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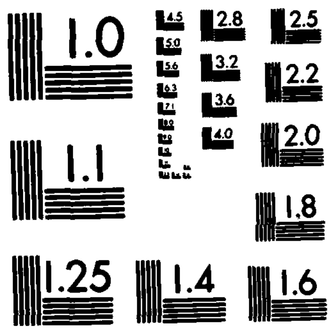

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SIMULATION AND MANPOWER FORECASTING MODELS FOR TACTICAL AERIAL PORT OPERATIONS IN A CONTINGENCY ENVIRONMENT

Michael A. Reusche, Captain, USAF
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LSSR 4-82

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Military Airlift Command (MAC), Mobile Aerial Port (MAP) contingency manpower requirements are currently determined through the use of the USAF Manpower Force Packaging System and Unit Type Codes (UTCs). The research objective was to develop quantitative models which accurately represented the functional relationship of the variables affecting the manning requirements of Mobile Aerial Ports. Two computer simulation models of MAP activities were developed and then statistically analyzed to isolate workload and processing time factors to be included in the predictive mathematical models. Analysis of the predictive models generally indicated that the model results, within certain limits, yield close approximations of UTC manpower requirements.

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SIMULATION AND MANPOWER FORECASTING MODELS FOR TACTICAL AERIAL PORT OPERATIONS IN A A CONTINGENCY ENVIRONMENT

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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This thesis, written by

Captain Michael A. Reusche

and

Captain Vaughn D. Wasem

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COMMITTEE CHAIRMAN

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CHAPTER 1

INTRODUCTION

Background

Major General John D. Bruen, USA, stated:

> Strategic mobility is not airplanes; it is not ships; it is not trains; it is not ports of people . . . . It is all these things molded into an integrated, smooth functioning system. The job to be accomplished by this system is to deploy our forces in CONUS to final destination in theatre on time--and then sustain these forces in combat [4:6].

The Military Airlift Command (MAC) supports these deployments through its airlift forces, and, in particular, its aerial port units. In their simplest form, a MAC aerial port unit receives, processes, and loads cargo and passengers aboard MAC owned, chartered, or Civil Reserve Air Fleet (CRAF) aircraft to insure the successful deployment of combat and support forces to their specified destination.

Aerial port units are classified as 'strategic' (fixed) or 'tactical' (mobile). The differences in the units lie in their ability to mobilize and deploy to alternate locations to support deployment or resupply operations. A fixed port is tied to permanent facilities while the tactical unit (Mobile Aerial Port--MAP) is characterized as capable of rapid deployment, by air or surface, to support contingencies (19:23-1).

A MAP unit may contain the following functional areas:

1. Air Terminal Operations Center
2. Passenger Service Operations
3. Vehicle Control and Maintenance
4. Joint Airdrop Inspection
5. Terminal Service Operations

These functions are performed to support the rapid deployment of forces participating in, or supporting contingency operations. MAP functions include the reception, processing, and loading/offloading of cargo and passengers. Additionally, mobile units may be tasked to support a wide variety of airlift missions such as airdrop or combat offloads associated with contingency operations. This complexity of operations could vary the support needed from one individual with no equipment, to one or more fully deployed mobile aerial port units with a wide variety of equipment (19:23-1). As stated in MAC Regulation 76-1,

> The primary function of a mobile unit is to deploy to a forward base of operations on short notice and to immediately begin operations. To insure the success of an operation, careful planning is vital [19:23-1].

Personnel manning is a major factor which must be considered when planning for contingency operations. Aerial port personnel requirements are normally determined by Headquarters, MAC, using the USAF Manpower Force Packaging (MANFOR) system (19:23-9). The MANFOR system was developed to identify manpower requirements needed to support anticipated contingency operations, to provide the means to communicate these requirements to all levels of command, and to provide a way to compare manpower requirements to approved authorizations (38:6-2). As specified,

> MANFOR objectives are accomplished through the development in an automated format, of predefined modules of units and elements usable in contingency plans and, once constructed, by insuring they are communicated Air Force wide and kept current [38:6-2].

The unit type code (UTC) is the key to the development and communication of the MANFOR system (38:6-2). A UTC is a standardized representation of similar types of military units and is the primary means of identification of units in an Operation Plan in Complete Format (OPLAN) Time Phased Force and Deployment List (TPFDL) (38:3-3). The standardized aerial port unit type codes are recognized through their unique coding which begins with the designation UFB. The final letters in the code (i.e., UFB<u>CE</u>) designate a specific unit size and allude to the function to be performed. Over 90 UTCs have been developed for use in the planning, description, and communication of MAC aerial port contingency personnel and equipment requirements (20).

The Joint Operations Planning System (JOPS) establishes the Department of Defense system to be used in the planning and support of military operations and establishes the UTC as the cornerstone of the MANFOR system. The Air Force established planning guidelines to:

1. Minimize the effort required to develop and keep operation plans current;

2. Facilitate the preparation, use, and understanding of plans through standard formats and content; and

3. Facilitate the deployment of forces and provisions of support when needs arise (38:3-1).

Operations Plans, as specified by JOPS, refer to any plan, except the Strategic Integrated Operations Plan, for the conduct of military operations in a hostile environment. An OPLAN is a complete operations plan normally prepared to meet the following situations:

1. Situations which tax the total forces available for planning, or

2. tax the total logistical and mobility support capability of the U.S.

OPLAN components include the Time Phased Force and Deployment List (TPFDL) and the Transportation Requirements List (TPTRL). These latter two sections reflect unit deployment information, including applicable UTCs (38:1-3 to 3-3).

MAC identifies aerial port UTCs as either strategic or mobile. Strategic UTCs provide for the support of fixed aerial port operations. On the other hand, tactical UTCs support a wide range of deployment possibilities because of the use of a modular or building block approach to their development. Tactical UTCs are used to task four active-duty

MAP squadrons, two combat mobility branches, and a large number of reserve aerial port units.

The aerial port UTCs were initially developed and validated in the 1970-71 time period, and the last major update was begun in the 1979-80 time period and is still in progress. Manpower personnel provided adjusted manpower formulas, initially developed to support peacetime manning standards, for use in determining strategic aerial port UTCs. Tactical UTCs are developed using the Air Transportation Warplanners' professional expertise, estimates, results of exercises, and input from other sources. Currently, UTC accuracy is evaluated by inspection teams, staff assistance teams, or through trip reports generated as a result of a unit's participation in an exercise, contingency operation, or other activity which required the use of designated UTCs (2).

Problem Statement

Quantitative judgements cannot be made about the accuracy and effectiveness of published unit type codes, because mathematical tools have not been applied to develop UTCs which represent mobile aerial port manpower requirements for a contingency environment. Therefore, there is no method available for the precise development or evaluation of the UTCs other than through the observation of training operations in which units were tasked using the published unit type codes. During these operations, however, units are allowed to adjust UTCs within published limits or at the unit commander's discretion; thus, actual UTCs are rarely evaluated.

During actual wartime and major contingency operations, Mobile Aerial Port unit commanders and supervisors may not have the latitude to deviate from specified UTCs. Therefore, a means to accurately develop, evaluate, and defend UTCs is important to Air Transportation warplanning efforts.

Research Objective

The primary objective of this research is to develop quantitative models which accurately represent the functional relationships of the variables affecting Mobile Aerial Port (MAP) terminal service and ramp service operations. Before delineating the supporting research objectives, the scope of the system to be studied will be identified. Next, supporting objectives will be presented and, finally, assumptions and limitations of the research will be discussed.

Scope. As previously identified, there are two major types of aerial port units--strategic and mobile (tactical). This research dealt only with mobile aerial port units. Furthermore, only the terminal service operations functions of the MAP were modelled. No attempt was made to specifically model the four remaining functions.

The terminal service function can be further subdivided into its component parts.

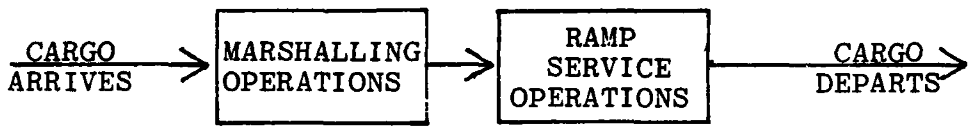

Figure 1-1

Terminal Service Operations

Figure 1-1 depicts the structural model of the terminal service function and its subdivisions. Marshalling operations include the joint inspection of cargo loads with representatives of the unit to be transported, weight validation, limited palletization, load segregation, and cargo control. Ramp service operations include the set-up of aircraft cargo loads, the on and offload of aircraft, and the supervision of the deploying unit support forces in the aircraft parking area. Structural models of the ramp service operation and terminal service functions are reflected in Appendix B.

Since a modular or building block approach was used to design tactical UTCs, MAP units may be tasked to support a variety of operations which could include:

1. Ramp service operations in support of a unit offload.

2. Marshalling and ramp service operations in support of onload operations.

Specific simulation models were developed for each of the above operations.

Within each model, three variables were analyzed: processing time, manpower, and workload. The variables were chosen because they are interrelated and could be labeled dependent or independent depending on the analysis accomplished. A diagraph of the interaction of the variables is shown in Figure 1-2. A plus (+) sign imposed on a relationship described by an arrow means the variables will change in the same direction. For instance, an increase in available manpower would increase the amount of production per time period, thus a plus (+) sign is used to show the direct relationship. A minus (-) sign is used to denote an indirect or opposite relationship. For instance, an increase in available manpower would cause a decrease in required processing time; thus, a minus sign would be used to denote that relationship.

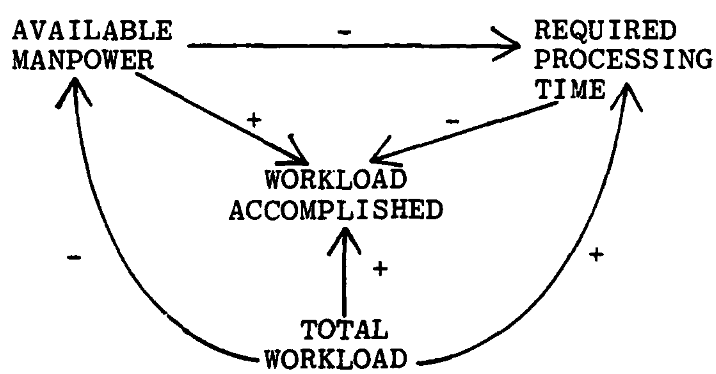

Figure 1-2

Variable Interactions

Objectives (Supporting). Supporting objectives were:

1. To use sensitivity analysis in the development of parameter ranges for the models which would better define the operational environment.

2. To predict manpower parameters given workload and processing time parameters.

3. To compare current tactical unit type codes to simulation models and manpower prediction models to determine the effectiveness of the modelling effort.

Assumptions. A number of assumptions were made concerning mobile aerial port operations in a contingency environment. Assumptions pertaining to the use of manpower, workload arrival times, equipment similarity, and the length of operations were made to enhance system definition and provide for accuracy in the simulation models.

First, it was assumed that the deploying unit would furnish qualified and motivated manpower to assist aerial port personnel as specified in deployment planning directives. Deploying units are currently tasked to palletize cargo, furnish operators for vehicles other than materials handling equipment, maintain custody of equipment, prepare cargo documentation other than air cargo manifests, and weigh cargo (19:23-9 to 23-12). The assumption that the tasks will be handled by qualified, motivated personnel permitted the elimination of additional manpower to perform these activities in the simulation models. Thus, when the simulation models were developed, unlimited resources were assumed to be available to perform the user tasks.

The next assumption dealt with prearranged arrival times for cargo tendered by the deploying unit. It was assumed that arrival times would be constant since MAP units coordinate arrival times with the deploying units at the deployment planning meetings. Experience has shown that many units require cargo to arrive before the first scheduled load departure time. Additionally, integral loads, provided by deploying units, are staged well ahead of schedule. Therefore, cargo generation was not considered a critical variable and was kept constant.

Next, it was assumed that similar types of equipment have similar airlift characteristics such as weight and length. This assumption enabled the cargo generated to be identified and characterized according to differing attributes. The assigned attributes were then used to route the transactions, representing cargo, through various decisions concerning manpower or processing time requirements. In turn, this decision branching led to greater accuracy in the simulation models and allowed grouping of transactions for service time purposes.

Additionally, it was assumed that operations would be short term. For the purposes of this research, short term was defined as seven to fourteen days depending on the type of operation involved.

Finally, it was assumed that the current UTCs were accurate.

Limitations. There were two major limitations which affected the research, and, in particular, the development of the simulation models. The lack of processing time data and the nonavailability of accurate, unclassified unit deployment data, hindered efforts in the simulation model development and verification stages.

Actual data relating to processing or activity times were not available, nor could the data be generated to support the research (24). Contingency mobile aerial port unit operations are only conducted during actual exercises, command ORIs, or actual contingencies. Units involved in these operations do not have the time or manpower to support a data gathering activity. Additionally, the authors could not perform the data gathering because of conflicts between class schedules and scheduled exercises, and because of the "no-notice" nature of ORIs and actual contingencies. This limitation was overcome through the use of sensitivity analysis and the development of processing time ranges. All simulation models were evaluated using the ranges of the parameters which were incorporated by model manipulation.

Deployment unit data availability was the second key limitation. Data concerning the actual deployment of units is classified and would have significantly reduced the scope of the accomplished research. This problem was overcome, however, through the use of deployment data published in unclassified reports. While deployment units sizing and deployment parameters are not totally accurate, the data used is representative.

Research Questions

Two research questions were posed:

1. Can structural and simulation models be developed which accurately reflect MAP unit operations in a contingency environment?

2. Can the simulation models be used to develop a mathematical model which can predict UTC size based on given planning factors?

Justification

There are two basic reasons for conducting research into the development of structural and simulation models representing MAP operations in a contingency environment and the development of mathematical models to predict UTC sizing. Even though strategic aerial port operations have been modelled and a MAC project is currently in progress to update and revise models dealing with strategic aerial port operations (24), there is no quantitative method available to develop or evaluate tactical UTCs (2). Additionally, manpower specialists have developed and validated formulas for use in determining strategic unit manning standards. These formulas may be used to determine contingency strategic requirements by changing some parameters to reflect personnel availability during contingency conditions. The fact remains, however, that transportation planners can now only rely on their professional judgement and expertise, as well as other experts' estimates, when developing UTCs for MAP units.

A second reason for the development of simulation models is due to the analytical capability of the simulation technique. Shannon states,

> Simulation is one of the most powerful analysis tools available to those responsible for the design and operation of complex processes and systems . . . . It allows the user to experiment with systems (real and proposed) where it would be impossible or impractical otherwise [30:ix].

Specifically, the simulation models will provide assistance in the planning, development, and evaluation of plans tasking mobile aerial port units. The simulation models will provide planners a tool for the synthesis of manpower packages in support of unforeseen contingency operations, as well as a tool which could enhance UTC design and evaluation efforts. When using simulation models, the planner would not have to wait for feedback to determine the effectiveness of his planning actions.

Plan of Report

Chapter 1 presented an introduction to the research conducted. The background of the system studied was presented as were the research objectives, scope, assumptions, and limitations. It was noted that quantitative evaluation methods are not currently used to evaluate tactical UTCs; thus, the basic justification for the research was established. Chapter 2 will present a review of available literature concerning the technical aspects of the subject matter. Chapters 3 and 4 will present the methodology to be used in the conduct of the research. Chapter 5 will deal with an analysis of the simulation models and their significant variables, while Chapter 6 will present the manpower model development and validation. The final chapter will conclude the research with a discussion of conclusions and recommendations. Finally, Appendix A provides the definitions of terms referred to throughout the thesis.

CHAPTER 2

LITERATURE REVIEW

The literature review for this thesis was conducted using the resources of the Air Force Institute of Technology libraries, local university libraries, the Defense Technical Information Center, the Defense Logistics Studies Information Exchange, and the Military Airlift Command Air Transportation Staff. The review covered five major areas, including:

1. Case studies and research pertaining to aerial port operations or deployment planning;
2. Queuing Theory;
3. Modelling and simulation theory;
4. Applications of Q-GERT, a simulation language; and
5. Prospective data sources

Information found in each of the areas will be discussed separately.

Case Studies and Research

A review of case studies and research conducted on aerial port operations and deployment planning provided numerous information sources. The studies and research found, however, covered strategic aerial port operations, facility sizing, and materials handling equipment utilization.

Additionally, a number of studies were found which suggested planning and deployment parameters for U.S. Army units which could be tasked to deploy on short notice. Therefore, the studies were of limited use because they focused solely on strategic operations, or dealt with equipment and facility planning.

Conversely, a common factor introduced by the majority of the studies, provided some utility to the information. The studies used simulation to analyze the systems involved and to assist in the identification of study results. Therefore, the studies and research were useful in determining an approach to the problem, the limitation of the scope of the problem, and in the identification of possible data sources. In general, however, the studies will not be specifically cited in this thesis.

Queuing Theory

A queue is a waiting line of customers requiring service from a service activity consisting of one or more servers. A queue forms when demand for the service exceeds the capacity of the service facility. Queuing models involve the study of the trade-offs between the cost of service and the cost of waiting for service with the maximization of profit or minimization of cost as the two global criteria (5:429-432). Queuing models may be used to identify system operating characteristics such as:

1. The probability the servers are idle.

2. The probability that a specific number of customers are in the system.

3. The average number of units in the system.

4. The average number of units in the queues.

5. The average time a unit spends in the queue.

6. The percent of time an arriving unit will have to wait (1:599).

Queuing theory is important to this research because MAP operations are systems which employ servers to process transactions, representing cargo, through the system.

A general representation of the queuing process is shown in Figure 2-1. Units arrive from some population and require service from a service facility. The service facility may contain no server (i.e., self-service), one, or a multiple number of servers. The arriving customer joins a queue, is served, and ultimately departs the system (5:429-432). The system can be restricted or unrestricted. If restricted, the length of the queue would be limited. If the maximum length were reached, blocking would occur, meaning customers could not proceed to other service facilities until the queue length was reduced (25:40).

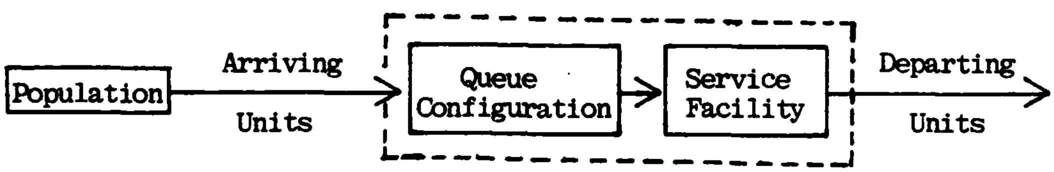

Figure 2-1

Queuing Process

Five features of a queuing system must be identified or specified before the system can be studied. The five features include the arrival process, queue configuration, queue discipline, service discipline, and the service facility. The arrival process could encompass the following conditions:

1. The source of the customers could be from a single or multiple population.

2. The source could be finite or infinite.

3. Arrivals could occur singularly or in bulk.

4. Control of arrivals could be partial, total, or there could be no control at all.

5. Arriving units could be from a deterministic or probabilistic generating process. Normally, if the control of arrivals is possible, the generating process is deterministic.

6. The arrival process could be characterized by independent or conditional arrivals depending on the state of the system.

7. A stationary arrival process may or may not exist. If the process is stationary, then the parameters describing the arrival process remain constant. The usual assumption of queuing theory is a stationary process (5:432-434).

