89%	1929	2532*
2	26	85.21	77.09	1863	2551
3	24	–	constraint violation	–	–
4	25	–	constraint violation	–	–
5	25	85.56	73.67	1838	2627
6	24	–	constraint violation	–	–
7	24	–	constraint violation	–	–
8	24	–	constraint violation	–	STOP

AIRCRAFT: B-727, Capacity 17.90 Tons -- No feasible solution...

AIRCRAFT: L-188, Capacity 15.22 Tons -- No feasible solution...

AIRCRAFT: DC-9, Capacity 15.11 Tons -- No feasible solution...

*The L-100 aircraft yeilds a least-cost solution flying 28 flights per week for a total average monthly cost of $2,532,000.

week may be considered with an average monthly operating
cost of $1,838,000. Should this solution prove to be
acceptable, a cost saving of $91,500 per month in operating
cost could be realized. The schedule would be as follows:

Flight Number*	Flights per Week	Days Flown
172	7	Daily
162	5	T,W,Th,F,Su
171	7	Daily
252	6	M,T,W,Th,F,Sa

*Flight numbers previously assigned, see Table 2-1.

Summary

This chapter presented a demonstration of the simu-
lation procedure within the context of the decision-making
framework set up in Chapter IV. A six-flight pattern was
tested with five different aircraft types. The heuristic
portion of the decision framework was used to reduce flight
frequencies at each successive iteration until a least-cost
schedule was obtained. Total cost curves were identified
for each aircraft type. The six-flight pattern turned out
to be most efficient with the L-100 aircraft.

As a further demonstration, a four-flight pattern
was tested with the same five aircraft types. Again, the
heuristic portion of the decision framework was used to
reduce flight frequencies as long as feasible solutions

could be obtained. Additional output features were indicated to the extent that they might have a bearing on the final selection. The four-flight pattern also produced a least-cost solution with the L-100 aircraft.

In each case, the decision procedure, using the simulation model and its associated heuristic, led to the identification of a feasible schedule at reduced cost. The next chapter summarizes the results of this research and describes what was learned from the process. Wider use of the model is discussed, and consideration is given to its potential value in the air transportation industry.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

Summary of Model Development

This research effort resulted in the development of a
transport simulation model which, for the first time, treat-
ed air shipment quantities as stochastic variables rather
than fixed inputs. A distinguishing feature in this study
lies primarily in the recognition that shipment quantities
fluctuate from day to day exhibiting characteristics of
randomness and probability distribution. Virtually all of
the vehicle scheduling models in the literature treat ship-
ment quantities as fixed inputs.

By developing a simulation model which replicates the
daily fluctuations of shipment quantities, vehicle load
measures are more accurate and delayed shipments can be
detected. Shipments which cannot be loaded due to random
high demand and space/weight limitations of the aircraft are
recorded, both in number and tonnage. If "average" shipping
quantities were used, as in other models, the quantity and
proportion of delayed shipments would be undetectable. In
fact, the output of other loading algorithms is suspect be-
cause the overload possibilities resulting from random

surges in demand are never revealed. The simulation model presented in this study was designed to overcome the primary disadvantage of previous models.

The air transport simulation model makes use of the SLAM computer package which allows for user interaction through the use of FORTRAN written subroutines. The SLAM package includes random number generators which are used to produce values representing stochastic shipment quantities for the simulation. All input parameters are derived from historical records provided by the Naval Material Transportation Office in Norfolk, Virginia. A curve-fitting program called SIMFIT was used to identify the probability distribution patterns for each origin-destination pair. The simulation model uses a discrete (next-event) simulation methodology to represent the pickup and delivery of shipments at various depots. The model was tested by applying appropriate statistical measures during the verification and validation phase.

A total cost response variable was formulated to provide a criterion for evaluating various flight pattern frequency and aircraft combinations. This variable is a function of aircraft type, speed, distance, number of landings, and service level. Its value is affected by the pattern and frequency of flights and the percentage of delayed shipments resulting from reduced service. If flights are increased, the operating cost component rises while the delay cost

component is reduced. If flights are decreased, operating costs are reduced and delay costs go up. The total cost function takes into account both the cost of operating the aircraft and the cost of not being able to transport all of the cargo due to space/weight limitations. Delayed cargo often has to be expedited or shipped by alternative means, thus a penalty cost has been incorporated into the analysis.

The simulation model was developed to analyze any number of different route patterns in the Navy's air transport system. However, a simulation run, by itself, does not necessarily bring about a least-cost solution. A simulation will only replicate the likely outcome of a particular trial. A number of replications are needed to select a least-cost solution and provide response values accurate enough for statistical interpretation. To this end, a heuristic was developed within the context of a decision framework that would automatically execute a search procedure and make rapid progress toward an efficient solution.

The decision framework calls for the selection of a route pattern which connects all points in the air network and provides for a balance in the distribution of aircraft. Route selection and optimal tour algorithms are available for this purpose (48), but none was required in conjunction with the QUICKTRANS model. The U.S. Navy has only a limited subset of route pattern alternatives to be considered for evaluation. Two of these were chosen for the purpose of

demonstrating the evaluation process and are featured in the next section.

Summary of Research Results

The U.S. Navy provided performance and cost data for five different aircraft types ranging in capacity from a high of 23 tons to a low of 15 tons. It was not known which of these aircraft would perform most economically given the route patterns under consideration. Furthermore, it was not known precisely how many days per week each flight would have to be offered in order to maintain an adequate level of service. To resolve these unknowns and obtain a least-cost solution, the simulation and search procedure was applied with the following results.

The first pattern consisted of six flights serving the eight-point air network using two cross-country corridors and north-south routes on either coast. This pattern was evaluated for each of five different aircraft types by starting with the maximum frequency for each flight (all flights daily, a total of 42 per week). The search heuristic rapidly reduced the number of flights until constraint violations began to occur. When this happened, different flight frequency combinations were tried until there were no more feasible alternatives in the solution zone. A least-cost solution was then selected from the simulation results. It was determined that the six-flight pattern could

meet the requirements of the QUICKTRANS air system by flying
L-100 type aircraft a total of 24 flights per week. A point
estimate of the minimum total average monthly cost was
$2,780,000. The evaluation procedure required a total of
90 simulation runs (18 iterations for each of the five air-
craft types).

The second pattern consisted of four flights serving
the eight-point air network using one cross-country corridor
and north-south routes on both coasts. This pattern was
also evaluated for each of five different aircraft types by
starting with the maximum frequency for each flight (all
flights daily, a total of 28 per week). The search heuristic
converged more rapidly with the four-flight pattern requiring
only eight iterations for each of the first two aircraft
types, and one iteration for each of the remaining three
aircraft types. (The last three types produced no feasible
solution.) The four-flight pattern, therefore, required a
total of 19 iterations for a complete evaluation.

From the standpoint of total cost function, the L-100
type aircraft flying the four-flight pattern a total of 28
flights per week turned out to be the least-cost alternative.
A point estimate of the minimum total average monthly cost
was $2,532,000. This result confirmed the Navy's own analysis
which for the past three years had selected the L-100 for its
flights using a four-flight pattern. (It is noteworthy, how-
ever, that the Navy did not consider the penalty cost of

delayed shipments in past analysis; this feature added a new dimension to the evaluation procedure.)

A number of lessons were learned during the course of this study, many of which pertain to the technical aspects of simulation model development. It turned out that the simulation package, SLAM, is an appropriate modeling vehicle for this type of simulation which involves a complex queueing system. There are some features, however, which could be improved to facilitate the modeling effort. One of these is the ability to set discrete end-points on probability distributions (using maximum and minimum parameters) without having to write additional statements into porgram subroutines. Other simulation packages contain this feature.[1]

Another finding resulting from this research pertains to the need for a carefully structured decision framework for evaluating simulation results. A valid simulation model is essential, but a logically derived decision procedure is equally important to conserve computer resources and find efficient solutions. When the simulation model produces results based on stochastic input, the margin of error associated with the response variable can confound the selection process. This difficulty was resolved in

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[1]GERT, Q-GERT, and GASP provide for maximum and minimum values as discrete end-points on continuous probability distributions.

part by the use of statistical analysis which identified the margin of error for given confidence levels.

The decision procedure also included a heuristic designed to seek out a least-cost solution with as few simulation iterations as possible. Biles states that direct search procedures generally make rapid early progress toward an "optimum," but "iterate laborously as a solution is neared. This is particularly true in the presence of random error, as encountered in simulation" (6, p. 11). It was discovered that the number of iterations can be reduced if stopping rules are based on constraint violations rather than random values of a response variable. This method assures that no infeasible alternatives are attempted more than once, and that other promising combinations are not overlooked. Each time a constraint violation occurs, the offending flight reduction is restored to its original value and retired from further alteration. When all flights have been so retired, the heuristic brings the simulations to a halt.

The air transport simulation model and its associated heuristic performed as intended when applied to the route structure of the Navy's QUICKTRANS system. Accordingly, the particular objectives of this research effort were realized. As noted earlier, an exhaustive analysis of all possible aircraft mixes was not required for demonstration purposes.

However, the model's utility was intended to extend beyond
this particular application. The next section examines the
prospect of general applicability to other air transport
networks.

CARGOSIM - An Air Transport Simulation Model

Although air transport systems differ in various
respects due to the nature of their mission and the types
of organizations they serve, there are key features that all
have in common. Whether military or commerical, air cargo
distribution systems include a network of terminals at vary-
ing distances from each other, a pool of aircraft with
limited capacity, and a continuing flow of materials into
and out of the system. In order to reflect the general
applicability of the air transport simulation model develop-
ed in this study, the name CARGOSIM has been given to the
model contained in Appendix B.