The next two features, queue configuration and queue discipline, deal with waiting line conditions. Queue configuration defines the number of queues in the system, their relationship to the servers, and spatial considerations. For instance, a single queue could lead to a single server or it could lead to multiple servers. Similarly, multiple queues could lead to multiple servers. Additionally, queues could physically be in one place or they could be in separate locations. Finally, queues could be conceptual (telephone busy signal) and immediate rejection of customers could occur if the servers are full. Thus, queue configuration defines the attributes of the waiting lines involved in a system. On the other hand, queue discipline refers to the behavior of arriving customers and their queue selection process. There are six possible actions a customer could take:

1. Rejection - if the queue is full.

2. Balk - the failure to immediately join the queue.

3. Renege - join a queue and later leave before service is provided.

4. Collusion - a state that occurs when the processing of one customer results in the processing of other customers waiting in the queue.

5. Jockey - move between queues.

6. Patience - the failure to exhibit any of the preceding states.

Thus, queue configuration describes the queue formation, while queue discipline describes customer behavior (5:434-435).

The next features, service discipline and service facility, are related. Service discipline is the processing policy established for the selection of customers, while service facility relates to the design and operation of the servers. Service disciplines can be classified into five selection processes:

1. FIFO (FCFS) - selection by first-in, first-out, or by first-come, first serve.

2. LIFO (LCFS) - selection by last-in, first-out.

3. SIRO - service in random order. Arriving customers are not monitored or controlled upon arrival in the queue; thus, any customer could be selected.

4. Round Robin Service - sequential service with every unit in the system receiving some service such as that provided by the time sharing computer.

5. Priority service - selection is based on predefined attributes.

The service facility also has five design and operating characteristics:

1. The facility may have none, one, or multiple servers.

2. The servers could be in parallel, in series, or both.

3. The channels (servers) may be cooperative (help if idle) or uncooperative.

4. Service times may be deterministic or probabilistic.

5. Service time parameters may be constant or depend on the state of the system (5:435-437).

Queuing models are classified according to a system devised by Kendall in 1953, refined by Lee in 1966, and again by Taka in 1971. There are two classification schemes in use, one of which is a shortened version of the other. The first scheme takes the form:

(X/Y/Z:U/V/W)

The components of the scheme are defined as follows:

X Arrival distribution

Y Service time distribution

Z Number of parallel servers

U Service discipline

V Maximum number of customers allowed in the system

W Size of the population

The following codes are used to replace the arrival and service time distribution components (X,Y):

M Poisson or exponential distribution

G General distribution (any)

GI General but independent distribution

D Deterministic time

The symbols Z, V, and W are replaced by the appropriate numerical designation, while the symbol U would be replaced by the appropriate service discipline (39:8-9). An alternative scheme is a shortened version of that already described. This version takes the form:

X/Y/Z

with the symbols defined as before. Other assumptions, represented by the symbols U, V, and W in the previous model, would be provided in the model description (5:438).

There are two methods used for the solution of problems dealing in queuing theory. Queuing problems can be solved using analytical methods or computer simulation. Analytical solution methods derive mathematical expressions for the operating characteristics of the queuing system under study. The expressions are then used to derive optimal values for the dependent and independent variables. The computer simulation method, on the other hand, attempts to use the computer to reproduce the operation of the system (5:438-440). Computer simulation will be discussed in detail in the next section of the literature review; therefore, further discussion will not be provided at this point.

An assessment of queuing theory identified both the uses of the method and problems caused by the rapid growth of the theory. It was found that the study of queuing theory and systems is important for the following reasons:

1. The output of one queue in a network is the input of other queues in the same queuing network.

2. In a queuing system, all processes (arrival, service, output) may not be observable; thus, one may wish to deduce characteristics of a part of or the entire system.

3. The performance of a queuing system is frequently specified in terms of its output.

It is also important to know how the system operates when heavy loads are incurred (23:492). Conversely, rapid developments in queuing theory have brought about problems. First, the application of theory has lagged behind the state of the art due to a communications gap between the applied researchers and the theorists. Secondly, there has been an indiscriminate use of M/M/c models without substantiating assumptions which, in turn, may lead to a credibility gap. Finally, there has been an absence of proper sampling, estimation, and hypothesis testing methods which has made some results questionable (5:463-464).

Modelling and Simulation Theory

System analysis encompasses many techniques useful in the evaluation of complex systems. Operations research and system analysis are said to be related because the latter may include simulation and modelling techniques which fall into the realm of operations research (28.134). This section of the literature review will cover the functions, types, characteristics, accuracy, advantages, and disadvantages of simulation modelling. Reitman said, "the representation of a system--the rules and relationships that describe it--is defined as a model [26:7]." Simulation is the process of designing models for use in experiments which evaluate or analyze a system (30:2). Thus, in this literature review, simulation and modelling for simulation were considered to be dependent on one another.

"The concept of representing some object, system, or idea with a model is so general that it is difficult to classify all the functions that models fulfill [30:5]." However, authorities agree that modelling supports decision making (3:8-9; 6:10; 11:304; 16:13; 21:139; 30:5-6). Further, the use of a model to aid in problem identification is also suggested by some authorities as the key instrument in decision making (3:8-9; 26:8; 33:1031). Similarly, it is also suggested that modelling's primary support lies in the alternative selection process (6:10; 16:13; 21:139). A second function suggested is that of prediction or forecasting (3:9; 9:691; 26:8; 30:5-6). In particular, Fildes suggests quantitative forecasting methods are gaining acceptance as decision making instruments (9:691). Next, system comparison was cited as an important function of modelling and simulation (3:12; 26:7-8; 30:6). System comparison may be the most important function because the user can analyze the system without impacting its operation or while the system is still on paper (26:7). Training is also cited as a function of modelling and simulation. "Models may be used for training personnel to give them experience that may be used to their advantage when placed on the job [3:9]." Finally, as Shannon stated, "Properly done, model building forces us to organize, evaluate, and examine the validity of thoughts [30:6]."

Two basic methods were used to describe the types of models and simulations available. Some authors used schemes or levels to describe their simulation models, while other authors defined their models based on the type of system evaluated or the evaluation method used. For instance, two extremes of modelling types were suggested to be operational level models and policy level models. Operational level models were defined as ones which concern themselves with technological systems which exhibit relatively repetitive behavior. Conversely, policy level models were characterized as ones which concern sociotechnical systems (systems involving both social and technical characteristics) that exhibit a diversity of behavior (12:304). Additionally, Shannon suggests four classifications of simulation models. He portrays these classifications as: static or dynamic, deterministic (input or output certainty) or stochastic (input or output uncertainty), discrete or continuous, and iconic (statute) or symbolic (30:7). Shannon further suggests that a model could fall into many of these schemes at the same time. For example, he shows how an airplane model, used in wind tunnel testing, is dynamic and iconic, while an architectural model is static and iconic (30:8-9).

As previously stated, model definitions may be based on the system under evaluation or the evaluation method used. The extrapolative model is identified as one form of the forecasting model. It was then subdivided by method to include trend curve analysis, smoothing, and Box-Jenkins methods (9:694). Other model types are identified as physical, pictorial, mathematical, gaming, waiting line, and critical path models (3:10; 30:8-10). Digman and Green combine waiting line and critical path models into an approach they label network analysis (6:10). Shannon sums up his discussion of model types by stating,

> In trying to model a complex system, the researcher will usually resort to a combination of pure types just discussed . . . . Most system studies will result in several different models of the same system [30:10].

The following list reflects the characteristics of good simulation models:

1. Simple for the user to understand.
2. Goal or purpose directed.
3. Robust; the model does not give absurd answers.
4. Easy for the user to control and manipulate.
5. Complete on important issues.
6. Easily updated.
7. Simple in construction, but may become more complex as the model grows.

Other authors, while agreeing with the preceding list, address other characteristics they feel are also important (9:691; 12:304; 29:101; 30:22). For instance, Fildes adds flexibility, ease of communications, and formality to the list (9:691). Schruben suggests the most rewarding characteristic is that of credibility. He states,

> A more rewarding objective would be obtaining and retaining credibility. Model credibility is reflected by the willingness of persons to place decisions on the information obtained from the model [29:101].

Stainton states, "testing, evaluation, and implementation require full measures of constructive criticism, cooperation, and the will to see it (the project) through [33:1035]." Konczal added, "Managerial guidance is important in . . . insuring the model is accurate [16:12]." Thus, accuracy, or as Schruben suggests--credibility--is an important characteristic of simulation models (12:304; 33:1035; 15:14; 16:12; 29:101; 30:208). Certification of accuracy was proposed to be a two step process consisting of verification and validation. Verification was defined as the determination of model logic, while validation was defined as testing to ensure that the model agrees with the real system (16:14).

The literature review found many authors who advocate certification but differ on the means of accomplishing the process (16:14; 29:101; 30:208). Schruben suggested that a technician should handle verification while management should handle validation (29:101). Konczal said management should be involved in verification and validation (16:14).

On the other hand, Shannon suggested the use of sensitivity analysis to accomplish validation as a step after the technical and managerial involvement (30:236). Shannon wrote,

> The mere fact that we have explored the sensitivity of the model results to changes, errors, etc., will help reassure the decision maker or ultimate user of the thoroughness of our study and the validity of our results [30:236].

Shannon states the greatest possible model validity and accuracy is achieved by:

1. Using common sense and logic;
2. taking maximum advantage of the knowledge and insight of those familiar with the system under study;
3. empirically testing, through statistical techniques, the assumptions and hypothesis;
4. paying close attention to details and rechecking all steps of the process;
5. using the technique of verification;
6. comparing the output of the model and the real world whenever possible;
7. running field tests;
8. performing sensitivity analysis; and
9. carefully checking the predictions made by the model (30:237).

Shannon sums up the accreditation process by stating, "validation is a continuous process that takes place throughout the modelling process [30:218]."

There are numerous advantages of simulation modelling. Advantages previously discussed as functions include: modelling's decision-making assistance and support of the planning process (3:8-9; 6:10; 16:13). Additionally, flexibility is a key advantage. Reitman wrote,

> Once a model is developed with a reasonably flexible structure, then it can be quickly and cheaply varied to include new wrinkles . . . . It makes for friendly relations to be able to use the same model to evaluate additional alternatives [26:9].

Modelling's theory building capability was suggested as another advantage (33:1031). Simulation models also provide a means for the systematic analysis of the problems confronting the manager (3:8; 6:10; 26:7; 30:ix). Furthermore, simulation techniques enable the manager to plan and implement corrective action in a more timely manner and on a more effective basis (3:8; 6:10; 14:1069; 16:12; 21:139; 26:7; 30:ix-x). Browne contends that models give the user the time and material to explore the environment in a greater depth (3:8), while Reitman adds,

> The development of the model and the use of simulation can give the system designer something no other tool in his repertory can give - the feeling, insight, and opportunity to operate and manipulate a system plus a measure of insurance - while the system is still on paper [26:7].

Shannon summarized the importance of simulation modelling by saying,

> Simulation is one of the most powerful analysis tools available to those responsible for the design and operation of complex processes and systems . . . . It allows the user to experiment with systems (real and

proposed) where it would be impossible or impractical otherwise [30:ix].

In contrast, the following disadvantages were expressed by authors writing about simulation and modelling. Sauls states,

> It becomes more important that the user realize the limitations of the technique. The adage, GIGO, garbage in garbage out, is increasingly true as the procedure becomes more general and complex [27:21].

It was suggested that as models become larger and more complex they lose flexibility (14:1071), and they may act as a filter for system characteristics which might not be easily handled by mathematical treatment (33:1031). Additionally, model and simulation development could be expensive and imprecise results could be accepted as a result of the decimal rounding process (30:13). However, Shannon concludes his discussion of disadvantages by stating,

> The development and use of simulation models are still to a very large degree arts rather than sciences. Thus, as with other arts, it is not so much the technique that determines success or failure, but rather how the technique is used [30:14].

Q-GERT

Q-GERT is a network modelling technique and computer analysis tool. GERT stands for Graphical Evaluation and Review Technique and the Q is added to reflect that the technique may be used to evaluate queuing systems. Q-GERT networks are models of queuing systems. The systems were described in preceding paragraphs and contain a customer, a service activity, a server or servers, and a service facility.

The technique supports a system analysis technique which has the following steps:

1. Separate the system into its key elements.

2. Analyze and describe the elements.

3. Build a network model of the system.

4. Use the network model and computer simulation to evaluate system performance.

In short, a Q-GERT network is an analysis tool which represents a system and can be used to evaluate system performance (25:vii-x). Q-GERT will be discussed in greater detail in succeeding chapters of this thesis.

Prospective Data Sources

A review of available literature identified many research studies and computer simulations involving aerial port activities. As stated previously, the studies dealt with strategic aerial port operations, facility evaluations, or material handling equipment utilization and were, therefore, of limited use. However, utility was provided in three areas. The studies suggested service time parameters, modelling techniques, and prospective data sources for use in the research conducted. Additionally, a review of the MANFOR and associated UTCs for tactical aerial port operations identified other data sources.

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CHAPTER 3

MODEL FORMULATION, DATA PREPARATION, AND VALIDATION

Introduction

Shannon prescribes eleven stages which encompass the simulation process:

1. System definition
2. Model formulation
3. Data preparation
4. Model translation
5. Validation
6. Strategic planning
7. Tactical planning
8. Experimentation
9. Interpretation
10. Implementation
11. Documentation (30:23)

The stages were used to guide the development and conduct of this research effort, and are now used to organize the material in this chapter. Some of the stages, such as system definition and model formulation, were completed and documented in Chapter 1. Other stages, such as data preparation, were begun in Chapter 1, and will be fully explored in this chapter. Additionally, the logic of the Q-GERT networks will be discussed, the transformation of the network into computer language will be documented, as will the pilot run made to verify and validate the model. Finally, model validation will be discussed. Before a network can be developed, however, a computer language must be chosen to insure the compatibility of the language and the modelling efforts.

Language Selection

A comprehensive list of factors to be considered in selecting a simulation language may be found in Shannon's text, System Simulation, The Art and Science. Q-GERT was chosen for this thesis for a number of reasons. First, the language was taught as a part of the curriculum in the Graduate Logistics Management Degree Program at the Air Force Institute of Technology; thus, the text and experienced personnel were available to assist in the resolution of problems. Next, the language was convenient because it was available on all three accessible computer systems. Additionally, Q-GERT was chosen because of the simplicity of error diagnosis which facilitated model translation. Finally, the Air Transportation staff, Military Airlift Command, has access to the language and the means to replicate or continue the analysis if desired. In general, Q-GERT was readily available and easy to use which led to its adoption as the simulation language.

Network Analysis

The Q-GERT networks developed to facilitate model translation are shown in Appendix C. Before discussing the logic of the networks, however, the symbology used in network preparation will be discussed.

Symbology. Appendix D reflects a summary of the Q-GERT symbols used to develop the Q-GERT networks found in Appendix C. Basically, a Q-GERT network is a graphical representation of a system or process and the flow of the transactions through the process (25:vii). For instance, in this research, the terminal service operations are the processes being represented by the network. Cargo and aircraft flowing through the system are represented by the transactions. The networks consist of branches, activities, nodes, and transactions which are logically constructed so that a system may be accurately represented. The passage of time is represented in the network by a branch with the symbol used to denote the activity or branch in the form of an arrow ($\longrightarrow$). Another type of arrow, the pointer ($\rightsquigarrow$), is used to denote the entry or exit of a transaction into or from the network, while the dashed arrow ($\dashrightarrow$) is used to denote the routing of transactions that balk from a queue node, or the flow of transactions between queue nodes and select nodes or allocate nodes (25:48). Service parameters are reflected above the arrows, as are passage conditions, if applicable. Appendix D contains a full explanation of the activity characteristics displayed above and below the arrow.

The Q-GERT networks developed have nine basic types of nodes. A full definition of all nodes is provided in Appendix D. In general, a source node generates transactions, transactions wait at queue nodes for a server, statistics are collected at statistics nodes, and transactions exit through sink nodes. A regular node receives and routes transactions through branching, which can be deterministic or probabilistic, conditional-take first, or conditional-take all. The latter types of branching require the transaction to meet a specified condition which is reflected above the arrow representing the branch or activity (25:1-49).

Network Logic-Terminal Services Operations. The network depicting the full terminal service operation is provided in Figures C-1 through C-10. The network has been broken into subnetworks; thus, each functional portion of the network will be discussed separately.

Figure C-1 reflects the cargo generation and the load sizing process. Sixty-six (66) transactions, representing cargo loads, are generated, subdivided by aircraft type, and further divided into their corresponding load components. The branch from node 2 to node 3 reflects the selection of fifty (50) C141 loads which consist of six (6) pieces (1 pallet, 2 large rolling stock, 3 small rolling stock) that represent a full aircraft load. Similarly, the branch from node 2 to 7 reflects the selection of C5 loads and the subsequent generation of load components. Four types of C5 loads are generated at node 8. First, transactions representing four (4) loads of eight (8) UH-1H helicopters are generated, followed by six (6) loads of twelve (12) AH-1G helicopters, five (5) loads of thirteen (13) OH-58A helicopters and one (1) load of 36 pallets representing support equipment. Additionally, at the start of the simulation, supervisors are allocated from the available personnel resources representing the deployed UTC (Figure C-2) and work schedule preparation is accomplished (Figure C-3).

The cargo generated is then routed through the portion of the network representing the spot check of cargo weights (Figure C-4). A 10 percent reweigh is simulated by the model at node 27, requiring the allocation of two (2) personnel resources per item weighed. Cargo not selected for reweigh is routed to the inspection function (Figure C-5) as are reweighed pieces. One (1) personnel resource per piece of cargo inspected is allocated to perform the function. Prioritizing of resource allocation and resource assignments were used to limit the amount of resources available to the inspection function. The model frustrates 10 percent of the cargo inspected at node 36 and time is then taken to correct the frustration deficiency prior to routing the cargo to marshalling, as reflected by the branch eminating from node 36. The time required to correct the simulated discrepancies, as well as the time required to perform the inspection, are found in Tables 3-1 and 3-2.

After completion of cargo inspection, the cargo is reassembled into aircraft loads. Figure C-6 represents the marshalling of C141 loads while Figure C-7 represents the marshalling of C5 loads. Two sets of equipment are allocated to the C5 pallet load at node 54 so that the subsequent load setup may be accomplished.

The bottom portion of Figure C-8 models the load setup function, while the top portion represents the aircraft arrival process. During load setup, service time and personnel resources are allocated with node 61 representing setup loads awaiting aircraft arrivals. The aircraft arrival process generates 50 transactions representing C141 aircraft and 16 transactions representing C5 aircraft. Upon aircraft arrival (node 64), the aircraft waits for a parking position (node 66). In the simulation model, as in the actual system, parking positions are limited to the MOG (maximum number of aircraft which may be parked concurrently as specified by the UTC in use) to limit the number of aircraft being serviced. Node 68 represents the assembly of aircraft and loads so that the aircraft upload process may begin.

The process of preparing for the aircraft upload is modelled in Figure C-9. Load teams are allocated (nodes 72 and 78) with the team size depending on the type of aircraft

TABLE 3-1

Initial Independent Variable Levels
(Constant)

		u (hrs)	s^2 (hrs)
Shift Length	12 Hrs		
Workload:			
Amount of Cargo	506 Pcs		
No. of Aircraft	66		
C141	50		
C5	16		
Aircraft Interarrival Rate			
C141	1.167 Hrs		
C5	4.250 Hrs		
Maximum Service Rate (MOG)	3		
Maximum Ground Time			
C141	2.25 Hrs		
C5 (Pallets)	4.25 Hrs		
C5 (Heli)	5.25 Hrs		
Cargo Failure Rate	10%		
Cargo Deficiency Correction Rate		.20	.01
Aircraft Arrival to Block			
C141		.25	.01
C5		.50	.02
Aircraft Block to Departure			
C141		.33	.02
C5		.833	.02
Load Crew Break			
C141		.361	.162
C5		.500	.278

TABLE 3-2

Initial Independent Variable Levels
(Controlled)

Personnel Resources 100

	u	s^2
Cargo Weighing Service Rate (hr)		
Pallets	.094	.0002
Rolling Stock	.117	.0010
Helicopters	.150	.0004
Cargo Inspection Service Rate (hr)		
Pallets	.150	.0004
Rolling Stock[a] (nal)	.100	.0004
Rolling Stock[b] (al)	.200	.0004
Load Setup Rate (hr)		
C141 Load	.633	.0170
C5 Pallet Load	1.083	.0100
C5 Helicopter Load	.75	.0240
Load Transport Rate (hr)		
C141 Load	.083	.004
C5 Pallet Load	.150	.004
C5 Helicopter Load	.650	.020
Aircraft Upload Rate (hr)		
C141	1.083	.0240
C5	2.917	.0450
Aircraft Download Rate (hr)		
C141	.567	.0181
C5	1.250	.0104

Notes: a - nal, no accompanying load

b - al, accompanying load

to be serviced. Equipment sets are allocated and loads are transported (represented by the passage of time) to the appropriate aircraft. Figure C-10 represents the model of the aircraft loading process by aircraft type (C141, top; C5, bottom) and the subsequent aircraft departure.

Network Logic-Ramp Operations. Ramp operations, depicted in Appendix C (Figures C-11 through C-14), are the offload of aircraft like those generated in the terminal service operations. The network is broken into four subnetworks: aircraft generation and identification, aircraft block-in and personnel utilization, equipment utilization and download, and aircraft block-out and departure.

Figure C-11 represents the generation of 66 aircraft (nodes 2 and 3) which are then split into either C5s or C141s. Branching from node 4 to node 5 identifies 50 aircraft transactions as C141s, while branching from node 4 to node 6 identifies 16 C5s. Once generated, the aircraft transactions flow to 'await landing' queues (nodes 5 and 6).

Figure C-12 depicts aircraft landing, awaiting parking (nodes 10 and 13), and aircraft block-in. As was previously discussed, the number of aircraft permitted to block-in is constrained by the MOG corresponding to the UTC being simulated. Once the aircraft transactions are simulated as blocked-in, they wait for the allocation of personnel and equipment resources before the download operation is initiated. Nodes 40 through 43 simulate personnel shift changes.

Figure C-13 depicts the allocation of equipment and the downloading of aircraft. Downloading times vary with both the type of aircraft and the type of load. Five load situations are modelled: C141s with mixed cargo, C5s with either 8, 12, or 13 helicopters, and a C5 with pallets. The appropriate parameters are shown in Tables 3-1 and 3-2.

Figure C-14 depicts the release of all resources (personnel and equipment), aircraft block-out (nodes 32, 35, and 37), taxi, and departure. As with the previous network, this network may be easily modified to include changes to the workload, flow, parameters, or the activities conducted.

Network Translation. The previously described networks were then used to develop the computer programs which were needed to perform the actual simulation. Appendix E, Figures E-1 and E-2, reflect the programs developed from the networks, while Appendix F contains an explanation of the program coding and terminology.

Appendix E provides the translation of the terminal service operations unit deployment network and the translation of the ramp operations offload network. Both programs were constructed by separating nodes from activities, parameters, and attribute assignments for ease in debugging and tracing.

It should be noted that the programs were developed in module form to facilitate modifications of the programs. For example, activities can be rerouted, work stations added, workloads modified, service time parameters adjusted and aircraft service times changed. This action was taken to lend flexibility to the model and increase its ability to model a variety of additional situations.

Data Preparation

Shannon suggests four steps in the model construction phase. First, he suggests that the purpose be specified; next, the components be identified; then the parameters and variables associated with the components should be defined; and finally, the functional relationships among the components, parameters, and variables should be specified (30:58-59). Since the model is now formulated and the components identified, this section will identify the parameters and variables associated with the components.

Table 3-3 specifies the data needed to support the initial sensitivity analysis and experimentation conducted with the simulation models, and Table 3-4 identifies the data required to support the post-experimentation sensitivity analysis. The tables identify the nature of the data through two major categories of classification: independent or dependent variables. Shannon also suggests that independent variables may contribute to the experiment in three ways: they could be held constant, they could be allowed to vary

TABLE 3-3

Data Requirements (Variables)

Independent Variables	
Constant	Controlled
Workload:	Personnel Resources
Amount of Cargo Number of Aircraft	Number of Aircraft Serviced (MOG)
Shift Length	Cargo Weigh Rate
Aircraft Interarrival Rate	Cargo Inspection Rate
Maximum Time in System	Load Setup Rate
Cargo Deficiency Correction Rate	Load Transport Rate
	Aircraft Upload Rate
Equipment Resources	Aircraft Download Rate
Aircraft Block-in Rate	
Load Crew Break	
Aircraft Block-out Rate	

Dependent Variables

Personnel Resource Utilization

Cargo Marshalling Completion Time

Simulation Completion Time

and become part of the experimental error, or the variables could be measured and controlled (30:154). For this research, the independent variables were held constant or controlled and were not allowed to vary freely during experimentation.

TABLE 3-4

Post-Experimentation Data Requirements
(Variables)

Independent Variables	
Constant	Controlled
All independent variables shown in Table 3-3 that are not shown under the controlled variables in this table.	Workload: Amount of Cargo Number of Aircraft Aircraft Interarrival Rate

Dependent Variables

Personnel Resource Utilization

Cargo Marshalling Completion Time

Simulation Completion Time

The model design and variable selection enables the modeler to specify the levels for the variables. It should be recognized that either of three types of data may be used as variable levels. The data can be either empirical, theoretical, or a mixture of both. Empirical data is actual data collected through the use of sampling techniques, while theoretical data is an estimation of actual data using theoretical distributions. The experimentation conducted used theoretical data for a number of reasons. First, and most importantly, empirical data was not available, as was discussed in the limitations presented in the first chapter. Next, theoretical data lends itself to experimentation and enables the analyst to determine the sensitivity of the model to the form of the probability distributions estimated (30:28). Finally, Shannon suggests that theoretical data is more computer efficient than empirical data (30:28). Tables 3-1 and 3-2 reflect the initial levels of the variables selected for use in the sensitivity analysis and experimentation. The initial levels for the post-experimentation sensitivity analysis cannot be determined until the initial experimentation is complete; therefore, those variable levels were not identified at this point.

Model Validation

The validation process was divided into two phases. First, technical validation was accomplished to insure the computer programs were functioning properly and that transactions were flowing through the network as required. The second phase, "real-life" validation, was used to verify that the simulation accurately modelled real life situations. The technical validation phase will be discussed first.

Technical Validation. The technical validation phase was divided into three steps. First, computer program traces were accomplished to insure the program was causing transactions to act as desired by the modelers. The trace showed the attributes present, the simulation time, and the location from which transactions entered the selected node. The nodal trace also showed when the transactions departed the node, the destination of the transactions, and the attributes present when the transactions were routed to the succeeding node. Next, program logic was reviewed to insure proper coding was accomplished and error conditions did not exist. This action was accomplished using embedded Q-GERT and FORTRAN error diagnosis techniques. Finally, the random number streams were tested to insure that the random number generators were producing the desired random deviates. This step was accomplished using the Chi-square, Goodness of Fit test, available in the Statistical Package for the Social Sciences (SPSS), a prepackaged statistical analysis program.

Technical validation was accomplished by the researchers The trace and error diagnosis showed, to the satisfaction of the modelers, that the programs were properly coded and that the transactions were flowing through the networks as intended. Next, the analysis of the random number streams tested the distribution of the random number deviates used to generate activity durations as reflected by the parameters embedded in the computer model (Table 3-5).

The SPSS Chi-square analysis tested the null (H_o) hypothesis:

$$H_o: \quad F(x) = f(x) = \begin{cases} \dfrac{2(x-a)}{(m-a)(b-a)} & \text{for all } x;\ a \le x \le m \\[2ex] \dfrac{2(b-x)}{(b-m)(b-a)} & \text{for all } x;\ m \le x \le b \end{cases}$$

SPSS generated a computed Chi-square (X^2) value, based on the expected value of the deviate as determined by the researchers, which was compared to a table (critical) value.

TABLE 3-5

Random Number Distribution Generator
Test Results

Random Number Stream	Distribution	Parm Set	Observed X^2	D.F	Critical X^2	Reject H_o
1	Triangular	1	7.607	5	11.0705	No
2	Triangular	2	5.561	6	12.5916	No
3	Triangular	3	4.679	7	14.0671	No
4	Triangular	4	11.743	9	16.9190	No
6	Triangular	7	2.210	3	7.8147	No
8	Triangular	10	0.400	3	7.8147	No
9	Triangular	11	0.250	3	7.8147	No
10	Triangular	12	4.544	4	9.4877	No

Note: Random Number streams 5 and 7 provided by Q-GERT were not used to generate variable values.

The decision rule used to "reject" or "fail to reject" the null (H_o) hypothesis was:

If $X^2_{obs} > X^2_{tab}$ or $-X^2_{obs} < X^2_{tab}$ for $\alpha = .05$, then fail to accept the null hypothesis (H_o) at the α=.05 significance level.

Table 3-5 provides the results of the test of the number streams in question. It should be noted that the researchers failed to reject the null (H_0) hypothesis and therefore concluded, at the α=.05 significance level, that the random number streams were generated and distributed properly. The researchers concluded that the models were technically valid since the traces reflected accurate handling of transactions and the Chi-square tests showed that the random number streams were generated and distributed as desired.

"Real-Life" Validation. "Real-life" validation was accomplished to insure the simulation models accurately reflected actual operations and concepts. Appendix G contains a copy of a package prepared by the researchers and forwarded to the DCS/Air Transportation, Plans and Resources Division, Headquarters, MAC, for their evaluation of the "real-life" aspects of the simulation model. The Plans Division is the office of primary responsibility for war plans, systems, and mobile aerial port resources. Appendix G also contains a partial copy of the reply from that office. In short, the reply states, "Your terminal service model substantially reflects actual deployment operations and the concept of operations in current plans [7:1]." Based on the reply received, and the actions taken by the researchers to accomplish the minor changes suggested, the models were determined to be valid and useful.

Summary

This chapter provided a description of the simulation networks and computer models designed to represent terminal service and ramp operations. It also provided the data requirements and initial parameters which were used to perform a simulation pilot run for validation purposes. The chapter reported that both a technical and "real-life" validation were accomplished. The researchers validated the technical aspects of the model and then the Air Transportation Staff performed the "real-life" validation. Both validations found the computer models accurate and useful. Subsequent chapters will discuss the experiment planning phase (Chapter 4), the results of model sensitivity analysis (Chapter 5), the development of the manpower models (Chapter 6), and finally, the researchers' conclusions and recommendations (Chapter 7).

CHAPTER 4

STRATEGIC/TACTICAL PLANNING

Introduction

Up to this point in the thesis effort, the authors have described the research problem, objectives, and models built to represent the systems involved. The research problem, general background information, and outline of the research objectives were introduced in Chapter 1. The current literature on the subject and techniques used to achieve the research objective were reviewed and discussed in Chapter 2. In Chapter 3, we developed the Q-GERT networks for the simulation models and detailed the data requirements. The next step, experimental design, is discussed in this chapter.

Since Shannon recommended two kinds of planning, strategic and tactical, for the experimental design process (31:30), the authors describe the design process by first presenting the strategic planning phase, followed by a section on tactical planning. Also, in this chapter, specific techniques such as sensitivity analysis, multiple regression, and model building are further discussed.

Strategic Planning

Shannon described strategic planning as the effort of designing an experiment that yields the needed information and tactical planning as dealing with the efficiency of the model and the number of computer runs necessary to meet statistical criteria (30:30-31). The strategic planning phase for determining experimental design was an important step in learning more about the problem at hand. Specifically, this phase allowed the researchers to gain additional information and learn more about the real world system being studied (30:30). As Shannon stated, two objectives of this phase are:

> (1) finding the combination of parameter values that will optimize the response (dependent) variable and/or
> (2) explaining the relationship between the response variable and the controllable (independent) factors in the system [30:30].

Shannon's second objective for strategic planning was directly applicable to this thesis, since the research objective, as identified in Chapter 1, was to develop a mathematical model which would accurately predict manpower utilization based on its functional relationship with the independent variables. The first step, then, was to examine the research objective, in a general sense, in order to identify parameter values and explain relationships between the dependent variable and the independent variables. The parameters (variables) and their values identified for this simulation were outlined in Tables 3-1 and 3-2. To gain additional knowledge of the system and to explain the relationship between the variables in the strategic planning phase, the authors used two techniques: (1) sensitivity analysis, and (2) multiple regression.

Sensitivity Analysis. Sensitivity analysis is one of the most important phases of the modelling process. During this phase, the values of the controllable variables are systematically varied in order to determine how sensitive the model is to changes (30:32). This step was particularly crucial since the authors' models relied upon theoretical distributions and it was necessary to know how much deviation the data could have without changing the output (30:235). By knowing the sensitivity of the model, one of two outcomes would exist. Either the model was not sensitive to changes and it was not necessary to invest the time to gain additional accuracy, or the model was highly sensitive to changes and it was necessary to be aware of external changes that could have an impact on the situation (30:236).

Sensitivity analysis was conducted in two phases of the experiment. The first phase, preexperimental sensitivity analysis, was conducted prior to development of the manpower model. During this phase, the authors chose to conduct a full factorial design in order to accomplish the preexperimental sensitivity analysis. The second phase, post-experimental sensitivity analysis, was conducted after the manpower models were developed in order to determine the validity of the manpower models based on changes to the constant independent variables.

After the preparation of the terminal service operations data needed for the full factorial design, the average resource utilization (dependent variable) was analyzed for sensitivity to various changes in the levels of the upload, weigh, inspection, load setup, and load transport independent variables. Additionally, a similar analysis was done for the download rate used in the ramp operations model. SPSS Analysis of Variance (ANOVA) tests were accomplished to determine if there was any difference in the response of the system. That is, the ANOVA was used to test a series of main factor effects and interactions. A p-value computed by the SPSS package was used to determine if the change in the independent variable(s) had a significant effect on the dependent variable. The rejection region for the null hypothesis was that area where values of the computed F were greater than the F statistic (18:477). Additionally, for this test, the SPSS package automatically computed a significant F value or p-value. When the null hypothesis is true, the p-value is the probability of obtaining a value of the test statistic (F value) which is equal to or more extreme than its observed value. Since the value is found from the probability distribution of the test statistic under the null hypothesis, a p-value that is very small implies that a result so extreme, when the null hypothesis is true, occurs only very rarely by chance alone (10:11-12). Since the researchers considered anything smaller than .01 a rare event, they established alpha at .01 prior to the test. For example, if a main effect variable or interacting variable had a p-value of .04, then the null hypothesis was accepted at the .01 alpha level. However, the researchers would reject the null hypothesis at the .05 alpha level. Those variables, both main effect and interacting, that were determined to cause significant differences, that is, those variables that were sensitive to value changes, were then considered for further analysis.

Multiple Regression. The next step toward the building of a manpower predictor model was the development of a multiple regression model. A multiple regression model has a number of desirable characteristics needed for development of the manpower prediction model. First, the model is used to determine the relationship between the dependent variable and two or more independent variables. Second, a multiple regression model may include higher order terms such as X^2 and X^3. The addition of these terms enables the incorporation of relationships beyond the simple linear form, thus allowing the model to explain additional error. As before, SPSS was used to perform the statistical analysis.

Several techniques exist in order to systematically test variables and combinations of variables to determine if they should be included in the multiple regression model. Four of these techniques are: (1) forward (stepwise) inclusion; (2) backward elimination; (3) stepwise solution; and (4) combinatorial solution (22:345). The researchers used the first of these techniques, forward (stepwise) inclusion, since this was the only technique available on the SPSS package accessed. With this technique, independent variables are included in the model only if they meet certain inclusion criteria. The variable that explains the greatest amount of variance (largest squared partial correlation) in the dependent variable is the first variable to enter the equation. Successive variables are then entered into the model by descending order based on their contribution to explain the variance in the dependent variable. The process continues until all combinations of the independent variables are either included in the model or are discarded due to failure to meet the preestablished inclusion criteria (22: 345).

Tactical Planning

Tactical planning considered four important factors: (1) simulation start up conditions; (2) the number of levels for each independent variable; (3) the number of repetitions for all possible level variations; and (4) the required tests to determine the relationship of the independent and dependent variables.

Start Up Conditions. The start up conditions for most simulations are a critical factor, since in most real world situations the activity being simulated rarely starts at an empty and idle state. Therefore, it is usually necessary to allow the computer simulation model to run for some period of time in order to work out the anomalies of system start up and reach a point of equilibrium from which the researchers can start collecting data. This requirement tends to make the model less efficient since the modeler is using computer time and gaining no information from the simulation during this initial time period.

Both the terminal service model and the ramp operations model reflected unique situations where the real life activity actually started at an idle state. Therefore, no computer time had to be used in order to reach a steady state. Because of this aspect, the model is computer efficient and data can be collected during the entire simulation. In real life situations, the system is also empty; thus, the simulation began with an empty system in order to mirror the real life situation.

Factorial Design. The next step was to decide on the number of levels and amount of change at each level for the controllable variables that were identified in Chapter 3 (Table 3-3). The variables, number of levels, the variable identifier, and the percentage increase or decrease for each is outlined in Table 4-1.

TABLE 4-1

Variable Levels, Factorial Design

Variable	Levels	Identifier	% Change
Upload Rate	3	UR1	Normal
		UR2	-50%
		UR3	+25%
Weigh Rate	2	WR1	Normal
		WR2	+50%
Inspection Rate	2	IR1	Normal
		IR2	+50%
Load Setup Rate	2	SR1	Normal
		SR2	+50%
Load Transport Rate	2	TR1	Normal
		TR2	+50%
Download Rate	3	DR1	Normal
		DR2	-50%
		DR3	+25%

It was necessary to increase and decrease the upload and download rates since a percentage change in either direction could have an impact on personnel resource utilization (the dependent variable, ARU). It was decided to decrease the value of these two variables by only 50 percent since any further decreases would be unrealistic. The increase of these two variables was held at 25 percent, since any further increase would have caused the service time to exceed the maximum ground time allowed for aircraft during a wartime contingency situation, without allowing any other activities to be accomplished. For instance, a 50 percent increase in the upload rate would have reflected 90 minutes for this activity alone. The 90 minutes, when coupled with the constant service times for the remaining aircraft service activities, would have caused the aircraft ground time to exceed the maximum time prescribed by regulation (2).

Since the initial state of the remaining four controllable variables was already at the minimum, it was necessary to evaluate only one additional level. The additional level was established as a 50 percent increase for each variable.

The outline of the group cells (each possible alternative at the specified level for each factor) for the full factorial experimental design pertaining to the terminal service operations model is depicted in Figure 4-1. Figure 4-2 reflects the outline of the cells to account for all variations of the experimental design for the ramp operations model.

At this point, the experimental design required a minimum of 48 computer runs for terminal service and three (3) for ramp operations to provide a single sample for each cell. However, a single sample for each variation would not be adequate since the design would only be able to detect very large shifts in the parameters and a sizable risk would be assumed when estimating the variability. Therefore, it was necessary to establish a larger sample size for each cell.