Early in this research effort, air cargo systems in
the private sector were studied as well as the Navy's
QUICKTRANS service. It was desired that the simulation
model be general enough to accomodate other systems rather
than being tied solely to QUICKTRANS network. This objec-
tive was largely achieved. With some minor changes in a
few subroutines, the model could be applied to any air
cargo system serving a simple network (or subnetwork) of

terminals and transloading points with regularly scheduled flights.

The simulation model is designed to evaluate the suitability of flights and aircraft assigned to various routes, and aid in the selection of a least-cost schedule. The specific problem of route finding or route optimization was not addressed in this study since numerous route finding algorithms have already been developed and are extensively treated in the literature. In fact, Mentzer and Schuster (48) identified more articles related to vehicle routing than any other class of transportation/distribution activity. Route selection and optimal tour algorithms are available for fleet application and can be used in conjunction with the CARGOSIM model. Those that are specifically designed for air cargo networks are a maximum payload network algorithm developed by Dantzig and Johnson (21), a variation of the Clark-Wright algorithm developed for Federal Express (13), and a mixed-integer program designed for Flying Tiger Airlines by Marsten and Muller (44). Vehicle routing algorithms tend to be network specific and should be chosen carefully. For instance, Federal Express uses a hub-and-spoke network design while Flying Tiger employs the concept of a spider graph with interconnected hubs. Once a deterministically selected route is obtained, the aircraft selection and scheduling process can be undertaken by using

the simulation model and the associated heuristic des-
cribed in this study.

CARGOSIM will provide the performance measures and
cost statistics essential to air transportation managers
using the model to evaluate flight pattern and aircraft
combinations when new alternatives are being considered.
Since most air transport systems call for regularly
scheduled flights, the associated heuristic (contained in
Appendix C) could be used to reduce flight frequencies un-
til a least-cost schedule is achieved without diminishing
service to unacceptable levels. The model has been demon-
strated to produce cost savings for the U.S. Navy's QUICK-
TRANS system. There is no reason to believe that similar
results could not be obtained by using CARGOSIM in other
transportation networks.

The use of this model has significant implications
for commercial aircraft usage as well as military applica-
tion. The desire for profitable load factors and the con-
commitant need for fast and efficient service suggests that
a model designed to achieve this balance could make signi-
ficant contributions to the air freight industry. The high
cost of aircraft used as dedicated air freighters makes
accurate aircraft selection and judicious scheduling a
matter of paramount importance. Too small a capacity will
cause prohibitive costs. Since commercial air freight

companies must purchase or lease aircraft for their operations, the aircraft selection decision affects a longer planning horizon and is therefore more crucial than the Navy's annual contract arrangement. Most air freight companies provide overnight service also, which requires a premium to be paid for nighttime operations. This fact underscores the need for cost effective aircraft selection and scheduling. Thus, this model could be most beneficial to the commercial air cargo industry.

There are, however, some features which are prerequisite to the application of the model. The major thrust of the simulation is to take into account the stochastic nature of shipping quantities. It is imperative, therefore, that accurate cargo data be maintained and analyzed in order to identify input parameters. Shipping records must include all shipments entering the air system at each terminal on at least a daily basis. Shipments are categorized by origin and destination within the air system. If this information is unavailable or cannot be closely approximated, the simulation model is not likely to be of value.

Once the shipment distribution parameters are identified, function SHPMT needs to be reprogrammed to generate appropriate random values based on the distribution types. The model does not assume a particular arrival pattern.

All shipment distributions must be determined by the user.

The model may require some modification for a user operating a large number of flights simultaneously. The primary reason for this is the basic time unit for the simulation. CARGOSIM was developed for air cargo systems operating a limited number of flights per day. Each flight is entered as input according to the order of departure, but specific times are not essential as far as the simulation is concerned. Once the flights for one day have been simulated, the model simply advances to the next day and begins again. By simplifying the basic time unit to one day, a considerable amount of computer time is saved. A more elaborate flight schedule would require shorter time units, such as hours or minutes, to represent the system adequately. This would require the availability of shipment arrival data on an hourly or minute-by-minute basis, as well as a substantial reprogramming effort.

Another feature that might require some reprogramming is the convention (listed in Table 3-9) that associates certain days of the week with specific flight frequencies. As noted in Chapter III, this convention can be overridden or replaced if the user wishes to specify different days. A reprogramming of subroutine SETFL would accomplish this purpose.

Remaining considerations pertain to the dimensions of the computer program and simulation package that constitute the air transport simulation model. CARGOSIM can be used without alteration to represent flight patterns consisting of up to nine flights in a network of ten terminals with as many as five different types of aircraft included in the aircraft mix. Storage arrays and input/output subroutines could be redimensioned and reprogrammed for larger networks as long as sufficient computing capability is available to execute the expanded model.

Further research may be required to fully demonstrate the applicability of CARGOSIM in an air cargo system apart from the Navy's system. Yet this study has produced a usable and workable simulation model that overcomes some of the objections of earlier models and can be used in conjunction with a decision framework leading to a least-cost solution. A heuristic is available to aid in the search for an efficient aircraft/flight pattern and frequency combination. The implementation of the decision process has been demonstrated, and some of the particulars of application to other air systems have been addressed. The next section discusses the potential of this approach and its wider industry implications.

Wider Industry Implications

CARGOSIM was developed as a generalized air transport simulation model which is able to estimate aircraft utilization, load factors, and service levels; all of which are important measures of performance affected by the stochastic behavior of shipment arrivals. By simulating actual cargo quantities over time, CARGOSIM can detect delayed shipments, under-utilization of aircraft, shipment queues at various terminals, and excess costs resulting from imbalance in capacity and service. The simulation approach is particularly suited to vehicle scheduling problems involving stochastic time and customer load demand variables.

The few researchers who have attempted to incorporate stochastic demand considerations in vehicle scheduling problems employed simulation to evaluate the procedure. Cook and Russell (20) used a GPSS simulation model to evaluate the suitability of deterministically generated routes to and from a central depot on stochastic demand loads. The CARGOSIM model expanded this concept further by considering all shipments picked up, delivered, and transloaded to subsequent vehicles for transfer to final destinations. This application is unique and can be employed in expanded networks including a number of transloading points.

Any transportation/distribution system meeting the general description described above could conceivably benefit from a stochastic simulation approach to the analysis of route pattern alternatives and vehicle assignments. An example would include a parcel pick-up and delivery service using trucks or vans to transport items on a regular basis. Once the distribution patterns are identified, a simulation model using the capabilities of CARGOSIM could provide the manager or dispatcher with information similar to that of the air cargo distribution system. The simulation would be able to detect delayed deliveries, under-utilization of vehicles, shipment queues at various depots, and excess costs resulting from imbalance in capacity and service. Other distribution/collection systems that might benefit from this approach include food service delivery, packaged goods distribution, and municipal waste collection.

With increased emphasis on recycling, many distribution activities now include the recovery of containers or other product components that must be returned to the factory. Logistics in reverse complicates the distribution picture by adding the responsibility of collecting goods as well as delivering them. Examples include fluid delivery and collection of containers, product delivery and return of waste materials for reprocessing, and component delivery

in exchange for used components that can be rebuilt. Since CARGOSIM was specifically developed for transportation systems requiring both pick-up and delivery, the simulation approach could be used to analyze the forward and reverse channels of distribution involved in the retromovement of goods.

Although CARGOSIM was intended for air cargo transport, the pick-up and delivery of passengers is a parallel activity for which the simulation approach may be applicable. A model similar to CARGOSIM can be applied to the passenger airline industry if capacity is measured in terms of seating availability, and shipments are replaced by passengers. The same points made with regard to air freight concerning capacity, service, and long-term commitments also apply to passenger air carriers. Recent airline deregulation has provided the incentive to experiment with different routes, aircraft, and schedules. A computer model like the one presented makes it possible to evaluate realistically the effects of aircraft and flight pattern combinations before resources are committed to a final selection. The application of this simulation model could help meet the competitive pressure to improve service while cutting costs.

In order to apply CARGOSIM to a passenger airline network, ton-miles should be converted to revenue passenger miles (RPMs), and passenger demand patterns should be

empirically derived. The distributions for passenger demand between origin and destination points are likely to be discrete rather than continuous, and seasonal fluctuations would have to be taken into account. Passenger demand forecasting techniques may be used to identify these patterns and replace the SHPMT subroutine with appropriate random variable generators.

The simulation approach used in this study could conceivably be extended to a great many transportation/distribution systems including those using road, rail, and water. Major benefits can be realized when the system experiences a pattern of fluctuating demand, pays a high premium for over-capacity, has vehicles of different sizes to choose from, and must perform on a regular schedule. Trends in the economy indicate that the costs of product movement and service distribution are likely to increase relative to other activities. This growing concern suggests that analytical techniques such as that represented by CARGOSIM will have an important role in the future of transportation management.

Promising avenues for further research include testing various aircraft mixes in a particular flight pattern, changing day-of-the-week assignments for flights of a given frequency, and incorporating an appropriate route-finding algorithm into the present simulation/heuristic combination.

Nevertheless, any transportation/distribution situation which meets the basic assumptions contained in the CARGOSIM model may benefit from the use of a similar approach to the selection, evaluation, assignment, and scheduling of vehicles used to transport cargo through a network of origin, destination, and transhipment terminals.

References

1. Air Transportation Regulatory Reform. Washington, D.C.: American Enterprise Institute for Public Policy Research, 1978.