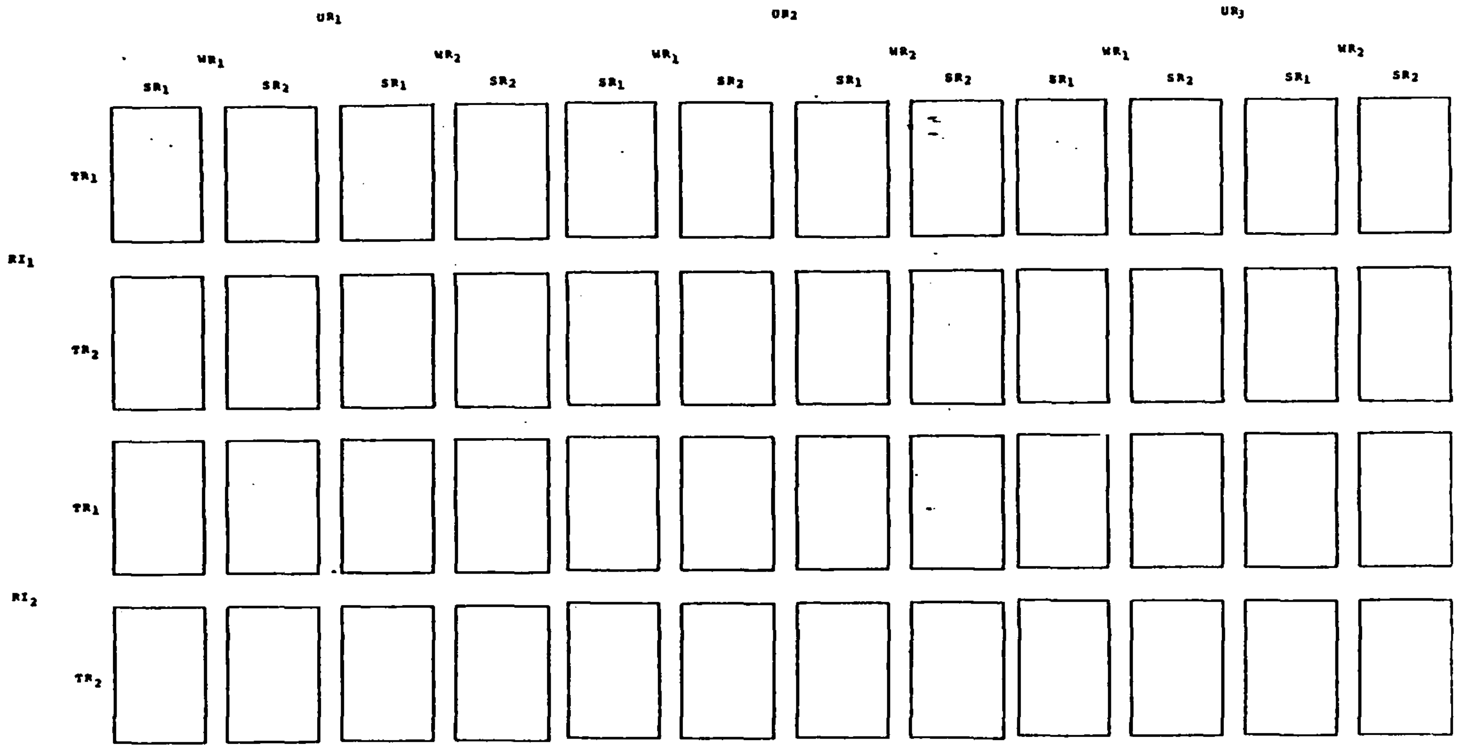

Figure 4-1

Terminal Service Operations, Full Factorial Design

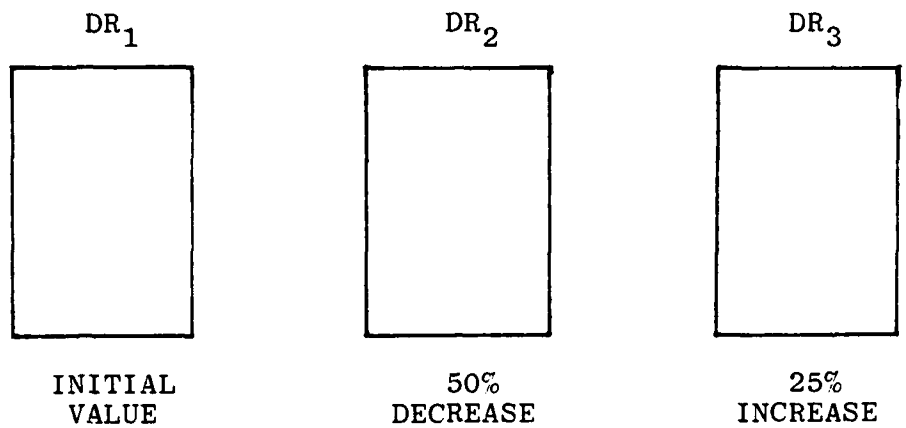

Figure 4-2

Ramp Operations, Full Factorial Design

The sample size can be determined either independently of the operation of the model or during the operation of the model. The authors chose the former approach. Shannon suggests that, as a general rule of thumb, the sample size should reflect no less than ten (10) degrees of freedom for the error term (30:164). Since 48 degrees of freedom (d.f.) are lost through main effects and interactions in the terminal service experimental design, a sample size of five (5) at each variation left at least ten (10) degrees of freedom in the error term. For the ramp operations experimental design, sample sizes of ten (10) at each level met Shannon's rule of thumb.

Statistical Analysis. Once the data points were collected, a SPSS ANOVA test was conducted to determine if differences in the means of the dependent variable were caused by changes in the independent variables. The same test was used to group the means and determine the effect that the changes of the individual independent variables (main effect and interacting) had on the dependent variable. These tests were conducted at the alpha = .01 significance level.

Analysis was then conducted to determine the relationship of all variables to the dependent variable and to establish models which represent the influence of the selected independent variables on the dependent variable. In all cases, the interactions of variables were checked to determine the interaction effect. The null hypothesis (H_o) and alternate hypothesis (H_a):

$$H_o: \quad B_i = 0, \quad \text{for all } B_i$$

$$H_a: \quad \text{At least one } B_i \neq 0$$

$$\text{where } i = 1 \text{ through } k$$

were tested to determine the utility of the overall model. The test statistic was computed using the F statistic supplied by the SPSS computer printout. The researchers failed to accept the null hypothesis if:

$$F > F_{\alpha,k,n-(k+1)}$$

where $F_{\alpha,k,n-(k+1)}$ are values derived from the appropriate F table.

Summary

This chapter focused on the strategic and tactical planning phases of the experimental design. In the strategic planning phase, the emphasis was on designing an experiment that would yield the needed information. The tactical planning phase concentrated on specific techniques to accomplish the experiment and dealt with the efficiency of the experiment. Additionally, the specific techniques of sensitivity analysis and multiple regression were discussed. The next chapter (Chapter 5) contains the results of model sensitivity analysis, while Chapter 6 deals with the formulation of the manpower model.

CHAPTER 5

SENSITIVITY ANALYSIS

Introduction

In previous chapters, the systems under study were defined and models were developed which described the systems. Additionally, the data requirements were identified and computer simulation models developed which accurately portrayed the operations being studied. This chapter provides the analysis of the results of model manipulations to determine the relationship between the dependent variable, average personnel resources used (ARU), and the independent variables which were previously described. Additionally, the sensitivity of the dependent variable to changes in the independent variables will be analyzed.

Sensitivity Analysis--Terminal Services Model

The sensitivity analysis of the terminal service model was undertaken in three steps. First, an analysis of variance (ANOVA) was conducted to determine those variables and/or interactions of variables which had a significant effect on the dependent variable (average personnel resources used). Next, the results of the ANOVA were plotted to determine the effects of interactions found to be significant. Finally, a oneway ANOVA was accomplished with one of the interacting variables held at a constant level to determine if the effect of the other interacting variable caused significant changes in the dependent variable. Table 5-1 reflects the levels of the independent variables studied and the resultant dependent variable group means. Figure 5-1 depicts the interpretation of the tables.

Group Number
Group Mean
Sample Size

Figure 5-1

Interpretation Key for Tables 5-1 and 5-5

ANOVA. An ANOVA test was conducted to determine the significant independent variables and interactions which affected the dependent variable. Five levels of interaction were checked with the results shown in Table 5-2. It was found that all levels of interactions tested had a significant effect on ARU at the alpha = .05 significance level. However, at the alpha = .01 significance level, only a few interactions through the third level were significant. Thus, the researchers included only those significant variables through the three-way interaction level in the proposed model.

TABLE 5-1

Factorial Design Data Table

		UR_1				UR_2				UR_3			
		WR_1		WR_2		WR_1		WR_2		WR_1		WR_2	
		SR_1	SR_2	SR_1	SR_2	SR_1	SR_2	SR_1	SR_2	SR_1	SR_2	SR_1	SR_2
RI_1	TR_1	1 17.332 5	2 17.452 5	[illegible] 17.337 5	4 17.454 5	17 15.657 5	18 15.783 5	19 15.663 5	[illegible] 15.784 5	33 16.304 5	34 16.430 5	35 16.310 5	36 16.432 5
	TR_2	5 17.582 5	6 17.715 5	7 17.595 5	8 17.715 5	21 15.924 5	22 16.035 5	23 15.922 5	24 16.0[illegible] [illegible]	37 16.666 5	38 16.795 5	39 16.677 5	40 16.812 5
RI_2	TR_1	9 17.643 5	10 17.750 5	11 17.643 5	12 17.784 5	25 15.992 5	26 16.116 5	27 16.003 5	28 16.12[illegible] 5	41 18.395 5	42 18.530 5	43 18.41[illegible] 5	44 18.519 5
	TR_2	[illegible] 17.9[illegible] [illegible]	14 18.004 5	[illegible] 17.908 5	16 18.035 5	29 15.766 5	30 16.378 5	31 15.679 5	[illegible] [illegible]	45 18.659 5	46 18.777 5	47 18.66[illegible] 5	48 18.778 [illegible]

TABLE 5-2

Summary of Significant Interaction Levels

Interaction Level	Computed F	Significant (p-value)
Main Effects Only	198.558	Yes (0.00)
2 Way	1807.789	Yes (0.00)
3 Way	1509.480	Yes (0.00)
4 Way	1412.718	No (0.02)

The initial ANOVA tests were screened and reaccomplished to include the levels of interactions selected to determine if any variables or combinations of variables could be excluded from the analysis because they had no significant effect on ARU. Appendix H provides a detailed breakdown of the findings. Table 5-3 summarizes those variables and interactions found to have a significant effect on ARU at the alpha = .01 significance level.

TABLE 5-3

Summary of Significant Variable/Interactions

Variable/Interaction	Computed F	p-Value
UR	380.987	0.00
IR	206.956	0.00
TR	13.783	0.00
SR	6.017	0.01
UR, IR Interaction	2266.088	0.00
UR, TR Interaction	31.321	0.00
IR, TR Interaction	40.465	0.00
UR, IR, TR Interaction	24.024	0.00

The means of ARU at the various levels of the independent variables were plotted to identify relationships which might be of interest to managers controlling the system under study. Figures 5-2 and 5-3 reflect the results of the plots. The left portion of Figure 5-2 represents the relationship of the interaction of the upload rate (UR) and inspection rate (IR). It should be noted that level 1 of UR represents the initial theoretical level, while level 2 is a decrease in the rate and level 3 is an increase in the rate. The relationship reflects that an increase in the upload rate, coupled with an increase in the inspection rate, will cause an increase in the average resources used, while a decrease in both will decrease ARU. The graph on the right hand side of the figure reflects the same for UR and the transport rate (TR). Finally, Figure 5-3 reflects the interaction of the inspection rate (IR) and the transport rate (TR). The relationship shows that as both the inspection and transport rates increase, the average resources used will also increase.

Threeway interactions were not plotted because of the complexity of a three dimensional response surface. It should be noted that questions remain to be answered. For instance, what is the effect of further changes in the independent variables? This question was left for further study because of the limited resources available to researchers.

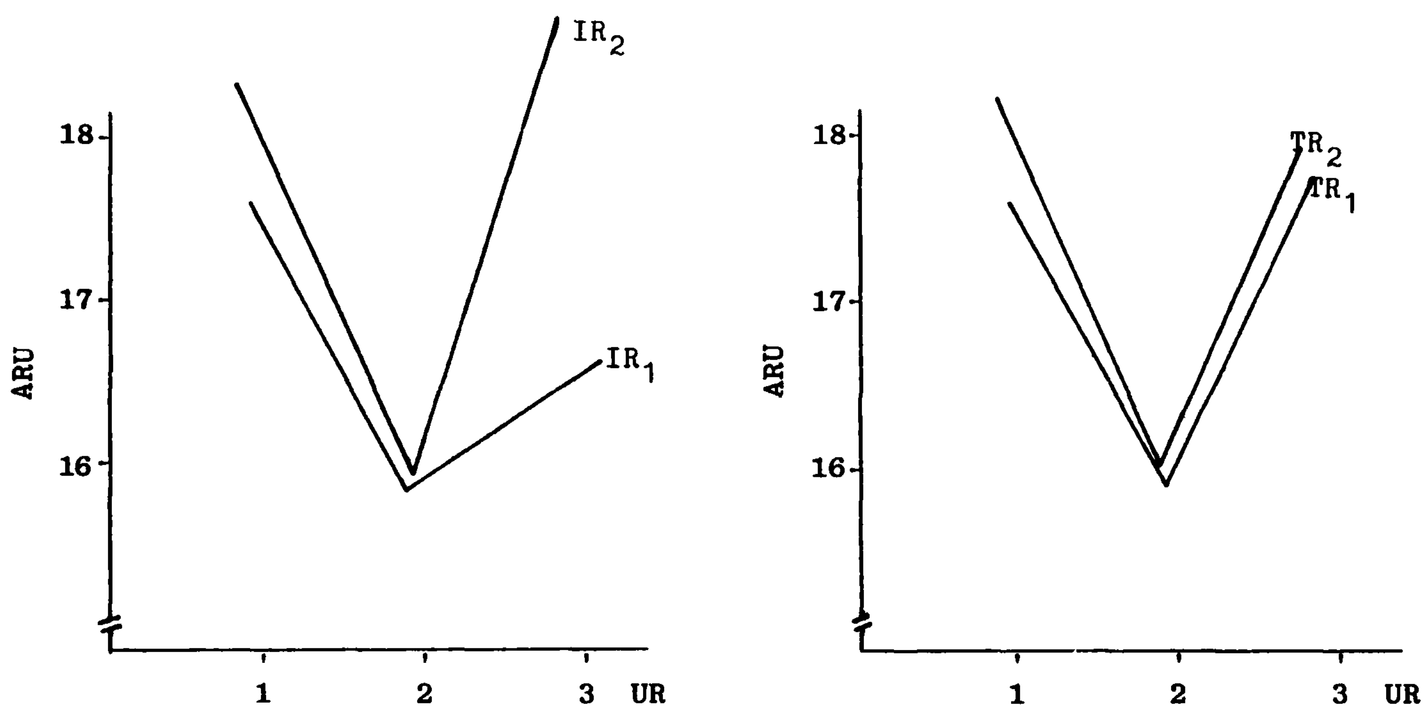

Figure 5-2

Interaction Relationships, UR-IR and UR-TR

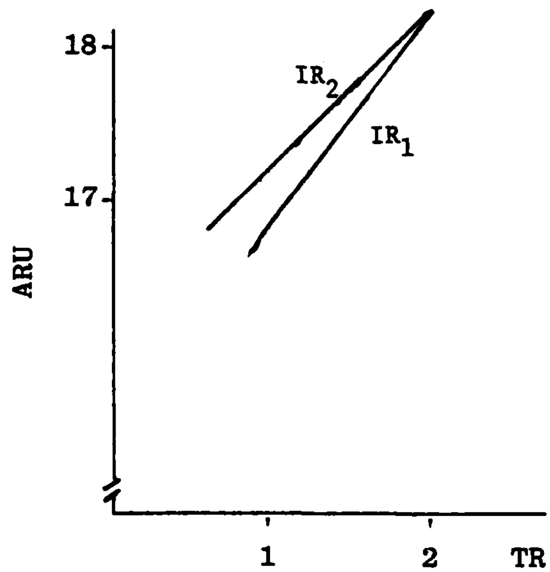

Figure 5-3

Interaction Relationship, TR-IR

Oneway ANOVA. A oneway analysis of variance and Duncan's Multiple Range test were conducted to determine the statistical significance (alpha = .05) of the interactions on the dependent variable while keeping one of the independent variables constant. Table 5-4 summarizes the significant results of those tests of interactions given that one variable was held constant while the other was allowed to vary. Relating the results to Figures 5-2 and 5-3, one can see how the interpretation of the graphs were statistically validated. Additionally, Duncan's Multiple Range Analysis showed that a decrease in the upload rate resulted in a decrease in ARU, while an increase resulted in an increase in ARU.

TABLE 5-4

Summary of Significant Interactions

Constant Level	Interacting Variable	F	Significance of Change
UR1	IR	76.296	0.0000
UR2	IR	14.192	0.0003
UR3	IR	2392.681	0.0000
UR1	TR	40.112	0.0000
IR1	TR	5.420	0.0216

Sensitivity Analysis--Ramp Operations Model

The sensitivity analysis of the ramp operations model variables was undertaken in two steps. First, a oneway ANOVA was conducted to determine the significance of the effect of various levels of the independent variable, download rate (DR), on the dependent variable, average personnel resources used (ARU). Table 5-5 reflects the group means of ARU at the various levels of DR. A oneway ANOVA was an appropriate first test since there were no interactions to consider. It was found that the variable DR affected ARU significantly since the computed F equaled 45863.41 with a p-value of 0.00. The group means are plotted in Figure 5-4 to graphically illustrate the effects of the download rate on average resource utilization.

From a management viewpoint, it can be concluded that control over the download rate can greatly affect the average personnel resources required as might be assumed by the

TABLE 5-5

Factorial Design Data Table, Ramp Operations

DR_1	DR_2	DR_3
1	2	3
8.098	4.112	10.139
10	10	10
INITIAL VALUE	50% DECREASE	25% INCREASE

practitioner. A Duncan's Multiple Range test at the alpha = .05 significance level verified this and indicated that management should attempt to reduce the aircraft download rate in order to reduce manpower requirements.

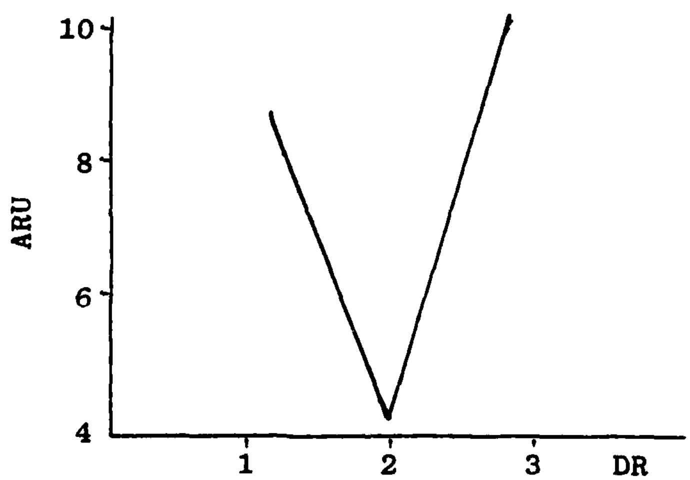

Figure 5-4

Variable Effects, Ramp Operations

Summary

This chapter analyzed the terminal services model to determine the sensitivity of the dependent variable (average personnel resources used) to changes in the five independent variables. Additionally, the ramp operations model was analyzed to determine the sensitivity of ARU to changes in the download rate. Next, ANOVA tests were used to determine the significance of the independent variables and, in the case of the terminal services model, to determine significant variable interactions which affected the average personnel resources used. Finally, relationships of the variables were analyzed from the management viewpoint and proven through statistical testing.