2. Auterio, V. J. "Q-GERT Simulation of Air Terminal Cargo Facilities." Proceedings: Pittsburgh Modeling and Simulation Conference 5 (1974), pp. 1181-1186.

3. Agin, N. I. and D. E. Cullen. "An Algorithm for Transportation Routing and Vehicle Loading." Logistics, ed. by M. A. Geisler. New York: American Elsevier, 1975, pp. 1-20.

4. Ballou, R. H. Business Logistics Management. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1973.

5. Baumol, W. J. and H. D. Vinod. "An Inventory Theoretic Model of Freight Transport Demand." Management Science 16 (March 1970), pp. 413-421.

6. Biles, William E. Optimization of Multiple-Response Simulation Models. South Bend, Indiana: Notre Dame University, Final report, October 31, 1978.

7. Binkley, John A. "The Air Freight Decision." New York: Columbia University, Doctoral Dissertation, 1974.

8. Bowersox, D. J. Logistical Management, 2nd Ed. New York: Macmillan Publishing Co., 1978.

9. Bowersox, D. J., D. J. Closs, J. T. Mentzer, and J. R. Sims. Simulated Product Sales Forecasting. East Lansing: MSU Business Studies, 1979.

10. Bowersox, D. J., et al. Dynamic Simulation of Physical Distribution Systems. East Lansing: MSU Business Studies, 1972.

11. Bowersox, D. J., E. W. Smykay, and B. J. LaLonde. Physical Distribution Management. New York: Macmillan Company, 1968.

12. Camp, Robert C. "The Effect of Variable Lead Times on Logistics (Physical Supply and Distribution) Systems." University Park, Pa.: The Pennsylvania State University, Doctoral Dissertation, 1972.

13. Chan, Y. and R. J. Ponder. "The Small Package Air Freight Industry in the United States: A Review of the Federal Express Experience." Transportation Research 13a (1979), pp. 221-229.

14. Chan, Y. "A Survey of U.S. Domestic Airline Industry." Transportation Planning Journal 4 (1975).

15. Clark, G. and J. W. Wright. "Scheduling of Vehicles from a Central Depot to a Number of Delivery Points." Operations Research 11 (1963), pp. 568-581.

16. Clayton, E. R. "A Model Simulating Corporate Travel Requirements Used as a Selling Tool." Proceedings: Fifteenth Annual Meeting, Southeastern Chapter, The Institute of Management Sciences (October 1979), pp. 108-113.

17. Connors, M. M., et al. "The Distribution System Simulator." Management Science 18 (April 1972), pp. 425-453.

18. Conway, R. W. "Some Tactical Problems in Digital Simulation." Management Science 10 (1963), pp. 47-61.

19. Cook, J. C. International Air Cargo Strategy. Philadelphia: Air Cargo Research Institute, 1973.

20. Cook, T. M. and R. A. Russell. "A Simulation and Statistical Analysis of Stochastic Vehcile Routing with Timing Constraints." Decision Sciences 9 (1978), pp. 673-687.

21. Dantzig, G. B. and D. L. Johnson. "Maximum Payloads per Unit Time Delivered Through an Air Network." Operations Research 12 (March 1964), pp. 230-236.

22. D'Esopo, D. A., H. L. Dixon and B. Lefkowitz. "A Model for Simulating an Air Transportation System." Naval Research Logistics Quarterly 7 (September 1960), pp. 213-220.

23. Ebeling, C. E. "Operations Research and the Air Base." Air University Review 29 (1978), pp. 43-48.

24. Fair, M. L. and E. W. Williams, Jr. Economics of Transportation and Logistics. Dallas: Business Publications, Inc., 1975.

25. Farrell, J. E. (ed.). "The Distribution Outlook: A Seminar." Traffic Management (August 1980).

26. Fishman, G. S. *Principles of Discrete Event Simulation*. New York: John Wiley and Sons, 1978.

27. Glenn, C. H. L. "Factors to be Considered in Airline Scheduling." *Canadian Aeronautics and Space Journal* (1972), pp. 149-156.

28. Gordon, C. L. *SIMFIT: A Frequency Distribution Analysis Program*. Dayton, Ohio: Wright-Patterson Air Force Base, Air University, Air Force Institute of Technology, October 1974.

29. Green, F. B. "A Survey of Graph Theory Applications in the Air Freight Industry." Virginia Beach, Va.: Paper presented to the 16th Annual TIMS Meeting, Southeast Chapter, October 8-10, 1980.

30. Green, F. B. "Stochastic Simulation of an Air Cargo Transport System." *Proceedings: Fifteenth Annual Meeting, Southeastern Chapter, Institute of Management Sciences* (October 1979), pp. 199-206.

31. Gunn, W. A. "Airline System Simulation." *Operations Research* 12 (March-April 1964), pp. 206-229.

32. Hammarskjold, K. "Aircraft Phase-out, Key Proposal in Over-capacity Rethink." *IATA News Review* (November-December 1974).

33. Hersh, M. and S. P. Ladany. "Optimal Seat Allocation for Flights with One Intermediate Stop." *Computers and Operations Research* 5 (1978), pp. 31-37.

34. Hershauer, J. C. "An Empirically Derived Simulation to Explore Sequencing Decisions." Indiana, Pa.: Indiana University, Doctoral Dissertation, 1970.

35. Holloman, A. A., Jr. Director, Operations Management Department, Naval Material Transportation Office, Norfolk, Virginia, personal communication, 1979 - 1981.

36. Hunter, J. S. and T. H. Naylor. "Experimental Design for Computer Simulation Experiments." *Management Science* 16 (1970), pp. 422-435.

37. Jackson, P. and W. Brackenridge. *Air Cargo Distribution: A Management Analysis of its Economic and Marketing Benefits*. London: Gower Press, 1971.

38. Jansson, Jan O. "A Simple Bus Line Model for Optimization of Service Frequency and Bus Size." Journal of Transport Economics and Policy 14 (January 1980), pp. 53-80.

39. Jones, S. "Computer Load Planning." Physical Distribution Management, ed. by F. R. L. Wentworth. London: Gower Press, 1970, pp. 411-434.

40. Keaton, Alvin (ed.). Air Cargo: An Integrated Systems View. Hampton, Va.: NASA-Langley Research Center, ASEE and ODU, Faculty Fellowship Program in Engineering System Design, September 1978.

41. Kelly, D. L. "Vehicle Itinerary Scheduling: A Procedure for Generating Efficient Pickup and Delivery Routes." Raleigh, N.C.: Research Triangle Institute, Working Paper No. 80-16, August 1980.

42. Keyes, L. S. Regulatory Reform in Air Cargo Transportation. Washington, D.C.: American Enterprise Institute for Public Policy Research, 1980.

43. Law, A. M. "A Tutorial on Statistical Analysis of Simulation Output Data." San Diego: Winter Simulation Conference, December 1979.

44. Marsten, R. E. and M. R. Muller. "A Mixed Integer Programming Approach to Air Cargo Fleet Planning." Management Science 26 (1980), pp. 1096-1107.

45. McMillan, C. and R. F. Gonzalez. Systems Analysis, 3rd Ed. Homewood, Illinois: Richard D. Irwin Co., 1973.

46. McNamee, L. P. and C. Lee. Development of a Standard Data Base and Computer Simulation Model for an Air Cargo Terminal. Champaign, Illinois: U. S. Army, CERL, 1973.

47. Melton, R. E. QUAM: A Simulation Model for the Navy QUICKTRANS System. Bethesda, Md.: David W. Taylor Naval Ship Research and Development Center, November 1976.

48. Mentzer, J. T. and A. D. Schuster. "Computer Modeling in Logistics." Journal of Business Logistics, Monograph Series (1982).

49. Mentzer, J. T. and S. C. Cosmas. "The Application of GERT Modeling and Simulation to Logistics." International Journal of Physical Distribution and Material Management 10 (1980), pp. 35-50.

50. Mize, J. H. and J. C. Cox. Essentials of Simulation. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1968.

51. Naylor, T. H., J. L. Balintfy, D. S. Burdick and Chu, K. Computer Simulation Techniques. New York: John Wiley and Sons, 1966.

52. Newsfront Air. "What's Bad for the Airlines Could be Good for the Shipper." Distribution (August 1980), p. 14.

53. O'Sullivan, P. and G. Holtzclaw. "Network Planning Under Ignorance." Transportation Planning and Technology 6 (March 1980), pp. 27-31.

54. Piercy, J. E. and R. H. Ballou. "A Performance Evaluation of Freight Transport Modes." The Logistics and Transportation Review 14 (Spring 1968), pp. 99-115.

55. Poist, R. F. and J. G. Mattingly. "Application of Quantitative Techniques in Physical Distribution Management, A Status Report." Logistics and Management Review 11, No. 4, pp. 338-347.

56. Poole, T. G. and J. Z. Szymankiewicz. Using Simulation to Solve Problems. New York: McGraw-Hill, 1977.

57. Pritsker, A. A. B. and C. D. Pegden. Introduction to Simulation and SLAM. New York: Halsted Press, 1979.

58. Pritsker, A. A. B. and C. D. Pegden. "SLAM Tutorial." Winter Simulation Conference Proceedings (1979), pp. 25-29.

59. Rakes, T. R. and J. Hammesfahr. "Simulating Air Traffic in the Terminal Area Using the Q-GERT Simulation Language." Proceedings; Fifteenth Annual Meeting, Southeastern Chapter, Institute of Management Sciences (October 1979), pp. 108-113.

60. Russell, R. and W. Igo. "An Assignment Routing Problem." Networks 9 (1979), pp. 1-17.

61. Sargent, R. G. "Validation of Simulation Models." Winter Simulation Conference Proceedings (1979), pp. 497-503.

62. Schruber, L. W. "Establishing the Credibility of Simulations." Simulation (March 1980), pp. 101-105.

63. Shannon, R. E. System Simulation: The Art and Science. Englewood Cliffs, N.J.: Prentice-Hall, 1975.

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64. Shycon, H. N. and R. B. Maffei. "Simulation: Tool for Better Distribution." Harvard Business Review 38 (November-December 1960), pp. 65-75.

65. Slater, A. "Vehicle Load Planning." International Journal of Physical Distribution and Material Management 10 (1980), pp. 79-99.

66. Smith, J. Computer Simulation Models. New York: Hafner Publishing Company, 1968.

67. Stock, J. R. and B. J. LaLone. "A Purchasing Approach to Transportation Mode Selection." Journal of Purchasing and Materials Management 14 (1978), pp. 2-5.

68. Stratford, A. H. Air Terminal Economics in the Supersonic Era, 2nd Ed. London: Macmillan Press, 1973.

69. Taff, C. A. Management of Physical Distribution and Transportation, 6th Ed. Homewood, Illinois: Richard D. Irwin, 1978.

70. Taylor, B. W. and P. F. Anderson. "Analyzing Logistics Systems with Q-GERT Network Simulation." Journal of Business Logistics 2 (1980), pp. 126-149.

71. Taylor, M. A. P. "Evaluating the Performance of a Simulation Model." Transportation Research 13a (1979), pp. 159-173.

72. U.S. Department of Transportation. Opportunities in Transportation Evolution. Washington, D.C.: Office of the Secretary of DOT, 1977.

73. U.S. Naval Supply Systems Command. Letter from A. A. Holleman, Jr., Assistant Deputy Commander, Transportation, May 21, 1981.

74. U.S. Naval Supply Systems Command. United States QUICKTRANS Air Freight System: Standard Operating Procedures. NAVSUP Publication 387, July 1971.

75. Vambery, R. G. "The Excess Capacity Problem in Air Transportation." New York: Columbia University, Doctoral Dissertation, 1975.

76. Van Horn, R. L. "Validation of Simulation Results." Management Science 17 (1971), pp. 247-258.

77. Wilson, J. R. and A. A. B. Pritsker. "Evaluation of Startup Policies in Simulation Experiments." <u>Simulation</u> 31 (September 1978), pp. 79-89.

78. Wilson, L. B. "Disaggregate Mode-Share Models for Air Freight Policy Analysis." <u>Transportation Research</u> 13a (1979), pp. 115-123.

79. Wyman, F. P. "Comment on Simulation Versus Analysis." <u>Decision Sciences</u> 3 (1972), pp. 143-144.

APPENDIX - A: TERMS ASSOCIATED WITH AIR CARGO TRANSPORT

AFB - Air Force Base.

Air Cargo Load (ACL) - Minimum capacity of aircraft in pounds or tons.

Air Network - All terminals and connecting links served by transport
aircraft. Terminals are nodes,and links are arcs or segments.

CAB - Civil Aeronautics Board.

Capacity - Measure of the amount of cargo an aircraft can accomodate.

CONUS - Continential United States; includes all states except Hawaii
and Alaska.

Cubed Out - Term applied to the loading of aircraft when volume capacity
is reached before weight limitation.

Feeder Line - Shorter route extending to a point or points outside
an air network, generally served by truck.

Flight Number - Trip identity number assigned to scheduled flights along
a particular route.

Load Destiny - Ratio of weight to volume of cargo.

Load Factor - A measure of the utilization of transport aircraft; ratio
of ton-miles carried to ton-miles available.

LOGAIR - An acronym for the U.S. Air Force's air-truck transportation
system.

NAVMTO - A acronym for the Naval Material Transportation Office, the
organization responsible for the Navy's domestic air cargo trans-
portation network.

Off-line - Designation for cargo carried by truck.

On-line - Designation for cargo carried by air.

Pallet - Platform used to secure freight prepared for shipment by air.

QUICKTRANS - An acronym for the U.S. Navy's air-truck transportation system.

Route Pattern - Route of one aircraft including all terminals from origin
to destination, also known as a flight pattern or flight path.

Route Segment - The joining of two or more terminals as part of a route
flown by transport aircraft, also known as a flight leg or link.

Terminal - Commercial or military airport where air cargo may be loaded or
off-loaded, also known as a depot or pick-up and delivery point.

APPENDIX - A: Continued

Ton-miles - The product of miles traveled and tons of cargo.

Transloading Point - Any terminal along a flight path where cargo is
loaded or off-loaded, excluding origin and destination points.

Transport Code - Three-letter code-name for a terminal.

Trunk Line - Main route served regularly by transport aircraft.

```
C     MAIN PROGRAM
      DIMENSION NSET(30000)
      DIMENSION A(30)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSDT(10,10)
      COMMON QSET(30000)
      EQUIVALENCE (NSET(1),QSET(1))
      EQUIVALENCE (ATRIB(1),A(1))
      EQUIVALENCE (XX(2),SLOAD)
      EQUIVALENCE (XX(3),FCAP)
      NNSET=30000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END
```

RELEASE 2.0   INTLC   DATE = 81211   19/46/21

```
      SUBROUTINE INTLC
      DIMENSION LOC(10,10),IO(10,10,10),IT(10,10,10),KKVNT(10,10)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,11,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/         FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSOT(10,10)
      CALL SCHDL(4,1.,ATRIB)
C  READ NUMBER OF POINTS IN NETWORK
      READ(NCRDR,101) NPTS
      LF=NPTS+1
      XX(1)=0.
C  READ IN DISTANCE MATRIX
      READ(NCRDR,102) (TCODE(J),J=1,NPTS)
      DO 5 I=1,NPTS
    5 READ(NCRDR,103) (DIST(I,J),J=1,NPTS)
      DO 10 I=1,NPTS
      DO 10 J=1,NPTS
   10 DIST(J,I)=DIST(I,J)
      READ(NCRDR,100)
C  READ IN PARAMETER MATRICES
      DO 15 I=1,NPTS
   15 READ(NCRDR,104) (PAR1(I,J),J=1,NPTS)
      READ(NCRDR,100)
      DO 20 I=1,NPTS
   20 READ(NCRDR,105) (PAR2(I,J),J=1,NPTS)
      READ(NCRDR,100)
C  READ IN AIRCRAFT DATA
   45 I=1
   47 READ(NCRDR,108) TYPE(I),TYP1(I),TYP2(I),CAP(I),SPEED(I),CPM(I),
     1CPL(I),(NFLT(I,J),J=1,10)
      IF(CAP(I).EQ.0.) GO TO 22
      I=I+1
      GO TO 47
C  READ IN ROUTE PATTERN AND ASSIGN EVENT CODES
   22 K=1
   25 READ(NCRDR,106) IFLT(K),IFREQ(K)
      IF (IFLT(K).EQ.999) GO TO 50
      L=1
   30 READ(NCRDR,107) LOC(K,L),(IO(K,L,M),M=1,10),(IT(K,L,N),N=1,10)
      IF (IO(K,L,1).EQ.0) GO TO 40
      IF (L.NE.1) GO TO 35
      KKVNT(K,L)=1
      CALL SETFL(KKVNT(K,L),LOC(K,L),K,L,IO,IT,        IFLT(K),IFREQ(K))
      L=L+1
      GO TO 30
   35 KKVNT(K,L)=2
      CALL SETFL(KKVNT(K,L),LOC(K,L),K,L,IO,IT,        IFLT(K),IFREQ(K))
      L=L+1
      GO TO 30
   40 KKVNT(K,L)=3
      CALL SETFL(KKVNT(K,L),LOC(K,L),K,L,IO,IT,        IFLT(K),IFREQ(K))
      K=K+1
      GO TO 25
   50 CALL ECHO   (KKVNT,LOC,IO,IT)
  100 FORMAT(I1)
  101 FORMAT (I2)
  102 FORMAT (5X,10A5)
  103 FORMAT (5X,10F5.0)
  104 FORMAT (5X,10F5.1)
  105 FORMAT (5X,10F5.2)
  106 FORMAT (I3,2X,I1)
  107 FORMAT(2X,I1,2X,10I1,10I1)
  108 FORMAT (A4,2A3,F5.2,F5.0,F10.5,F5.0,2X,10I3)
      RETURN
      END
```

APPENDIX B—Continued

```
      SUBROUTINE ECHO(KKVNT,LOC,ID,IT)
      DIMENSION IX(10)
      DIMENSION LOC(10,10),ID(10,10,10),IT(10,10,10),KKVNT(10,10)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),FLND(10,6),TNSDL(10,10),TNSUT(10,10)
      WRITE(NPRNT,101) NPTS
      WRITE(NPRNT,102) (TCODE(J),J=1,NPTS)
      WRITE(NPRNT,120)
      DO 5 I=1,NPTS
    5 WRITE(NPRNT,103) TCODE(I),(DIST(I,J),J=1,NPTS)
      WRITE(NPRNT,100)
      WRITE(NPRNT,104) (TCODE(J),J=1,NPTS)
      WRITE(NPRNT,120)
      DO 15 I=1,NPTS
   15 WRITE(NPRNT,105) TCODE(I),(PAR1(I,J),J=1,NPTS)
      WRITE(NPRNT,100)
      WRITE(NPRNT,106) (TCODE(J),J=1,NPTS)
      WRITE(NPRNT,120)
      DO 20 I=1,NPTS
   20 WRITE(NPRNT,107) TCODE(I),(PAR2(I,J),J=1,NPTS)
      WRITE(NPRNT,100)
      WRITE(NPRNT,108) (TCODE(J),J=1,NPTS)
      DO 22 L=1,NPTS
   22 IX(L)=L
      WRITE(NPRNT,115) (IX(L),L=1,NPTS)
      WRITE(NPRNT,109)
      K=1
   25 IF (IFLT(K).EQ.999) GO TO 45
      WRITE(NPRNT,110) IFLT(K),IFREQ(K)
      L=1
   30 WRITE(NPRNT,111) LOC(K,L),(ID(K,L,M),M=1,10),(IT(K,L,N),N=1,10)
      IF (ID(K,L,1).EQ.0) GO TO 40
      IF (ID(K,L,1).EQ.0) GO TO 40
      L=L+1
      GO TO 30
   40 K=K+1
      GO TO 25
   45 WRITE(NPRNT,112)
      I=1
```

Subroutine ECHO continued on next page.