Next, the simulation models were used to prepare new data for use in regression analysis. This technique, used to prepare and justify the manpower predictor models, is fully discussed in Chapter 6.

CHAPTER 6

MANPOWER MODEL DEVELOPMENT

Introduction

In previous chapters, simulation models were designed, validated, analyzed, and ANOVA tests were used to determine significant relationships between the dependent variable and the independent variables. This chapter describes how the simulation models were used to provide data so that the form of the manpower models might be hypothesized and validated.

The prime tools for the development of the final manpower models were the multiple regression analysis program that was available on the SPSS package and AFIT's MULREG (MULtiple REGression) package. The building of a model through the use of regression techniques is a six step process. The process includes: (1) hypothesize the model form; (2) develop data; (3) estimate model parameters; (4) check for model utility and abnormalities; (5) estimate the random error component (E) of the final model; and (6) test the model selected. Since the development of each model required different degrees of analysis, each is discussed separately.

Terminal Services Manpower Model

Initial Model Selection. Based on the statistical tests conducted and the conclusions drawn by the researchers, the variables and interactions reflected in Table 5-5 of the previous chapter were selected for initial inclusion in the hypothesized manpower predictor model. Additionally, the variable, missions requiring concurrent servicing (MRCS), was added to the hypothesized model since it was used to vary the degree of workload intensity. The question at this point concerned the level of the model to be considered. For example, should the initial model be a Pth order polynomial plus interactions taking the form:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_1X_2 + B_4X_1^2 + \dots + B_{i-1}X_{k-1}^{p-1} + B_iX_k^p \quad ,$$

or should the model be a linear model of the form:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_1X_2$$

To answer this question, scattergrams were constructed to determine the shape of the model's response surfaces. McClave and Benson noted that a linear model has a straight line response surface while a higher order polynomial will contain curvature (18:380-387). Since all but one scattergram appeared to reflect a curved response surface, a second order polynomial was determined to be the logical starting point for the model development. It was noted, however, that the scattergram comparing MRCS with ARU showed a linear

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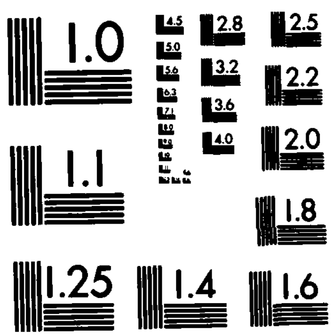

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

relationship; therefore, MRCS was evaluated at the first order. As stated in Chapter 4, multiple regression techniques were used to develop the final model. Thus, the proposed manpower predictor model took the initial form:

$$\begin{aligned} ARU = {} & B_0 + B_1UR + B_2IR + B_3TR + B_4SR + B_5(UR)(IR) \\ & + B_6(UR)(TR) + B_7(IR)(TR) + B_8(UR)(IR)(TR) \\ & + B_9UR^2 + B_{10}IR^2 + B_{11}TR^2 + B_{12}SR^2 + B_{13}MRCS + E \end{aligned}$$

where,

B_0 = Y intercept of the line

B_i = coefficients of the respective variables or interactions which must be estimated

E = random error component

Data Development. Before the model could be developed, the data had to be gathered in an appropriate sample size, which the researchers determined using Tchebycheff's theorem. The theorem says that if the researchers are unwilling to assume normality of the dependent variable output, then the sample size may be computed based on the Central Limit Theorem, the desired alpha level, and the desired size of the confidence interval about the dependent variable mean value (30:189-190). The researchers used an alpha equal to .05 and arbitrarily selected $\sigma/4$ as the desired width of the confidence interval about the dependent variable mean. These values were chosen to insure sufficient computer resources were available for data preparation.

Based on the values selected, Shannon shows that 320 data points would be the required sample size (30:190).

The data samples were prepared using the terminal service simulation model previously developed and validated. Simulation model parameters were allowed to vary subject to the total aircraft ground time constraints. The number of missions requiring concurrent servicing (MRCS) and the aircraft interarrival time parameters were also varied to insure the data covered a wide range of workload intensity. Specifically, MRCS was varied from level one (one mission/ scheduled ground time) to ten (ten missions/scheduled ground time), and 32 samples were drawn at each level to provide the required 320 data points.

<u>Model Parameter Estimation</u>. The SPSS multiple regression package available on the AFIT Harris computer system was used to make the initial parameter estimates shown in Table 6-1. If a variable was not included in the table, SPSS reflected that the B_i for the variable had a value approximately equal to zero and, therefore, the variable was not useful in the developed model. Based on the multiple regression techniques, the model form changed to:

$$ARU = B_0 + B_1 MRCS + B_2 IR + B_3 SR^2 + B_4 TR + B_5 UR + B_6 (UR)(TR) + E$$

with the B_i's having the values found in Table 6-1.

TABLE 6-1

Terminal Service Manpower Model Estimates

Variable	B_i	Estimate of B_i
MRCS	1	3.3488
IR	2	-265.3267
SR^2	3	4.0147
TR	4	-949.0579
UR	5	-167.4501
(UR)(TR)	6	673.3414
Constant	0	306.7394

Test for Utility and Abnormalities. A test of model utility is the determination of the usefulness of the model as a predictor of the dependent variable. A test for abnormalities is an analysis of results to determine if the model is accurate and a determination of the circumstances under which a prediction may be made.

In testing for model utility, the researchers tested the null (H_o) and alternate (H_a) hypothesis:

$$H_o\text{:}\quad B_1 = B_2 = B_3 \ldots = B_i = 0$$

$$H_a\text{:}\quad \text{At least one } B_i \neq 0$$

The test value, $F_{computed}$, was determined by the SPSS package and was compared to the appropriate tabular F or $F_{critical}$. The researchers would reject the null hypothesis and conclude that the model was useful if $F_{computed} > F_{critical}$ (20:408). The utility of the initial model was analyzed using $F_{critical}$ = 2.21 (a=.05; k=6, n-(k+1)=313 degrees of freedom) and $F_{computed}$ = 4561.0789. Since the computed F was greater than the critical F, the researchers failed to accept the null hypothesis and concluded that the model had utility at an alpha = .05 significance level. The regression analysis was reaccomplished using various levels of MRCS and the technique of forcing the independent variables not previously selected into the model. Table 6-2 is a comparison of selected results from the analysis. The first model developed continued to achieve the lowest Mean Square Error (MSE), the highest values for the coefficient of determination (R^2) and the adjusted R^2, as well as the highest computed F. Since all models tested would have been accepted as having utility, the MSE, R^2, and adjusted R^2 became the important statistics for final model selection.

TABLE 6-2

Summary of Selected Terminal Service Manpower Models Tested

Model	MSE	R^2	Adj. R^2	F Computed	F Critical
MRCS, IR, SR^2, TR, UR, (UR)(TR)	.8113	.993	.993	4561.0789	2.21
MRCS, IR^2, SR^2, TR^2, UR^2, (UR)(TR)	.8566	.993	.992	4088.1771	2.21
MRCS, IR, SR, TR, UR, (UR)(TR)	.8558	.992	.992	4095.2272	2.21

The MSE is important because it reflects the estimated variance (σ^2) for the model which the researchers should minimize. The R^2 is a measure of the degree of fit between the model and the data analyzed. For example, $R^2 = 0$ would reflect a complete lack of model fit, while $R^2 = 1$ would show a perfect fit; thus, the higher the R^2, the better the model fit (18:342-350). Since the first model tested achieved the smallest variance and the best R^2 values ($R^2 = 0.993$), which indicated an almost perfect fit, the first model developed was selected as the manpower predictor model.

A model could have any of four abnormalities which could affect its power of prediction. There could be (1) an insufficient number of data point, (2) multicollinearity, (3) a narrow prediction window, or (4) autocorrelation errors (18:417-420). A review of the selected model results found no evident abnormalities. The sample size was large enough to insure that enough data points were available for analysis. Next, an analysis of correlation coefficients for twoway interactions did not reflect any correlated independent variables and predictions were projected to be accurate if MRCS was less than ten (10). The possibility of autocorrelation was dismissed since time series data was not used. Thus, the researchers concluded that the model was useful in predicting values for the dependent variable (ARU) within the appropriate prediction window. The final selected model took the form:

$$ARU = B_0 + B_1MRCS + B_2IR + B_3SR^2 + B_4TR + B_5UR + B_6(UR)(TR) + E$$

with the estimated parameters for the B_i's as shown in Table 6-1.

<u>Random Error Component Evaluation</u>. After selection of the model, a number of assumptions concerning the model's random error component (E) were evaluated. The data used to evaluate the component were those residual values left during the "fit" of the regression model. Regression assumes that the error component is normally distributed with a mean of zero and a constant variance. To test the assumptions, the Kolmogrov-Smirnov Goodness of Fit Test (K-S Test) was used. The test showed that the residuals formed were normally distributed about a mean of zero and a standard deviation of 0.996. The researchers then concluded that the model met the appropriate error term assumptions.

<u>Model Acceptance</u>. The test of model utility and search for model abnormalities indicated that the model was a good predictor of the dependent variable. A review of the random error component found that the assumptions necessary to use regression were met. Therefore, the model was accepted as the appropriate manpower predictor model. The final form of the model accepted was:

$$ARU = 306.7394 + 3.3488(MRCS) - 265.3267(IR) + 4.0147(SR^2) - 949.0579(TR) - 167.4501(UR) + 673.3414(UR)(TR)$$

It should be noted, however, that the model is only good over a limited range of the independent variables, a point discussed later in this chapter. Additionally, the model predicts the aggregate manpower requirements to support a 12 hour shift; thus, model results must be doubled to determine the requirements per day. Finally, a single point prediction is not recommended. Instead, it is suggested that users compute a prediction interval for the desired alpha level, a technique also elaborated on later in the thesis.

Ramp Operations Manpower Model

The development of the ramp operations manpower model followed the same steps that were used for the terminal service manpcwer model. Tchebycheff's Theorem was again used to determine the required sample size; however, a confidence interval of $\sigma/2$ with an alpha level of .05 was selected. This reduced the required sample size for this model to 80. The ramp operations simulation model was used to prepare data for the regression analysis. Samples were drawn which represented five levels of workload intensity (MRCS = 1 to 5) at a wide range of service parameters subject only to the simulation ground time constraints.

Initial parameter estimation was accomplished using the following model which was hypothesized by using the data that was developed in the previous chapter and the variable MRCS:

$$ARU = B_0 + B_1 DR + B_2 MRCS$$

Results of the regression and model "fit" are shown in Table 6-3.

TABLE 6-3

Ramp Operations Model Test Data

Model	MSE	R^2	Adj R^2	F Computed	F Critical
$ARU=B_0+B_1DR+B_2MRCS$	.129	.989	.988	8421.5	3.92

The model,

$$ARU = B_0 + B_1DR + B_2MRCS$$

had a computed F (8421.5271) that was greater than the tabular F (3.92) which indicated that the model had utility and was, therefore, a good predictor of the dependent variable.

The next steps were to check for abnormalities and analyze the random error term. A review of available data found no problems; however, the prediction window includes only those values of MRCS which are less than or equal to 5. A K-S test was used to determine the characteristics of the random error component. Again, the residuals were found to approximate a normal population with a mean equal to zero at the alpha = .05 significance level.

The final model form, then, is:

$$ARU = -3.5066 + 2.336(MRCS) + 2.392(DR)$$

This model is also subject to constraints as was the terminal service model. First, prediction intervals should be formed in lieu of point predictions. Next, the prediction window should not exceed an MRCS > 5. Finally, the model is a predictor by shift; thus, values obtained must be doubled to determine manpower requirements per day.

Manpower Model Analysis

The manpower models developed were analyzed to determine their accuracy and the individual ranges within which the models were accurate. The accuracy was determined through the construction of prediction intervals and the comparison of the intervals to the appropriate UTC sizings developed by the Military Airlift Command. Individual variable ranges were developed so that the user could insure that the data to be evaluated was within the predictive capability of the model.

Predictive Capability. Table 6-4 compares the manpower model predictions to the unit sizing made by the MAC developed UTCs for the terminal services manpower model. It is apparent that at low levels of MRCS (1 to 3) the predictions are relatively close to the manning figures obtained from appropriate UTCs. However, it can be seen that at an MRCS greater than three, the terminal service manpower model generates predictions much lower than the UTCs. An analysis of the differences found that the simulation model kept areas (not specifically modelled) other than inspection, setup, and load teams at a constant value, while the UTCs

TABLE 6-4

Terminal Service Model Prediction Comparisons

MRCS	UTC Requirement per Shift	Manpower Model Prediction per Shift
1	12[a]	14.3913 - 17.7321
2	20[b]	17.7442 - 21.0768
3	28[c]	21.3634 - 24.1551
4	36[d]	24.7140 - 27.5021
5	48	28.0637 - 30.8498
6	56	31.4127 - 34.1985
7	64	34.7607 - 37.5479
8	72	38.1080 - 40.8982
9	81	41.4544 - 44.2493

[a]Includes UTCs UFBJA(3), UFBBR(5), UFBMA(3), UFBQ1(1)

[b]Includes UTCs UFBJA(3), UFBBS(10), UFBMC(4), UFBQ3(3)

[c]Includes UTCs UFBJA(3), UFBBT(15), UFBMB(6), UFBQ4(4)

[d]Includes UTCs UFBJA(3), UFBBU(20), UFBMD(8), UFBQ5(5)

appeared to gradually increase the size of these functions. The same problem was observed in an analysis of the ramp operations manpower model predictions (Table 6-5). However, in this case, all areas were considered and modelled; therefore, it was determined that service rates may not be appropriate for the model developed or there were insufficient data points considered. The authors concluded that the predictive ability of the ramp operations model was suspect.

TABLE 6-5

Ramp Operations Model Prediction Comparisons

MRCS	UTC Requirement per Shift	Manpower Model Prediction per Shift
1	5	3.015 ± 0.254
2	10	5.351 ± 0.254
3	15	7.689 ± 0.254
4	20	8.665 ± 0.254

Further analysis was conducted in order to account for the apparent underpredictions of the research model at higher levels of MRCS. The research models developed predictions for each higher level of MRCS independent of previous, lower level MRCS predictions. On the other hand, MAC UTCs are developed based on a building block approach. For example, to determine the UTC requirement for an MRCS of 5, the UTC requirement for an MRCS of 4 would be added to a UTC requirement for an MRCS of 1. When the MAC building block concept was used in conjunction with the terminal service research model, the model manpower predictions were much closer to the MAC UTCs for all levels of MRCS. To illustrate the finding, comparative results for the terminal service model are displayed in Table 6-6. As shown in Table 6-6, the research model manpower predictions were close to the UTC requirements and it was concluded that the manpower models were accurate if a building block approach was used.

TABLE 6-6

Terminal Service Manpower Model
Prediction Comparison (Building Block Approach)

MRCS	UTC Requirement per Shift	Manpower Model Prediction per Shift
1	12	14.39 - 17.73
2	20	17.74 - 21.08
3	28	21.36 - 24.16
4	36	35.75 - 41.89
5	48	50.14 - 59.62
6	56	53.49 - 62.97
7	64	57.11 - 66.05
8	72	71.50 - 83.78
9	81	85.89 - 101.51

It should be noted that accuracy of the research models was measured against MAC UTCs which were assumed to be accurate. The research models underpredicted when compared to MAC UTC manpower requirements at higher levels of MRCS. It was shown that model prediction accuracy could be forced by using a building block approach rather than independent prediction at each level of MRCS. However, this procedure raises an important question and gets at the main contribution of our research. It may be that the building block approach is inappropriate--that adding UTCs together to obtain higher UTC requirements for higher levels of MRCS overstates the actual manpower required. For example, if 36 personnel are required for an MRCS of 4, somewhat less than 12 additional personnel (that amount required for an MRCS of 1) are required for an MRCS of 5. The research model answers the question, how many personnel are required for an MRCS of 5, independently of how many personnel are required for a MRCS of 4 or 1 and, thus, may better reflect the actual relationships.

Range Analysis. Table 6-7 reflects the means and standard deviations for the individual ranges of the independent variables for which the models are accurate. If during predictions of requirements, data is used in which the mean of the data falls outside the ranges shown, the means reflected should not be used as data may be outside the model prediction window. If the data is within the prediction window, then the following simplified models may be used:

Terminal Services

$$ARU = 13.0536 + 3.3488(MRCS)$$

Ramp Operations

$$ARU = 0.679 + 2.336(MRCS)$$

TABLE 6-7

Summary of Terminal Service Model Activity Service Time Ranges

Activity	Service Time (% hr/min) Mean	Standard Dev.
Cargo Inspection	.2354/14.12	.0022/0.132
Transport Load	.2549/15.29	.0132/0.792
Upload Aircraft	1.4695/88.17	.1236/7.416
Setup Load	1.1597/69.58	.0458/2.740
(UR)(TR) Interaction	.3774/NA	NA

In the case of each model, the constant was computed by performing the mathematical computations required in the expanded model (not to include MRCS). The prediction intervals for the ramp operations model were computed as follows:

$$ARU \pm 0.254, \text{ where } 0.254 = t_{\alpha/2},\ n-2 \quad (MSE)$$

The development of intervals for the terminal service model was more complex and involved vector mathematics. Therefore, the authors used MULREG (MULtiple REGression) which was available on the AFIT computer systems to develop the intervals. Table 6-4 reflects the results.

Summary

Manpower predictor models were developed which, under some circumstances, reflected manpower requirements as specified in current UTCs. The terminal service model was found to be appropriate only within specified ranges as shown in Table 6-7. Further, the terminal service model predictions appeared to be useful over a wide range of workload intensity if the building block approach was used. However, the ramp operations model did not appear to provide adequate predictions, when compared to existing UTCs, at any given workload level. Consolidated models were provided, but the user must insure that the data evaluated falls within the appropriate prediction window. A full discussion of conclusions and recommendations for further research are provided in the next chapter.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Two simulation and associated manpower models were developed, analyzed, and validated in an attempt to build quantitative models with the power to predict manpower requirements for contingency situations. This chapter reviews the results, in terms of the research objectives and questions, which enabled the authors to draw conclusions concerning the research problem.

Specific objectives set forth in Chapter 1 include:

1. The accurate depiction of the functional relationships of selected variables used in the terminal service and ramp operations quantitative models.

2. The development of parameter ranges which define the environment applicable to the prediction models.

3. The use of models to predict manpower requirements for mobile aerial ports engaged in contingency operations.

4. The comparison of model predictions to current UTC requirements as a means of measuring the effectiveness of the research models.

Two research questions were designed to guide the research effort toward achievement of the objectives:

1. Can valid simulation models be developed which accurately represent MAP operations?

2. Can the simulation models be used to provide theoretical data for use in the development of manpower predictor models?

The research objectives and associated questions were designed as a means to the solution of the overall problem identified in Chapter 1. Research conclusions and recommendations for further study are discussed in the following sections.

Conclusions

The conclusions concerned three areas: the validity of the simulation models, the sensitivity of the selected dependent variable to changes in the independent variables, and the form and effectiveness of the manpower predictor models. First, the researchers concluded, and received verification from HQ MAC, that the simulation models accurately reflected anticipated contingency operations. However, the simulation models did not account for all functions, and, in fact, generalized about the resources needed to accomplish some of the functions performed. It was concluded that the generalizations probably detracted from the accuracy of the simulation models. Next, the authors concluded that the simulation models could be useful as a tool in providing data. However, it was found that a separate FORTRAN conversion program was necessary to speed up the simulation programs and put the data generated into a useful form. A standard conversion program was not provided in this thesis because the FORTRAN program structure depends on the tests to be accomplished.