APPENDIX B--Continued

Continuation of Subroutine ECHO.

```
   50 IF(CAP(I).EQ.0.) GO TO 65
      WRITE(NPRNT,113) TYPE(I),TYP1(I),TYP2(I),CAP(I),SPEED(I),CPM(I),
     1CPL(I)
      J=1
   55 IF(NFLT(I,J).EQ.0) GO TO 60
      WRITE(NPRNT,114) NFLT(I,J)
      J=J+1
      GO TO 55
   60 I=I+1
      GO TO 50
  100 FORMAT (1H0)
  101 FORMAT (1H1,09X,'INPUT DATA FOR ROUTE PATTERN SIMULATION'//09X,
     1'OF TRANSPORT NETWORK CONSISTING OF ',I2,' TERMINALS'//)
  102 FORMAT (1H0,09X,'DISTANCE MATRIX'///19X,'DESTINATION'//7X,10A7/
     12X,'ORIGIN'//)
  103 FORMAT (2X,A5,1X,10F7.0/)
  104 FORMAT (1H0,09X,'STOCHASTIC SHIPMENT VALUES FOR PARAMETER ONE'///
     119X,'DESTINATION'//7X,10A7/2X,'ORIGIN'//)
  105 FORMAT (2X,A5,1X,10F7.1/)
  106 FORMAT (1H0,09X,'STOCHASTIC SHIPMENT VALUES FOR PARAMETER TWO'///
     119X,'DESTINATION'//7X,10A7/2X,'ORIGIN'//)
  107 FORMAT (2X,A5,1X,10F7.2/)
  108 FORMAT (1H1,09X,'FLIGHT PATTERN DESCRIPTION'//4X,'TERMINAL CODE',
     14X,10A5)
  109 FORMAT(1H0,'FLIGHT    FLIGHTS    FLIGHT        SHIPMENT            DESTINA
     1TIONS'/3X,'NO.    PER WK.   PATH        DESTINATIONS           TO BE TRANSH
     2IPPED')
  110 FORMAT(1H0,2X,I3,6X,I1)
  111 FORMAT (1H+,18X,I2,3X,10I2,1X,10I2/)
  112 FORMAT (1H1,9X,'AIRCRAFT DATA'///2X,'AIRCRAFT   CAPACITY',11X,'COST
     1        COST     FLIGHT NO.'/4X,'TYPE      IN TONS       SPEED    PER MI.
     2PER LOG.    ASSIGNED')
  113 FORMAT (1H0,A4,2A3,2X,F6.3,4X,F5.0,2X,F8.5,2X,F7.2)
  114 FORMAT (1H+,52X,I3/)
  115 FORMAT(1H0,'ASSIGNED POINT NO.',10I5)
  120 FORMAT (1X,'ORIGIN')
   65 RETURN
      END
```

APPENDIX B—Continued

```
      SUBROUTINE SETFL (KEVNT,LOC,K,L,ID,IT,KFLT,KFREQ)
      DIMENSION A(30)
      DIMENSION ID(10,10,10),IT(10,10,10)
      COMMON/SCOM1/ATRIB(100),DU(100),DDL(100),DTNOW,I1,MFA,MSTOP,NCLNR
     1,NCRUR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLNO,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),FLNO(10,6),TNSOL(10,10),TNSOT(10,10)
      EQUIVALENCE (ATRIB(1),A(1))
C     FILL ATRIB ARRAY
      DO 5 I=1,6
      DO 5 J=1,10
      IF (KFLT.EQ.NFLT(I,J)) GO TO 8
    5 CONTINUE
    8 A(5)=CAP(I)
      A(6)=SPEED(I)
      A(7)=CPM(I)
      A(8)=CPL(I)
      A(9)=KFLT
      A(10)=LOC
      DO 10 M=1,10
      A(M+10)=ID(K,L,M)
   10 A(M+20)=IT(K,L,M)
C     SET FIRST WEEK'S SCHEDULE OF FLIGHTS
      DTIME=0
      IF(KFREQ.GE.3) GO TO 20
      IF(KFREQ.EQ.2) GO TO 15
      IF(KFREQ.EQ.1) DTIME=6.
      CALL SCHDL(KEVNT,DTIME,A)
      RETURN
   15 DTIME=2.
      CALL SCHDL(KEVNT,DTIME,A)
      DTIME=5.
      CALL SCHDL(KEVNT,DTIME,A)
      RETURN
   20 IF(KFREQ.EQ.5) GO TO 22
      DTIME=1.
      CALL SCHDL(KEVNT,DTIME,A)
   22 IF(KFREQ.EQ.3) GO TO 25
      DTIME=2.
      CALL SCHDL(KEVNT,DTIME,A)
   25 IF(KFREQ.EQ.4) GO TO 30
      DTIME=3.
      CALL SCHDL(KEVNT,DTIME,A)
   30 IF(KFREQ.EQ.3) GO TO 35
      DTIME=4.
      CALL SCHDL(KEVNT,DTIME,A)
   35 IF(KFREQ.EQ.4) GO TO 40
      DTIME=5.
      CALL SCHDL(KEVNT,DTIME,A)
   40 IF(KFREQ.EQ.3) RETURN
      IF(KFREQ.EQ.5) GO TO 45
      DTIME=6.
      CALL SCHDL(KEVNT,DTIME,A)
   45 IF(KFREQ.EQ.4) RETURN
      IF(KFREQ.EQ.6) RETURN
      DTIME=7.
      CALL SCHDL(KEVNT,DTIME,A)
      RETURN
      END
```

APPENDIX B—Continued

```
      SUBROUTINE EVENT(IX)
      DIMENSION A(30)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREJ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSUT(10,10)
      EQUIVALENCE (ATRIB(1),A(1))
      EQUIVALENCE (XX(2),SLOAD)
      EQUIVALENCE (XX(5),FCAP)
      IF(IX.EQ.4) GO TO 40
      DO 3 I=1,30
    3 B(I)=A(I)
C     SCHEDULE FLIGHT FOR FOLLOWING WEEK
      CALL SCHDL(IX,7.,A)
C     BRANCH TO APPROPRIATE SUBROUTINE
      GO TO (5,10,15),IX
    5 CALL TQUE
      K=B(10)
      FDIST=0.
      FTNMI=0.
      FLND=0.
      SLOAD=SUMQ(3,LF)
      FCAP=B(5)
      IF(TNOW.EQ.1.) CALL GPLOT(1)
      RETURN
   10 CALL OFFLD
      CALL TQUE
      GO TO 20
   15 CALL UFFLD
      IF (NNQ(LF).GT.0) CALL PRNTF(9)
      IF (NNQ(LF).GT.0) CALL ERROR(6)
C     SET VALUES OF FLIGHT VARIABLES
   20 L=B(10)
      IF(TNOW.EQ.1.) CALL PROFL(K,L)
      FDIST=FDIST+DIST(K,L)
      FTNMI=FTNMI+SLOAD*DIST(K,L)
      FLND=FLND+1.
      SLOAD=SUMQ(3,LF)
      K=B(10)
C     COLLECT FLIGHT STATISTICS
      IF(TNOW.EQ.1.) CALL GPLOT(1)
      IF     (IX.EQ.3) CALL FSTAT
C     HAS TIME CONSTRAINT BEEN VIOLATED?
      TIME=FDIST/B(5)+.5*FLND-.5
      IF(TIME.LE.10.) RETURN
      IF (TNOW.GT.7.) RETURN
      KFLT=B(9)
      N=B(10)
      WRITE(NPRNT,101) KFLT,TIME,TCODE(N)
  101 FORMAT (1H0,09X,'FLIGHT NO. ',I3,' REQUIRES A TOTAL OF',F6.2,
     1' HOURS TO REACH TERMINAL',A5,1H./10X,'CREW CHANGE MAY BE REQUIRED
     2 AT PRIOR TERMINAL.')
      RETURN
   40 CALL SCHDL(4,1.,A)
      CALL DIVRT
      CALL GQUE
      RETURN
      END
```

APPENDIX B—Continued

RELEASE 2.0   OFFLD   DATE = 81211   19/46/21

```
      SUBROUTINE OFFLD
      DIMENSION A(30)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFL(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSUT(10,10)
      EQUIVALENCE (ATRIB(1),A(1))
C   OFFLOAD SHIPMENTS FOR THIS DESTINATION
   10 NRNK=NFIND(1,LF,2,0,B(10),0)
      IF (NRNK.EQ.0) GO TO 20
      CALL RMOVE(NRNK,LF,A)
      CALL LSTAT
      GO TO 10
C   OFFLOAD TRANSHIPMENTS
   20 I=21
   30 IF (B(I).EQ.0.)   RETURN
      NSRCH=1
   35 NRNK=NFIND(NSRCH,LF,2,0,B(I),0)
      IF (NRNK.EQ.0) GO TO 40
      CALL RMOVE(NRNK,LF,A)
C   PLACE TRANSHIPMENTS IN QUEUE
      K=B(10)
      CALL FILEM(K,A)
      NSRCH=NRNK
      IF (NSRCH.LE.NNQ(LF)) GO TO 35
   40 I=I+1
      GO TO 30
      END
```

RELEASE 2.0   GQUE   DATE = 81211   19/46/21

```
      SUBROUTINE GQUE
      DIMENSION A(30)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFL(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSUT(10,10)
      EQUIVALENCE (ATRIB(1),A(1))
C   GENERATE NEW SHIPMENTS
      DO 10 I=1,NPTS
      DO 10 J=1,NPTS
      IF(I.EQ.J) GO TO 10
      A(2)=J
      A(3)=SHPMT(I,J)
      A(4)=TNOW
      A(10)=I
C   PLACE NEW SHIPMENTS IN QUEUES
      CALL FILEM(I,A)
   10 CONTINUE
      RETURN
      END
```

APPENDIX B—Continued

```
      SUBROUTINE LOAD
      DIMENSION A(30)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),INEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSUT(10,10)
      EQUIVALENCE (ATRIB(1),A(1))
C     TEST TO SEE IF SHIPMENT WILL FIT ABOARD AIRCRAFT
      DIFF=B(5)-SUMQ(3,LF)
      IF(DIFF.LT.A(3)) GO TO 10
C     LOAD SHIPMENT ABOARD AIRCRAFT
      CALL FILEM(LF,A)
      RETURN
C     PLACE DEFERRED SHIPMENT IN QUEUE
   10 K=B(10)
      CALL FILEM(K,A)
      RETURN
      END
```

```
      SUBROUTINE TQUE
      DIMENSION A(30)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),INEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSUT(10,10)
      EQUIVALENCE (ATRIB(1),A(1))
C     TEST QUEUE FOR SHIPMENTS TO BE LOADED
      K=B(10)
      I=11
   10 IF (NNQ(K).LE.0) RETURN
      IF(B(I).EQ.0.) RETURN
C     LOCATE SHIPMENTS TO BE LOADED
      NSRCH=1
   20 NRNK=NFIND(NSRCH,K,2,0,B(I),0)
      IF (NRNK.EQ.0) GO TO 30
      CALL COPY(NRNK,K,A)
      DIFF=B(5)-SUMQ(3,LF)
      IF (DIFF.GE.A(3)) GO TO 40
      NSRCH=NRNK+1
      IF(NSRCH.LE.NNQ(K)) GO TO 20
   30 I=I+1
      GO TO 10
C     REMOVE FROM QUEUE AND LOAD
   40 CALL RMOVE(NRNK,K,A)
      DELAY=TNOW-A(4)
      IF(DELAY.GE.1.) CALL COLCT(DELAY,K)
      CALL LOAD
      NSRCH=NRNK
      IF (NSRCH.LE.NNQ(K)) GO TO 20
      GO TO 30
      END
```

APPENDIX B—Continued

```
      SUBROUTINE DIVRT
      DIMENSION A(30),DAY(1)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSO(10,10)
      EQUIVALENCE (ATRIB(1),A(1))
      IF (TNOW.EQ.DAY(1)) RETURN
      XLATE=TNOW-3.
C  SEARCH ALL QUEUES FOR EXCESSIVE DELAYS AND DIVERT TO TRUCK
      DO 15 NF=1,NPTS
   10 NRNK=NFIND(1,NF,4,-1,XLATE,0.)
      IF (NRNK.LE.0) GO TO 15
      CALL RMOVE (NRNK,NF,A)
      DELAY=TNOW-A(4)
      IF(DELAY.GE.1.) CALL COLCT(DELAY,NF)
      CALL LSTAT
      GO TO 10
   15 CONTINUE
      DAY(1)=TNOW
      RETURN
      END
```

```
      SUBROUTINE PROFL(K,L)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
C  RECORD PLOT POINTS
      IF(XX(1).EQ.0.) RLAST=0.
      EOD=XX(1)+DIST(K,L)-50.
   25 IF(RLAST.GE.EOD) GO TO 30
      RLAST=RLAST+50.
      XX(1)=RLAST
      CALL GPLOT(1)
      GO TO 25
   30 XX(1)=EOD+50.
      RETURN
      END
```

APPENDIX B--Continued

```
RELEASE 2.0              FSTAT              DATE = 81211           19/46/21
        SUBROUTINE FSTAT
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NJRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
       1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
       2CPM(6),CPL(6),NFLT(6,10),B(30)
        COMMON/UCOM2/         FDIST,FINMI,FLND,TDIST(10,6),TTNMI(10,6),
       1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSOT(10,10)
      C   IDENTIFY FLIGHT NUMBER AND AIRCRAFT TYPE
        KFLT=B(9)
        DO 10 I=1,10
        IF (KFLT.EQ.IFLT(I)) GO TO 15
     10 CONTINUE
     15 FCAP=B(5)
        DO 20 J=1,6
        IF(FCAP.EQ.CAP(J)) GO TO 25
     20 CONTINUE
      C   SET CUMULATIVE VALUES FOR FLIGHT STATISTICS
     25 TTNMI(I,J)=TTNMI(I,J)+FINMI
        ATNMI(I,J)=ATNMI(I,J)+FCAP*FDIST
        TDIST(I,J)=TDIST(I,J)+FDIST
        TLND(I,J)=TLND(I,J)+FLND
        RETURN
        END



RELEASE 2.0              LSTAT              DATE = 81211           19/46/21
        SUBROUTINE LSTAT
        DIMENSION A(30)
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
       1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
       2CPM(6),CPL(6),NFLT(6,10),B(30)
        COMMON/UCOM2/         FDIST,FINMI,FLND,TDIST(10,6),TTNMI(10,6),
       1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSOT(10,10)
        EQUIVALENCE (ATRIB(1),A(1))
        K=A(10)
        L=A(2)
      C   COMPUTE DAYS DELAYED AND COLLECT STATS
        DELAY=TNOW-A(4)
        IF (DELAY.LT.3.) GO TO 10
      C   COMPUTE TONS DELAYED
        TNSDL(K,L)=TNSDL(K,L)+A(3)
        RETURN
      C   COMPUTE TONS ON TIME
     10 TNSOT(K,L)=TNSOT(K,L)+A(3)
        RETURN
        END
```

APPENDIX B—Continued

```
      FUNCTION SHPMT(I,J)
      DIMENSION VAL(4),CP1(4),CP2(4),CP3(4),CP4(4)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),IYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      DATA VAL/.0,.25,.75,1.25/
      DATA CP1/.52,.96,.98,1.0/
      DATA CP2/.70,.98,1.0,1.0/
      DATA CP3/.92,.99,1.0,1.0/
      DATA CP4/.90,1.0,1.0,1.0/
C     SET ISTREAM VALUES
      IS=4
      IT=5
      IR=6
C     SELECT APPROPRIATE DISTRIBUTION
      XK=PAR1(I,J)
      IF(XK.GE.99.) GO TO 20
      IF(XK.GT. 5.) GO TO 10
      IF(XK.LE. 0.) CALL ERROR(7)
C     GENERATE SHIPMENT FROM ERLANG DISTRIBUTION
      EMN=PAR2(I,J)/XK
      SHPMT=ERLNG(EMN,XK,IS)
      RETURN
C     GENERATE SHIPMENT FROM COMBINED DISCRETE/ERLANG DISTRIBUTION
 10   PZERO=XK/91.
      RN=URAND(IT)
      SHPMT=0.
      IF(PZERO.GE.RN) RETURN
      EMN=PAR2(I,J)
      SHPMT=ERLNG(EMN,1.,IS)
      RETURN
C     GENERATE SHIPMENT FROM DISCRETE DISTRIBUTION
 20   IF(I.EQ.1.AND.J.EQ.4) GO TO 21
      IF(I.EQ.4.AND.J.EQ.8) GO TO 22
      IF(I.EQ.4.AND.J.EQ.9) GO TO 23
      IF(I.EQ.9.AND.J.EQ.4) GO TO 24
      CALL ERROR(8)
 21   SHPMT=UPROB(CP1,VAL,4,IR)
      RETURN
 22   SHPMT=UPROB(CP2,VAL,4,IR)
      RETURN
 23   SHPMT=UPROB(CP3,VAL,4,IR)
      RETURN
 24   SHPMT=UPROB(CP4,VAL,4,IR)
      RETURN
      END
```

```
      SUBROUTINE UTPUT
      COMMON/SCOM1/ATRIB(100),UD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),IYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSOT(10,10)
      CALL FLIOT
      CALL TYPOT
      CALL DEPOT
      CALL SVLOT
      RETURN
      END
```