Conclusions concerning the effect of the independent variables on the dependent variable were developed through the use of sensitivity analysis. The authors found that changes to a number of independent variables and interactions caused significant changes to the mean value of the average resources used (dependent variable). Additionally, it was found that other variables and interactions were insignificant and were therefore eliminated from further consideration in later modelling efforts. Specifically, it was found that the upload, inspection, setup, and transport rates significantly affected the average resources used. The authors were able to analyze interactions between the significant variables and found that control over the upload rate would provide more control over average resource requirements than would controlling any other significant variable.

Finally, it was concluded that the manpower predictor models could be developed from the data provided by the simulation models. However, the authors also concluded that the manpower models were not entirely accurate and that a building block approach, which added prediction intervals, was necessary to achieve a semblance of accuracy in the terminal service model. On the other hand, the accuracy of the ramp operations model was suspect and the model was not usable in its current form. The authors concluded that the deficiencies in the models may lie either in the service rates used for the activities modelled, in the generalizations made about some of the functional areas contributing to the average resources used, or in the validity of the building block concept. Either of the first two problems mentioned affect the data that was generated and, ultimately, the predictive capabilities of the manpower models. The latter problem suggests that the research models are accurate relative to the actual UTCs. In any case, the authors concluded that the terminal service model:

$$ARU = 13.0536 + 3.3488\ (MRCS)$$

is usable under the conditions already discussed in this and previous chapters. Since a reasonably accurate model was developed, it must be concluded that quantitative models could support the estimates of experts in the development of mobile aerial port Unit Type Codes. However, since the authors only achieved limited success and made a significant assumption concerning the current UTCs, recommendations for further research were developed to guide other researchers.

Recommendations for Further Research

The recommendations for further research also cover the areas of simulation models, sensitivity analysis and the development of the manpower models. First, in dealing with the simulation models, the authors recommend that exercises be studied and appropriate samples of service rates taken in order to develop accurate probability density functions. This action could increase the accuracy and effectiveness of the simulation models. The authors also recommend that the scope of the simulation models be expanded to include all activities and functions encountered in contingency mobile aerial port operations which contribute to the average manpower resources used. This action would enable total manpower requirements to be developed through simulated conditions and eliminate the generalizations currently made about some functional areas. Additionally, the authors recommend that the manpower resources be broken out in the simulation models by Air Force Specialty Code and skill level. These actions could enhance the predictive capability and effectiveness of the simulation models.

Sensitivity analysis also contributed to recommendations for further research. First, the authors recommend the study of additional variables. While significant relationships were found and analyzed, other variables which were not considered could also have a significant impact on the dependent variable. Additionally, the authors recommend that the sensitivity analysis be conducted over a wider range of changes to the independent variables. This would enable the researchers to fully develop the effect of interactions on the dependent variable and lead to a much fuller understanding of the system. The enhanced sensitivity analysis could also pinpoint other variables which could enhance the predictive power of the manpower models.

Finally, recommendations are established concerning the manpower predictor models. Once the simulation models are fully developed and data tables reaccomplished, regression analysis should be reaccomplished and new manpower models developed. Additionally, it is recommended that the current differences between the predictions and UTCs be explored to determine if the current deviations can be attributed to activities not included in the models, but which are included in the UTCs, or to the accuracy of the UTCs developed through the building block approach. The study of actual contingencies or exercises, recommended for data gathering, would serve as a test to study the deviations between model and actual UTC manpower requirements. Finally, the use of regression techniques may be beneficial if applied to equipment requirements using the same techniques applied in this thesis. This final recommendation, along with the aforementioned recommendations, could enhance the accuracy, effectiveness, and credibility of the Air Transportation warplanner's efforts.

Summary

In conclusion, simulation models were developed, validated, and used to prepare the theoretical data needed to accomplish sensitivity analysis and regression analysis.

Manpower predictor models were also developed, but were found to be of limited accuracy and only effective under specified conditions. It has been shown, however, that if the recommendations for further research are enacted, quantitative models can be developed which could reduce the guess-work in the Air Transportation warplanning effort and provide for a quantitative means of developing mobile aerial port Unit Type Codes.

APPENDIX A

DEFINITIONS

ANOVA - Analysis of Variance. A procedure for comparing two or more population means.

BALK - A queuing theory term that refers to a user or transaction leaving the system when a line or server is at maximum capacity.

BLOCK - Idle server condition caused when a transaction cannot be routed to a queue from a preceding server activity.

CHI-SQUARE TEST (X^2) - Statistical test to determine the characteristics of a sample distribution.

CONSTANT INDEPENDENT VARIABLE - Any independent variable that is held at a steady value throughout the experimental process.

CONTROLLED INDEPENDENT VARIABLE - An independent variable that can be precisely manipulated so that the reaction to the dependent variable can be measured as a result of the change.

DEPENDENT VARIABLE - The variable that reacts to changes in the independent variable(s). May also be referred to as an output variable.

FACTORIAL DESIGN - An experimental design to test all possible variations of two or more independent variables when only one variable is changed at a time, while holding the other(s) constant, until all possible combinations of variables have been tested.

FORWARD (STEPWISE) REGRESSION - A multiple regression screening technique where independent variables are included in the multiple regression model only after meeting pre-established statistical criteria.

INDEPENDENT VARIABLE - The variable(s) that, when changed, will cause a change to the dependent variable. May also be referred to as an input variable or predictor variable (see controlled independent variable and constant independent variable).

JOPS - Joint Operations Planning System. A system that defines operational/contingency planning requirements, concepts, and procedures.

MANFOR - Manpower Force Package. Manpower packages that identify requirements which meet specific capabilities.

MOBILE AERIAL PORT - A highly mobile and flexible unit which is capable of rapid deployment to support air cargo/ passenger handling requirements.

MODEL NETWORK - The system of nodes and branches which represent (simulate) the flow of transactions that approximate the real-life system that is being modelled.

MULTIPLE REGRESSION - A predictive device used to model two or more independent variables and the interactions of those variables as a function of a dependent variable. The analysis includes the fitting of the model (see forward stepwise regression), the testing of the model, and then the use of the model to predict the dependent variable based on varying values of the independent variable.

OPLAN - Operation Plan In Complete Format. A specific plan that discusses unit responsibilities and procedures for a particular exercise or contingency operation.

Q-GERT - Acronym for Graphical Evaluation and Review Technique. The Q is added to indicate the queuing theory application. The package is designed to be a network modelling tool for computer simulation and analysis.

SENSITIVITY ANALYSIS - The act of systematically varying selected independent variable(s) in order to measure the effect that the change has on a dependent variable.

SIMPLE REGRESSION - A predictive model that demonstrates the linear relationship of a dependent variable as a function of a single independent variable.

SIMULATION - A representation of the operation or design of a complex process or system in order to experiment with and better understand the behavior of the system.

STRATEGIC AERIAL PORT - A permanent (fixed) unit, squadron, or operating location designed to meet the day-to-day air cargo handling requirements of the unit to which it is attached.

TRIANGULAR DISTRIBUTION - A distribution that has three specified values: minimum, maximum, and mode. The density function is composed of two linear parts with one extending from the minimum to the mode and the other from the mode to the maximum. The X axis forms the basis of the triangle.

APPENDIX B

STRUCTURAL MODELS

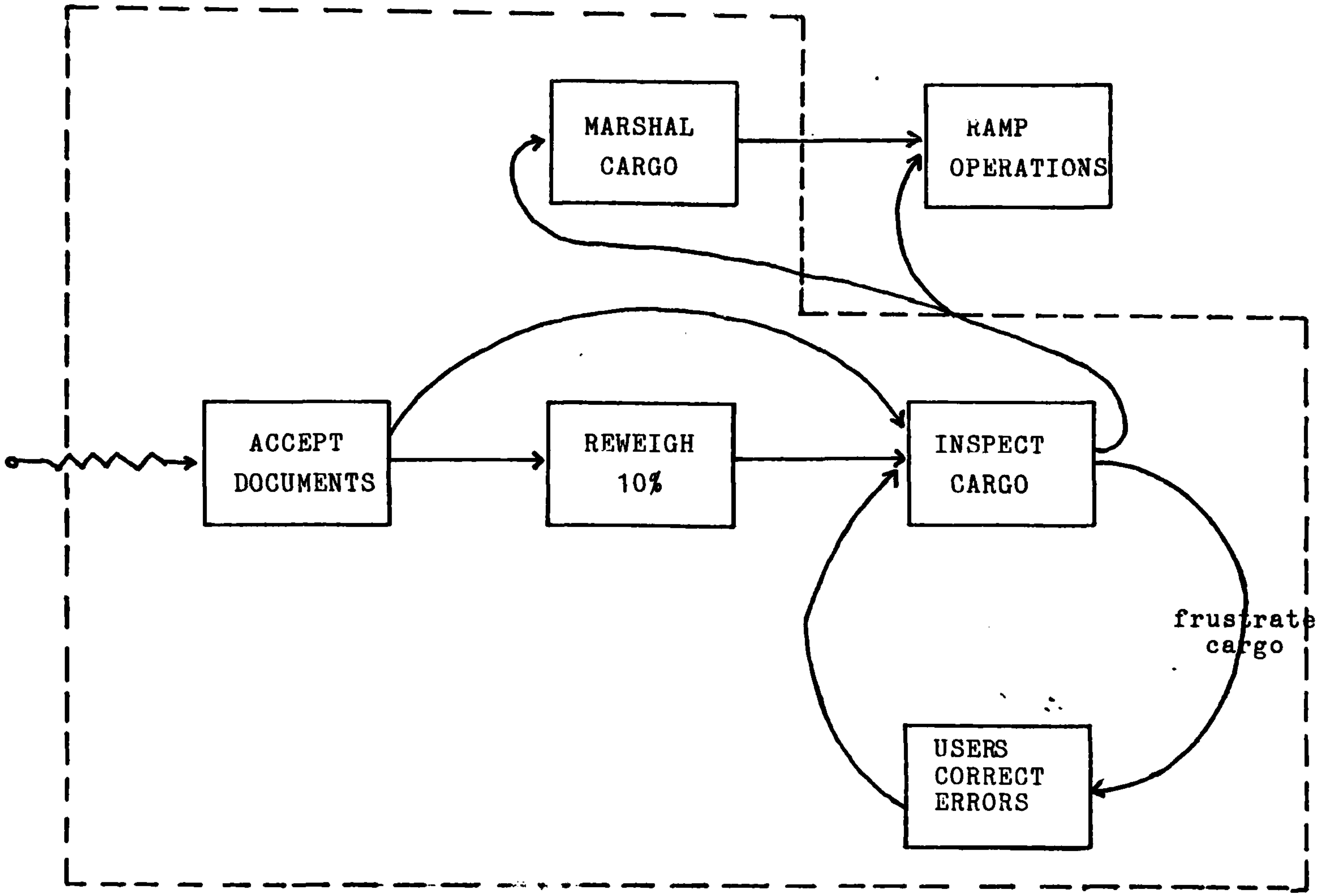


Figure B-1

Terminal Service Checkpoint Operations

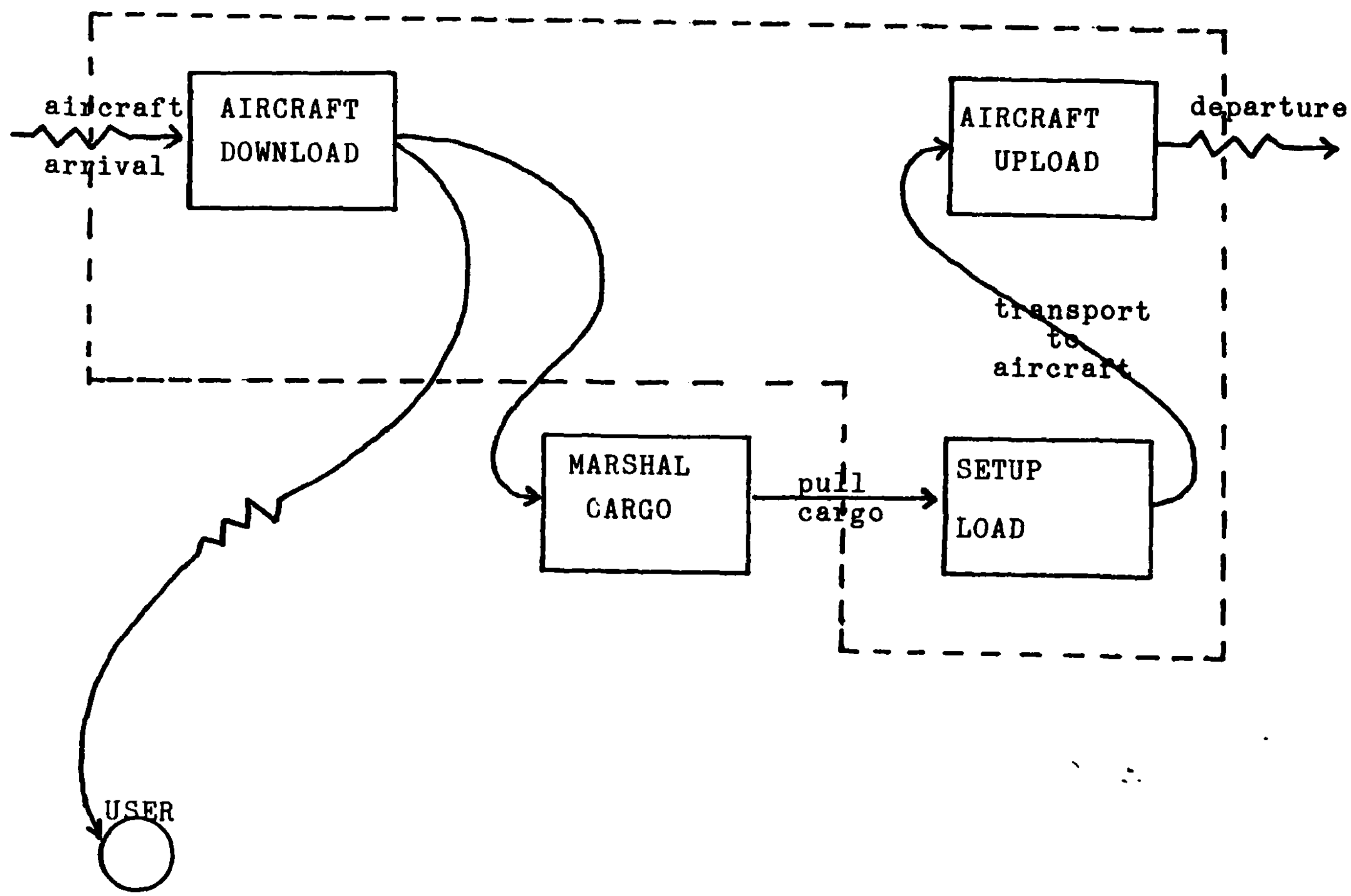


Figure B-2

Terminal Service Ramp Operations

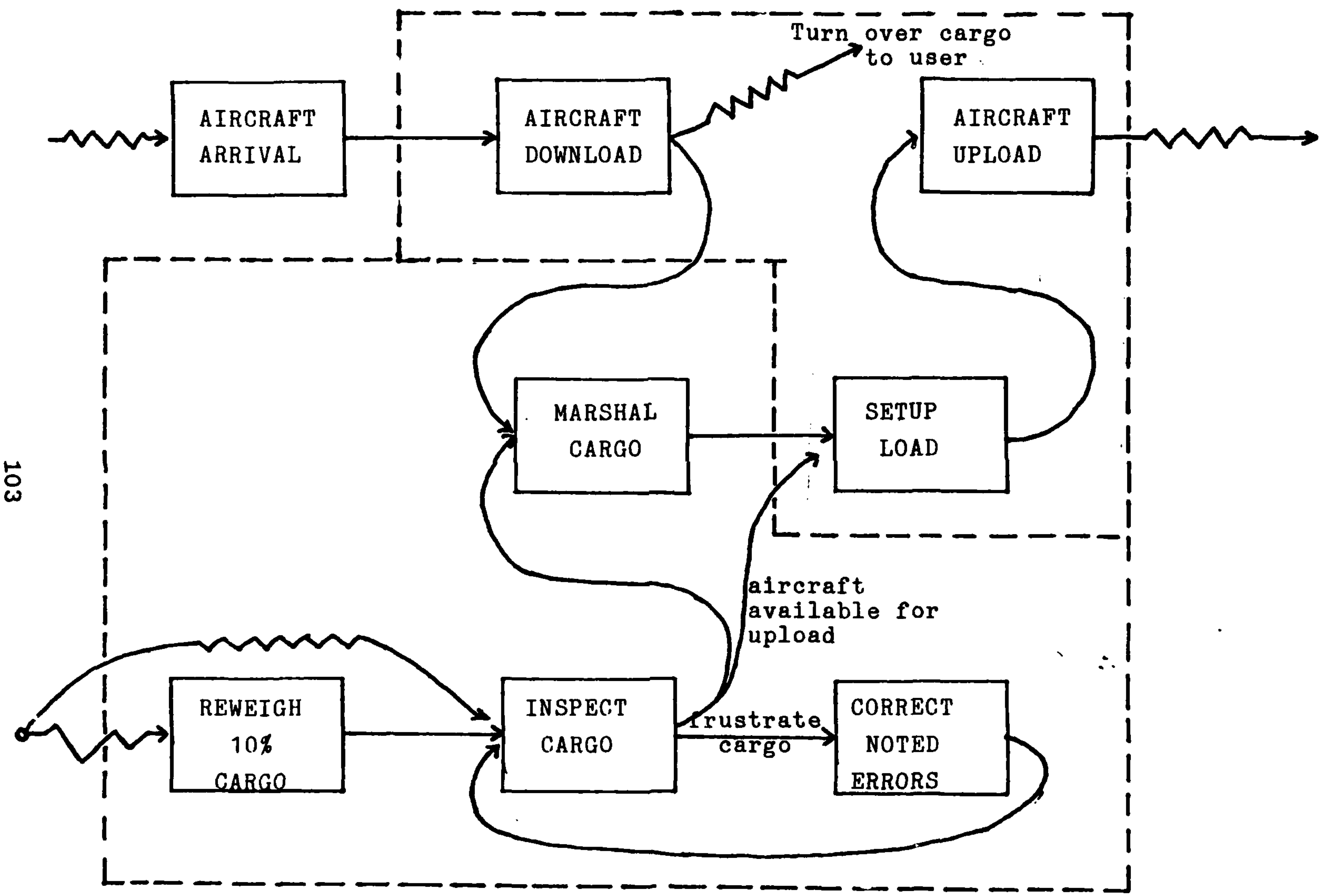


Figure B-3

Terminal Service Cargo Flow

APPENDIX C

Q-GERT NETWORKS

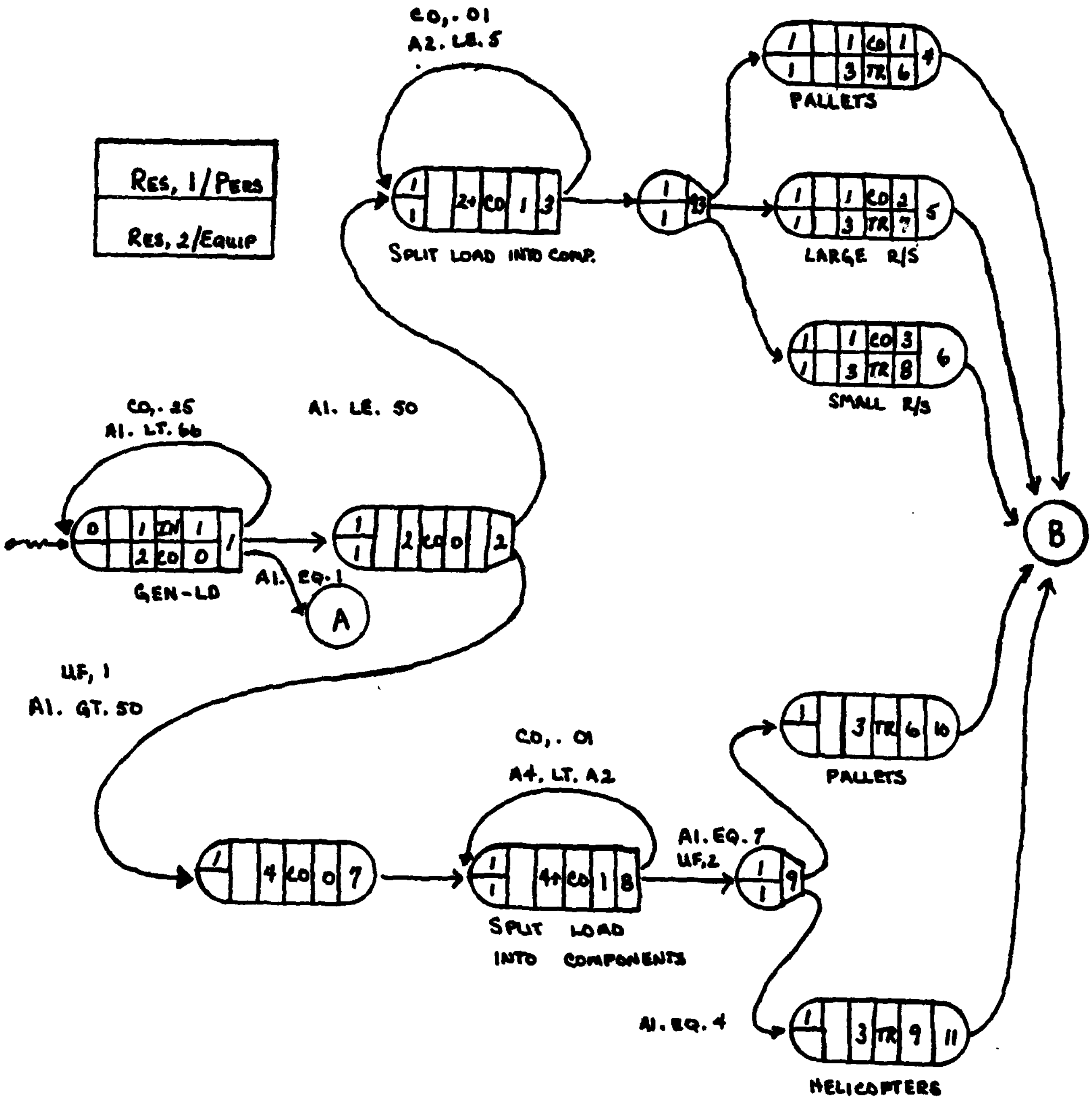


Figure C-1

Cargo Generation

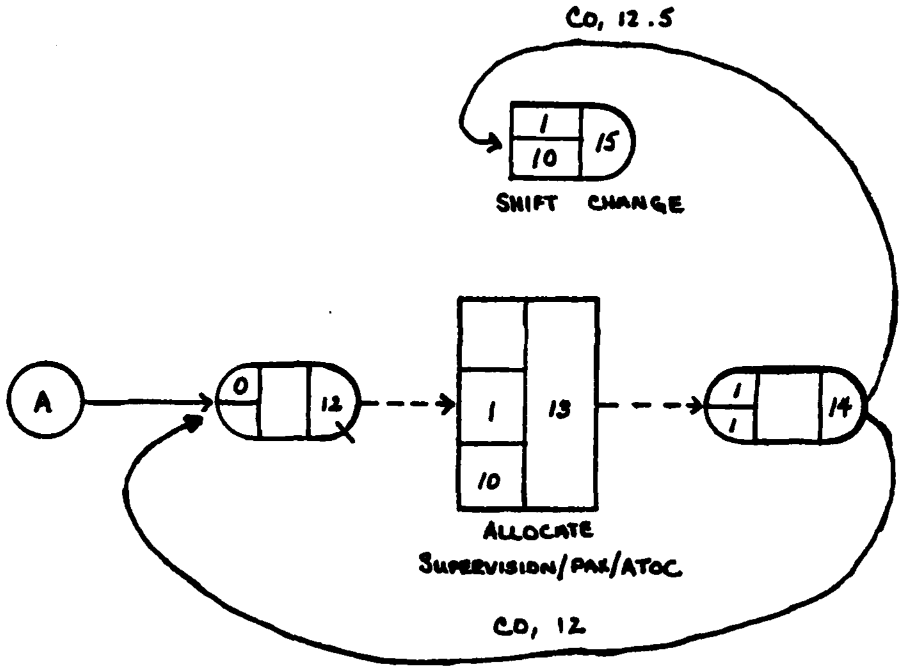


Figure C-2

Allocation of Supervision

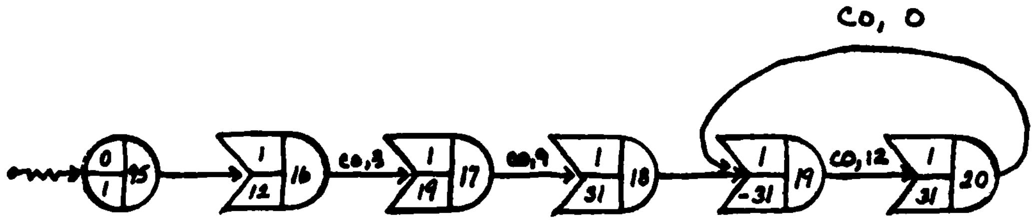


Figure C-3

Shift Change Timer

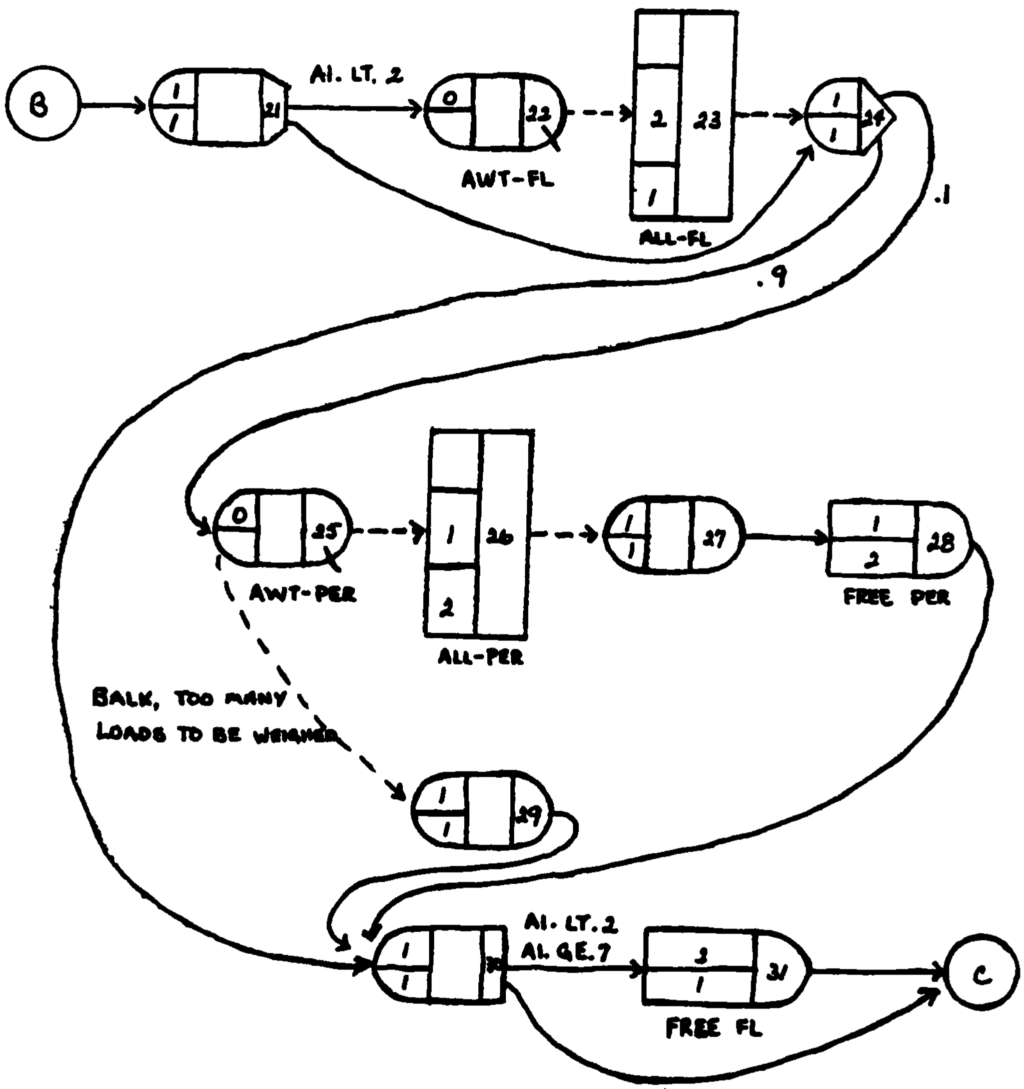


Figure C-4

Reweigh Cargo (10%)