APPENDIX B—Continued

RELEASE 2.0   FLTOT   DATE = 81211   19/46/21

```
      SUBROUTINE FLTOT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/       FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),TNSDL(10,10),INSDT(10,10)
      NPRNT=6
C   PRINT HEADINGS
      WRITE(NPRNT,99)
      WRITE(NPRNT,101)
      WRITE(NPRNT,100) TNOW
      WRITE(NPRNT, 98)
      WRITE(NPRNT,110)
C   COMPUTE LOAD FACTOR AND PRINT FLIGHT LOAD STATISTICS
      I=1
    5 IF(IFLT(I).LE.0) GO TO 20
      J=1
   10 IF(J.GT.6) GO TO 20
      IF(TTNMI(I,J).GT.0.) GO TO 15
      J=J+1
      GO TO 10
   15 FACTR=TTNMI(I,J)/ATNMI(I,J)*100.
      WRITE(NPRNT,111) IFLT(I),TDIST(I,J),TTNMI(I,J),ATNMI(I,J),FACTR
      I=I+1
      GO TO 5
C   PRINT HEADINGS
   20 WRITE(NPRNT,120)
C   COMPUTE COSTS AND PRINT FLIGHT STATISTICS
      I=1
   25 IF(IFLT(I).LE.0)  GO TO 40
      J=1
   30 IF(J.GT.6) GO TO 40
      IF(TDIST(I,J).GT.0.) GO TO 35
      J=J+1
      GO TO 30
   35 DCOST=TDIST(I,J)*CPM(J)
      ACOST=TLND(I,J)*CPL(J)
      TCOST=DCOST+ACOST
      WRITE(NPRNT,121) IFLT(I),TDIST(I,J),DCOST,TLND(I,J),ACOST,TCOST
      I=I+1
      GO TO 25
   40 RETURN
   98 FORMAT (1H0)
   99 FORMAT (1H1,9X,'AIRCRAFT PERFORMANCE STATISTICS'/)
  100 FORMAT (1H+,22X,'- SIMULATION FOR ',F5.0,' DAYS')
  101 FORMAT (6X,'BY FLIGHT NUMBER')
  110 FORMAT (1H0,'FLIGHT   DISTANCE    TON-MILES    TON-MILES     LOAD'/
     13X,        'NO.    TRAVELED     CARRIED     AVAILABLE    FACTOR'/)
  111 FORMAT (3X,I3,3X,F9.0,2F12.0,2X,F5.2)
  120 FORMAT (1H0,'FLIGHT    MILES     DISTANCE     NO. OF    LANDING
     1TOTAL'/ 3X,  'NO.    TRAVELED     COST      LANDINGS     COST
     2 COST'/)
  121 FORMAT (3X,I3,3X,F9.0,F12.0,2X,F7.0,F11.0,2X,F11.0)
      END
```

APPENDIX B—Continued

RELEASE 2.0   SVLOT   DATE = 81211   19/46/21

```
      SUBROUTINE SVLOT
      DIMENSION TOTAL(10),TTTOT(10),SVLEV(10)
      COMMON/SCOM1/ATRIE(100),UU(100),UUL(100),DTNOW,II,MFA,MSTOP,NCLNK
     1,NCKUR,NPRNT,NNRUN,NNSET,NIAPE,SS(100),SSL(100),INEXT,TNOW,XX(100)
      COMMON/UCUM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCUM2/         FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),FLND(10,6),TNSUL(10,10),TNSOT(10,10)
      WRITE (NPRNT,100)
C    COMPUTE SERVICE LEVELS
      DU 15 J=1,NPTS
      UU 10 I=1,NPTS
      TTTOT(J)=TTTOT(J)+TNSOT(I,J)
   10 TOTAL(J)=TOTAL(J)+TNSOT(I,J)+TNSUL(I,J)
   15 SVLEV(J)=TTTOT(J)*100./TOTAL(J)
      WRITE (NPRNT,101) (SVLEV(J),J=1,NPTS)
      WRITE (NPRNT,103)
      WRITE (NPRNT, 99)
      RETURN
   99 FORMAT(1H0,7X,'LATE SHIPMENTS ARE THOSE EXCEEDING TWO DAYS DELIVER
     1Y')
  100 FORMAT (1H0,'SERVICE')
  101 FORMAT (2X,'LEVEL',1X,10F7.2)
  103 FORMAT(2X,'- - - - - - - - - - - - - - - - - - - - - - -
     1- - - - -')
      END
```

APPENDIX B—Continued

```
      SUBROUTINE DEPOT
      DIMENSION TOTOT(10),PCTOT(10),PCTOL(10)
      COMMON/SCOM1/AIRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,TCODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/         FDIST,FTNMI,FLND,IDIST(10,6),FTNMI(10,6),
     1ATNMI(10,6),ILND(10,6),TNSOL(10,10),TNSOT(10,10)
C     PRINT HEADINGS
      WRITE(NPRNT,100)
      WRITE(NPRNT, 98) TNOW
      WRITE(NPRNT,101) (TCODE(J),J=1,NPTS)
      WRITE(NPRNT,102)
      WRITE(NPRNT,103)
      WRITE(NPRNT,103)
C     PRINT TONNAGE DATA
      DO 5 I=1,NPTS
      WRITE(NPRNT,104) TCODE(I),(TNSOT(I,J),J=1,NPTS)
      WRITE(NPRNT,105)          (TNSOL(I,J),J=1,NPTS)
    5 WRITE(NPRNT,103)
      WRITE(NPRNT, 99)
C     PRINT HEADINGS
      WRITE(NPRNT,200)
      WRITE(NPRNT, 98) TNOW
      WRITE(NPRNT,101) (TCODE(J),J=1,NPTS)
      WRITE(NPRNT,102)
      WRITE(NPRNT,103)
C     COMPUTE AND PRINT PERCENTAGE DATA
      DO 20 I=1,NPTS
      DO 15 J=1,NPTS
      TOTOT(J)=TNSOT(I,J)+TNSOL(I,J)
      IF(TOTOT(J).LE.0.) GO TO 10
      PCTOT(J)=TNSOT(I,J)*100./TOTOT(J)
      PCTOL(J)=TNSOL(I,J)*100./TOTOT(J)
      GO TO 15
   10 PCTOT(J)=0.
      PCTOL(J)=0.
   15 CONTINUE
      WRITE(NPRNT,204) TCODE(I),(PCTOT(J),J=1,NPTS)
      WRITE(NPRNT,205)          (PCTOL(J),J=1,NPTS)
   20 WRITE(NPRNT,103)
      RETURN
   98 FORMAT(13X,'SIMULATION FOR ',F5.0,' DAYS'//)
   99 FORMAT(1H0,7X,'LATE SHIPMENTS ARE THOSE EXCEEDING TWO DAYS DELIVER
     1Y')
  100 FORMAT(1H1,14X,'MATRIX OF TONS DELIVERED'//
     113X,        'ON TIME AND TONS DELIVERED LATE'//)
  101 FORMAT(1H0,18X,'DESTINATION'//7X,10A7)
  102 FORMAT(2X,'ORIGIN')
  103 FORMAT(2X,'- - - - - - - - - - - - - - - - - -
     1- - - - -')
  104 FORMAT(2X,A5,1X,10F7.1)
  105 FORMAT(8X,10F7.1)
  200 FORMAT(1H1,12X,'MATRIX OF PERCENT OF CARGO'//
     18X,         'DELIVERED ON TIME AND DELIVERED LATE'//)
  204 FORMAT(2X,A5,1X,10F7.2)
  205 FORMAT(8X,10F7.2)
      END
```

APPENDIX B—Continued

```
      SUBROUTINE TYPOT
      REAL MILES
      DIMENSION TNMI(6),ATMI(6),TDST(6),ALND(6),DCST(6),ACST(6),TCST(6)
      COMMON/SCOM1/AIRB(100),DD(100),DDL(100),DINOW,II,MFA,MSTOP,NCLNR
     1,NCKDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/NPTS,ICODE(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
     1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
     2CPM(6),CPL(6),NFLT(6,10),B(30)
      COMMON/UCOM2/        FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
     1ATNMI(10,6),TLND(10,6),INSDL(10,10),INSDT(10,10)
      NPRNT=6
C   PRINT HEADINGS
      WRITE(NPRNT, 98)
      WRITE(NPRNT, 99)
      WRITE(NPRNT,101)
      WRITE(NPRNT,100) TNOW
      WRITE(NPRNT, 97)
      WRITE(NPRNT,110)
C   INITIALIZE VARIABLES
      DO 5 J=1,6
      TNMI(J)=0.
      ATMI(J)=0.
      TDST(J)=0.
      ALND(J)=0.
      DCST(J)=0.
      ACST(J)=0.
    5 TCST(J)=0.
C   COMPLETE TOTALS BY AIRCRAFT TYPE AND PRINT STATISTICS
      J=1
   10 IF(CAP(J).LE.0.) GO TO 20
      DO 15 I=1,10
      TNMI(J)=TNMI(J)+TTNMI(I,J)
      ATMI(J)=ATMI(J)+ATNMI(I,J)
      TDST(J)=TDST(J)+TDIST(I,J)
   15 ALND(J)=ALND(J)+TLND(I,J)
      FACTR=TNMI(J)*100./ATMI(J)
      WRITE(NPRNT,111) TYPE(J),TYP1(J),TYP2(J),TDST(J),TNMI(J),ATMI(J),
     1FACTR
      J=J+1
      GO TO 10
   20 WRITE(NPRNT,120)
      J=1
   25 IF(CAP(J).LE.0.) GO TO 30
      DCST(J)=TDST(J)*CPM(J)
      ACST(J)=ALND(J)*CPL(J)
      TCST(J)=DCST(J)+ACST(J)
      WRITE(NPRNT,121) TYPE(J),TYP1(J),TYP2(J),TDST(J),DCST(J),ALND(J),
     1ACST(J),TCST(J)
      J=J+1
      GO TO 25
C   PRINT HEADINGS
   30 WRITE(NPRNT, 97)
      WRITE(NPRNT, 99)
      WRITE(NPRNT,201)
      WRITE(NPRNT,100) TNOW
      WRITE(NPRNT, 97)
      WRITE(NPRNT,210)
C   INITIALIZE VARIABLES
      TONMI=0.
      AVTMI=0.
      MILES=0.
      ALAND=0.
      DCOST=0.
      ACOST=0.
      TCOST=0.
```

Subroutine continued on next page.

APPENDIX B—Continued

Continuation of Subroutine TYPOT

```
C    COMPUTE TOTALS FOR ALL FLIGHTS AND PRINT STATISTICS
     DO 40 J=1,6
     TONMI=TONMI+TNMI(J)
     AVTMI=AVTMI+ATMI(J)
     MILES=MILES+TDST(J)
     ALAND=ALAND+ALND(J)
     DCOST=DCOST+DCST(J)
  40 ACOST=ACOST+ACST(J)
     FACTR=TONMI*100./AVTMI
     TCOST=DCOST+ACOST
     WRITE(NPRNT,211) MILES,TONMI,AVTMI,FACTR
     WRITE(NPRNT,220)
     WRITE(NPRNT,221) MILES,DCOST,ALAND,ACOST,TCOST
     RETURN
  97 FORMAT (1H0)
  98 FORMAT (1H1)
  99 FORMAT (1H0,9X,'AIRCRAFT PERFORMANCE STATISTICS'/)
 100 FORMAT (1H+,22X,'- SIMULATION FOR ',F5.0,' DAYS')
 101 FORMAT (6X,'BY AIRCRAFT TYPE')
 110 FORMAT(1H0,' AIRCRAFT   DISTANCE    TON-MILES    TON-MILES    LOAD'/
    14X,           'TYPE      TRAVELED     CARRIED     AVAILABLE   FACTOR'/)
 111 FORMAT (1X,A4,2A3,2X,F9.0,2F12.0,2X,F5.2)
 120 FORMAT(//'  AIRCRAFT     MILES     DISTANCE     NO. OF     LANDING
    1 TOTAL'/5X,'TYPE      TRAVELED      COST      LANDINGS     COST
    2    COST'/)
 121 FORMAT (1X,A4,2A3,2X,F9.0,F12.0,2X,F7.0,F11.0,2X,F11.0)
 201 FORMAT (6X,'ALL FLIGHTS')
 210 FORMAT(1H0,'   ALL      DISTANCE    TON-MILES    TON-MILES    LOAD'/
    12X,          'FLIGHTS    TRAVELED     CARRIED     AVAILABLE   FACTOR'/)
 211 FORMAT (1X,10X,        F9.0,2F12.0,2X,F5.2)
 220 FORMAT(//'    ALL       MILES     DISTANCE     NO. OF     LANDING
    1 TOTAL'/4X,'FLIGHTS   TRAVELED      COST      LANDINGS     COST
    2    COST'/)
 221 FORMAT (1X,10X,       F9.0,F12.0,2X,F7.0,F11.0,2X,F11.0)
     END
```

RELEASE 2.0   EVAL   DATE = 81223   18/20/41

```
        SUBROUTINE EVAL
        DIMENSION PSERV(10),NFREQ(10),KAP(10)
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,FMA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/GCOM1/ JJCDR,KKNN,LLFIL,LLRNK,LLTRY,MFEX,NNAM1,NNAM2,NNAM3,
       1NNAPO,NNAPT,NNATR,NNFIL,NNTRY,TTBEG,TTCLR,TTFIN,
       2TTSET,XXI(100),TTTS,TTTF
        COMMON/CGOM5/IISED(10),JJBEG,JJCLR,MMNIT,MMON,NNAME(5),NNCFI,
       1NNDAY,NNPT,NNPRJ(5),NNRNS,NNSTR,NNYR,SSEED(10),LSEED(10)
        COMMON/UCOM1/NPTS,TCOD(10),DIST(10,10),PAR1(10,10),PAR2(10,10),
       1LF,IFLT(10),IFREQ(10),TYPE(6),TYP1(6),TYP2(6),CAP(6),SPEED(6),
       2CPM(6),CPL(6),NFLT(6,10),B(30)
        COMMON/UCOM2/      FDIST,FTNMI,FLND,TDIST(10,6),TTNMI(10,6),
       1ATNMI(10,6),TLND(10,6),TNSDL(10,10),TNSOT(10,10)
        COMMON/UCOM3/FACTR,TCOST,SVLEV(10),FFACT(10),COD,OCOST,DAYS
        IF (NNRUN.EQ.1) IFLAG=0.
C     CHECK FOR DESIRED LEVEL OF SERVICE AT ALL DESTINATIONS
        DO 10 J=1,NPTS
        IF(SVLEV(J).LT.60.) GO TO 60
     10 CONTINUE
        IF (IFLAG.GE.1) GO TO 70
C REDUCE FREQUENCY OF FLIGHTS WITH LOWER LOAD FACTORS
        DO 20 I=1,10
        IF(IFLT(I).EQ.999) GO TO 25
        NFREQ(I)=IFREQ(I)
        IF(FFACT(I).LT.85.) IFREQ(I)=IFREQ(I)-1
     20 CONTINUE
C     CHECK FOR REDUCTION OF FREQUENCY
     25 DO 30 K=1,10
        IF(IFREQ(K).NE.NFREQ(K)) GO TO 40
     30 CONTINUE
        GO TO 70
     33 IF (IFLAG.GE.NIX) GO TO 90
        IFREQ(ISUB)=IFREQ(ISUB)+1
        KAP(IFLAG)=ISUB
        DO 35 L=2,IFLAG
        KKAP=KAP(L)
     35 FFACT(KKAP)=100.
        GO TO 70
C     RECORD KEY STATISTICS FROM CURRENT SIMULATION
     40 PFACT=FACTR
        PCOST=TCOST
        POCST=OCOST
        POSRV=TSERV
        DO 50 J=1,NPTS
     50 PSERV(J)=SVLEV(J)
C     PRINT FLIGHT FREQUENCIES
        DO 55 L=1,10
        IF(IFLT(L).EQ.999) NIX=L
        IF(IFLT(L).EQ.999) RETURN
     55 WRITE(NPRNT,100) IFLT(L),IFREQ(L)
        RETURN
```

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Continuation of EVAL Subroutine.

```
C     CHECK FOR POSSIBILITY OF IMPROVEMENT
   60 IF(NNRUN.EQ.1) GO TO 95
      IFLAG=IFLAG+1
      IF(IFLAG.GE.2) GO TO 33
      DO 65 I=1,10
   65 IFREQ(I)=NFREQ(I)
C     REDUCE FREQUENCY OF FLIGHT WITH LEAST LOAD FACTOR
   70 SFACT=FFACT(1)
      ISUB=1
      DO 80 J=2,10
      IF(FFACT(J).LE.O.) GO TO 85
      IF(SFACT.LE.FFACT(J)) GO TO 80
      SFACT=FFACT(J)
      ISUB=J
   80 CONTINUE
   85 IFREQ(ISUB)=IFREQ(ISUB)-1
      IF(IFREQ(ISUB).LE.O) FFACT(ISUB)=100.
      GO TO 40
C     IF NO IMPROVEMENT IS POSSIBLE, STOP SIMULATION
   90 MSTOP=-1
      NNRNS=0
      WRITE(NPRNT,101) NNRUN
      RETURN
C     FIRST RUN - NO FEASIBLE SOLUTION, STOP SIMULATION
   95 MSTOP=-1
      NNRNS=0
      WRITE(NPRNT,102)
      RETURN
  100 FORMAT (6X,'FLIGHT NUMBER',I4,5X,I2,'FLIGHTS PER WEEK')
  101 FORMAT(1HO,5X,'SOLUTION HAS VIOLATED SERVICE LEVEL CONSTRAINT'/
     14X,'SELECT PRIOR SOLUTION',5X,'HEURISTIC REQUIRED',I4,
      2' ITERATIONS')
  102 FORMAT (6X,'FIRST RUN, SERVICE LEVEL CONSTRAINT VIOLATED')
      END
```

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ANALYSIS OF AIR CARGO TRANSPORT SYSTEMS
USING STOCHASTIC SIMULATION

By

Forrest B. Green

(ABSTRACT)

A major problem associated with air cargo transport
is the assignment and scheduling of aircraft to routes that
include several transloading points. This problem is com-
plicated by the fact that shipping quantities vary at each
terminal from one day to the next, and there are often wide
fluctuations in demand for high priority cargo. Rapid
delivery requirements calling for frequent flights to main-
tain satisfactory service often result in over-assignment
and excess capacity. The balancing of capacity and service
is a significant problem for air freight carriers.

The problem investigated was to develop a means of
evaluating various combinations of aircraft and route
schedules taking into account the frequency of flights and
the stochastic nature of shipping quantities. Key perform-
ance and cost variables were identified, and shipping data
were analyzed to determine distribution parameters. A
computer simulation model called CARGOSIM was developed to

represent the air transport system and provide a tool for the evaluation of various alternatives. The simulation model allows for the stochastic behavior of cargo quantities and the detection of shipment delays due to random surges in demand. Accordingly, both the extent to which assigned aircraft can transport available cargo and the level of service at each terminal are determined through simulation.

The simulation model is used in conjunction with a heuristic designed to search through aircraft types and flight frequency combinations until a least-cost solution is found. The cost function includes both the cost of operating the air transport system and the cost of service delays, thus a balance is achieved between capacity and service when an efficient solution is obtained. This feature represents a decision framework designed so that successive iterations of the simulation model will lead to a least-cost solution within statistically determined margins of error.