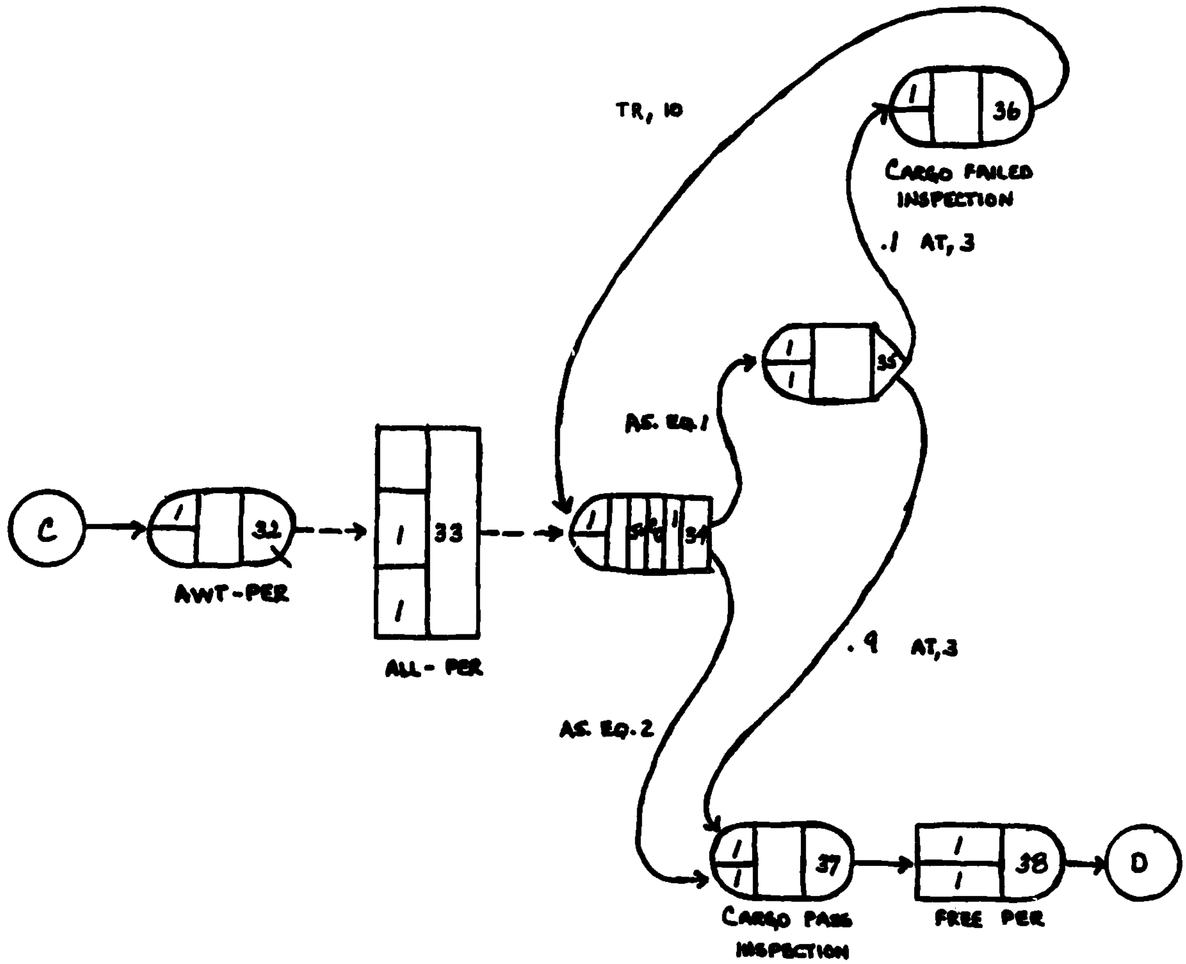


Figure C-5

Inspect Cargo

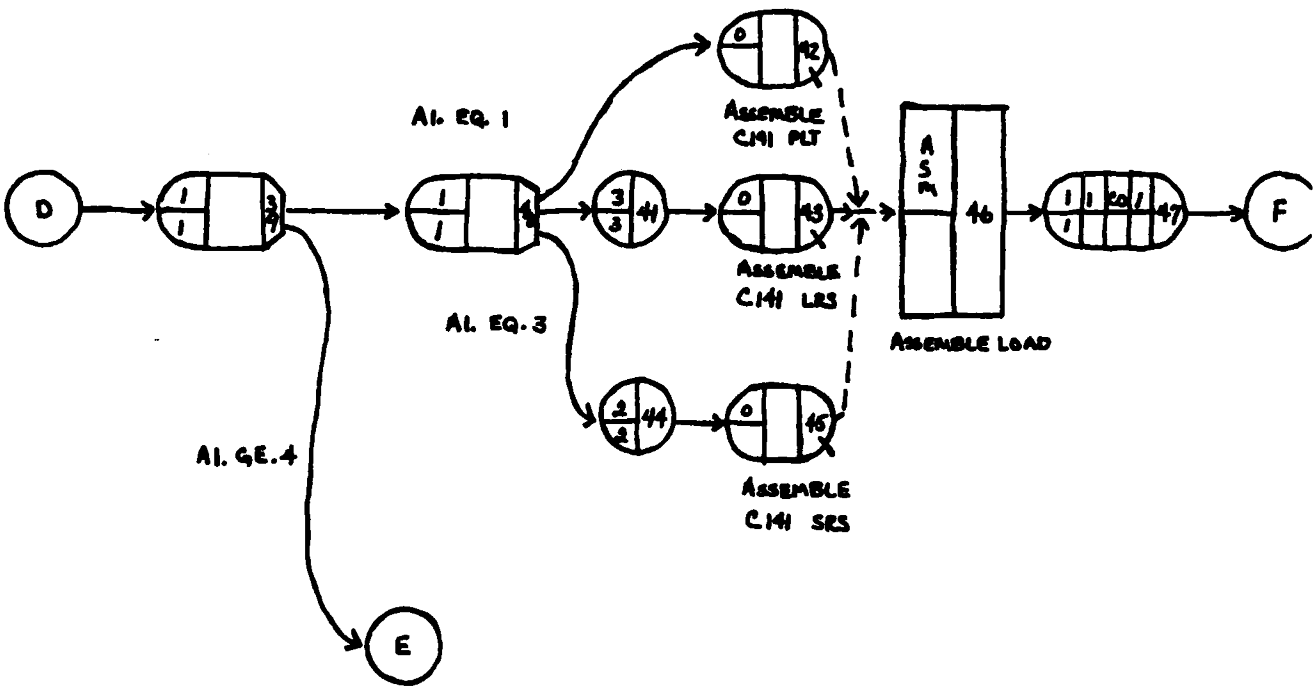


Figure C-6

Marshall C-141 Loads

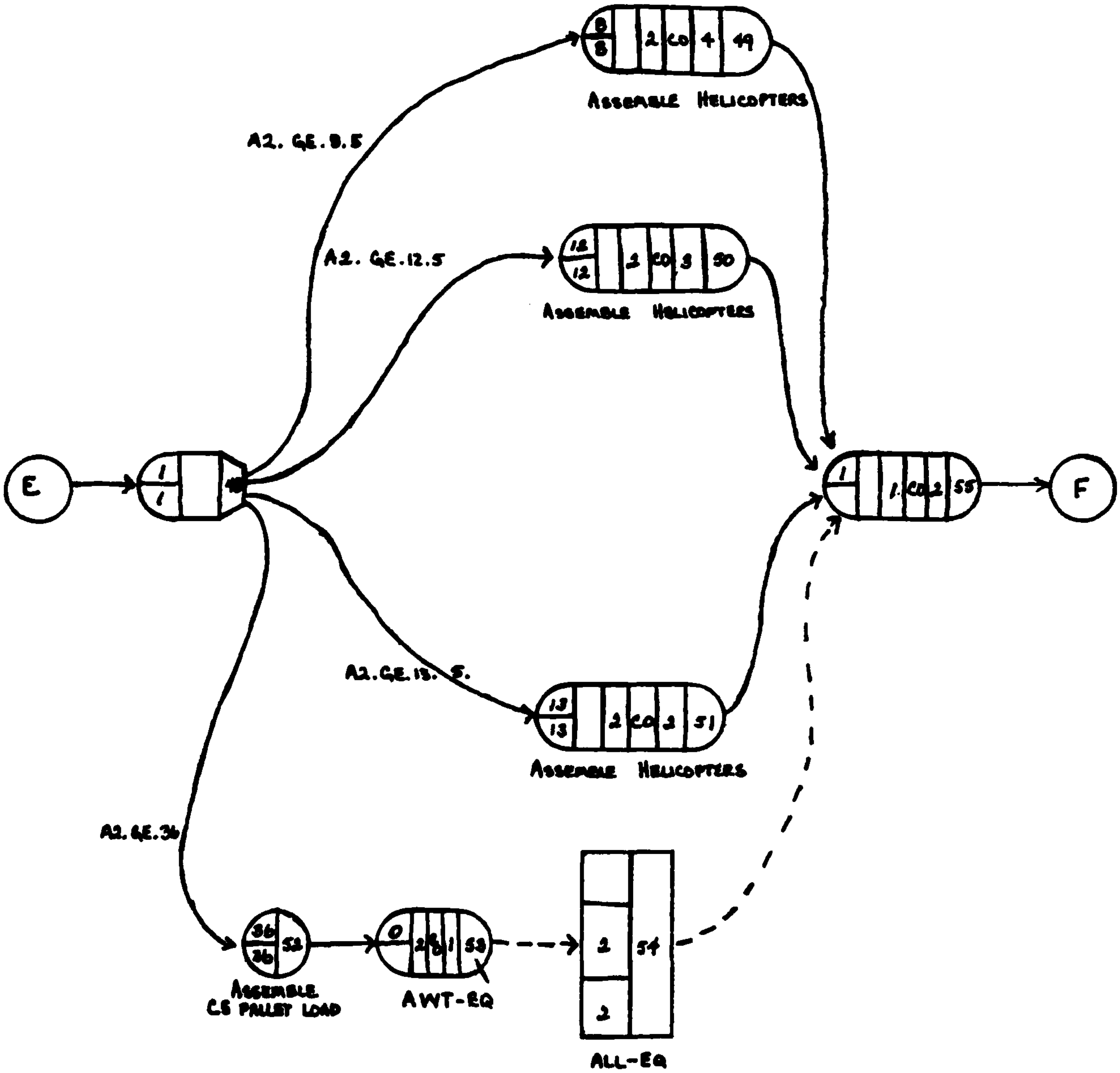


Figure C-7

Marshall C-5 Loads

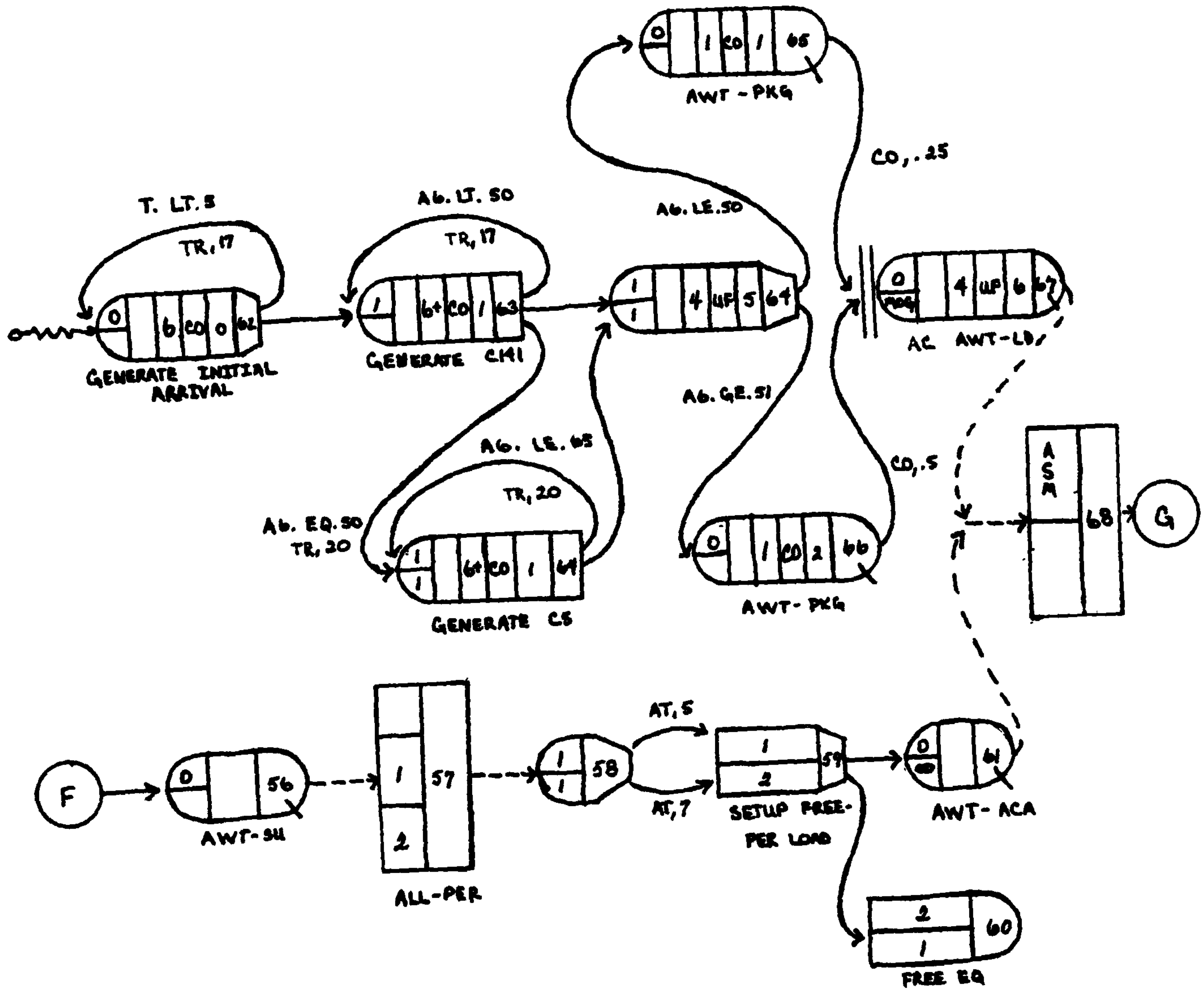


Figure C-8

Generate Aircraft/Setup Loads

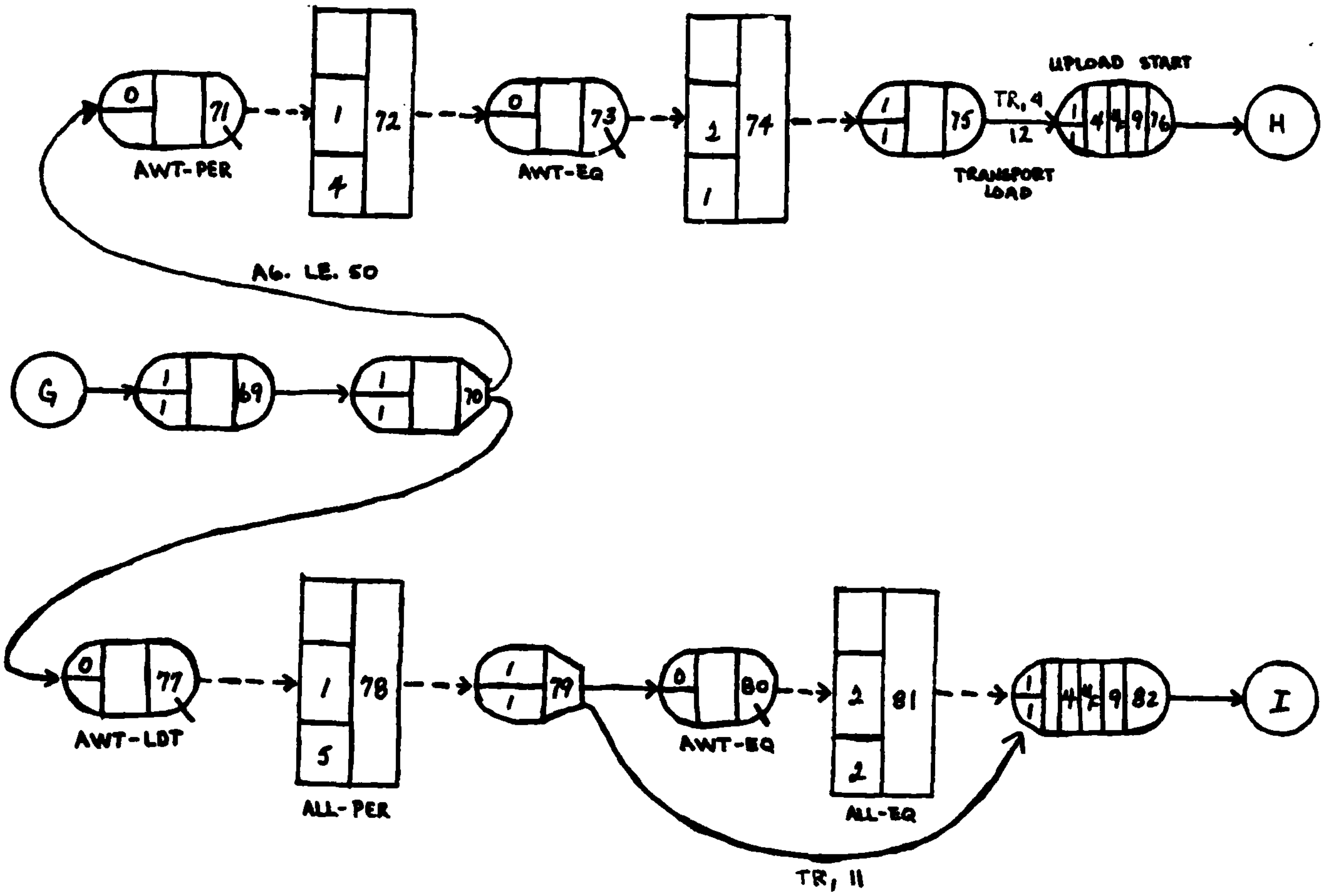


Figure C-9

Prepare to Load Aircraft

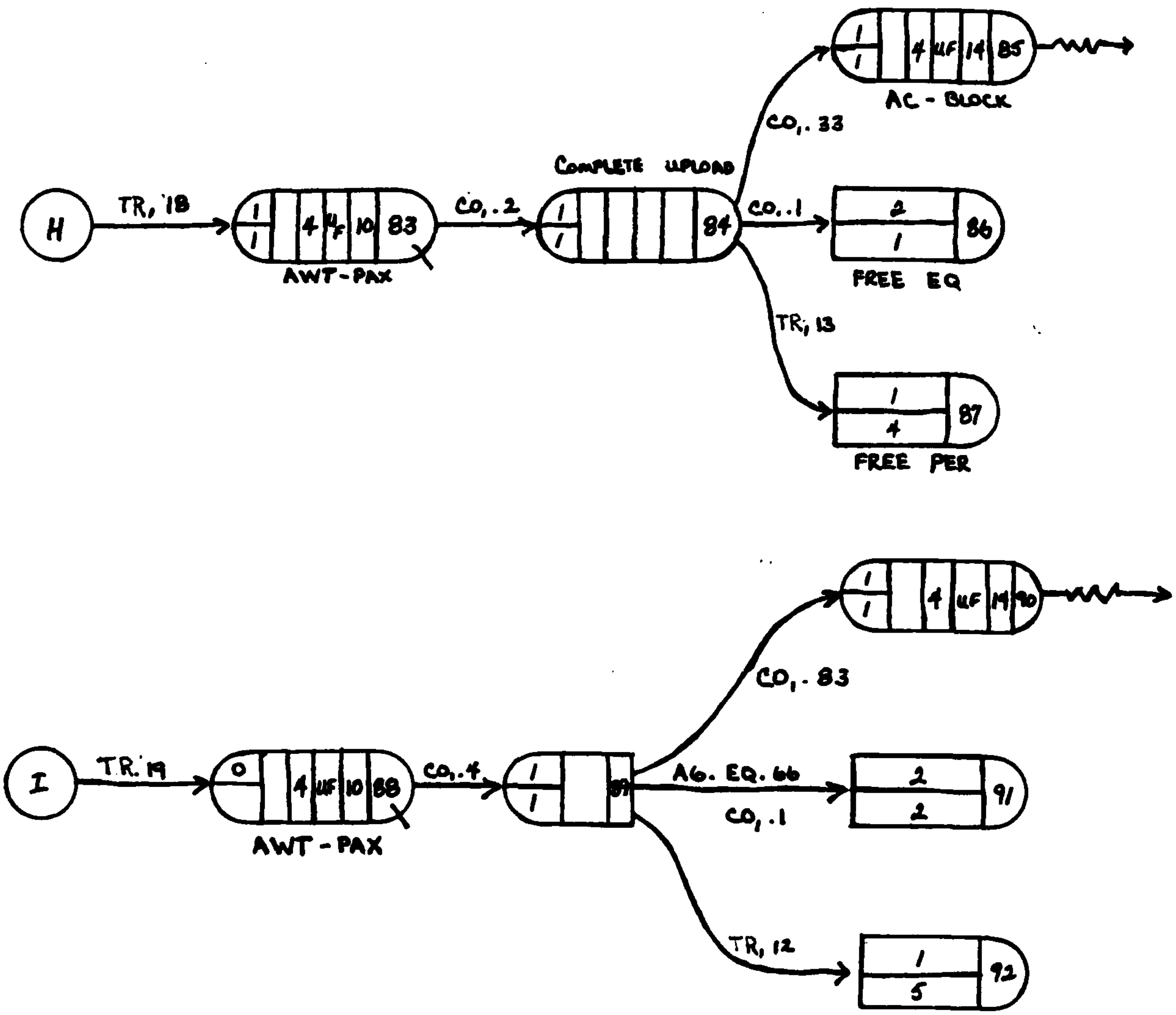


Figure C-10

Load Aircraft

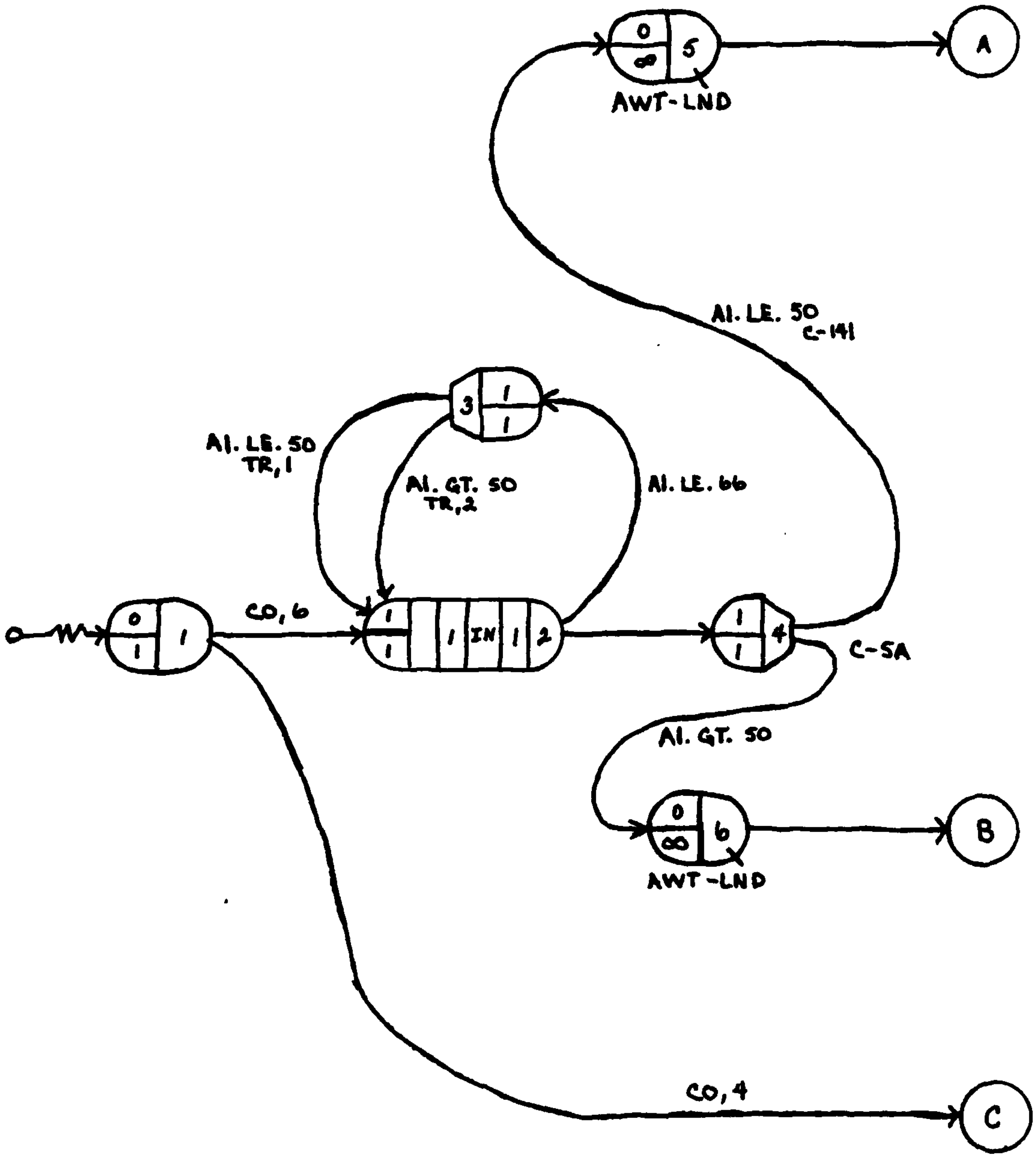


Figure C-11

Generate Aircraft

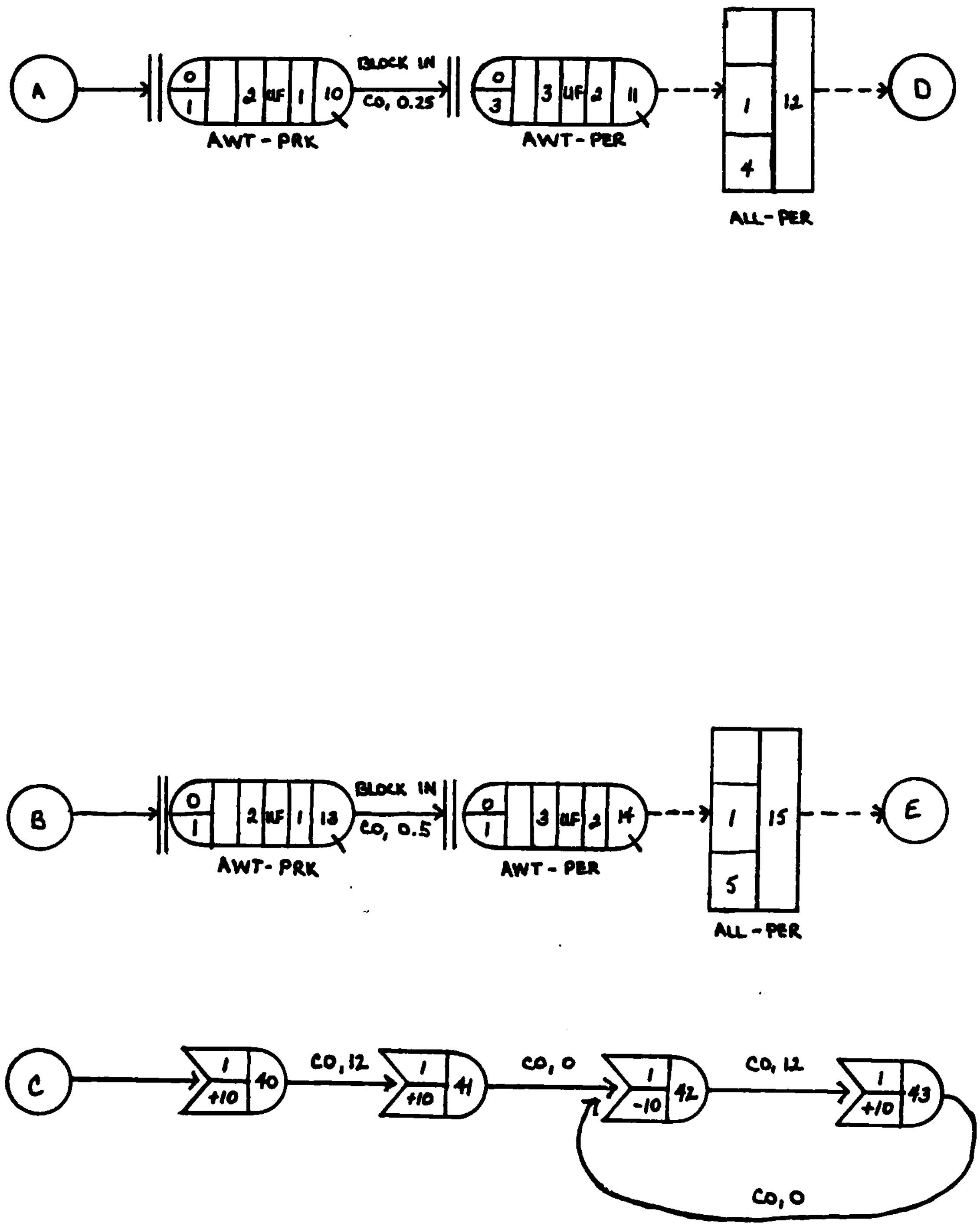


Figure C-12

Prepare to Download / Shift Change Timer

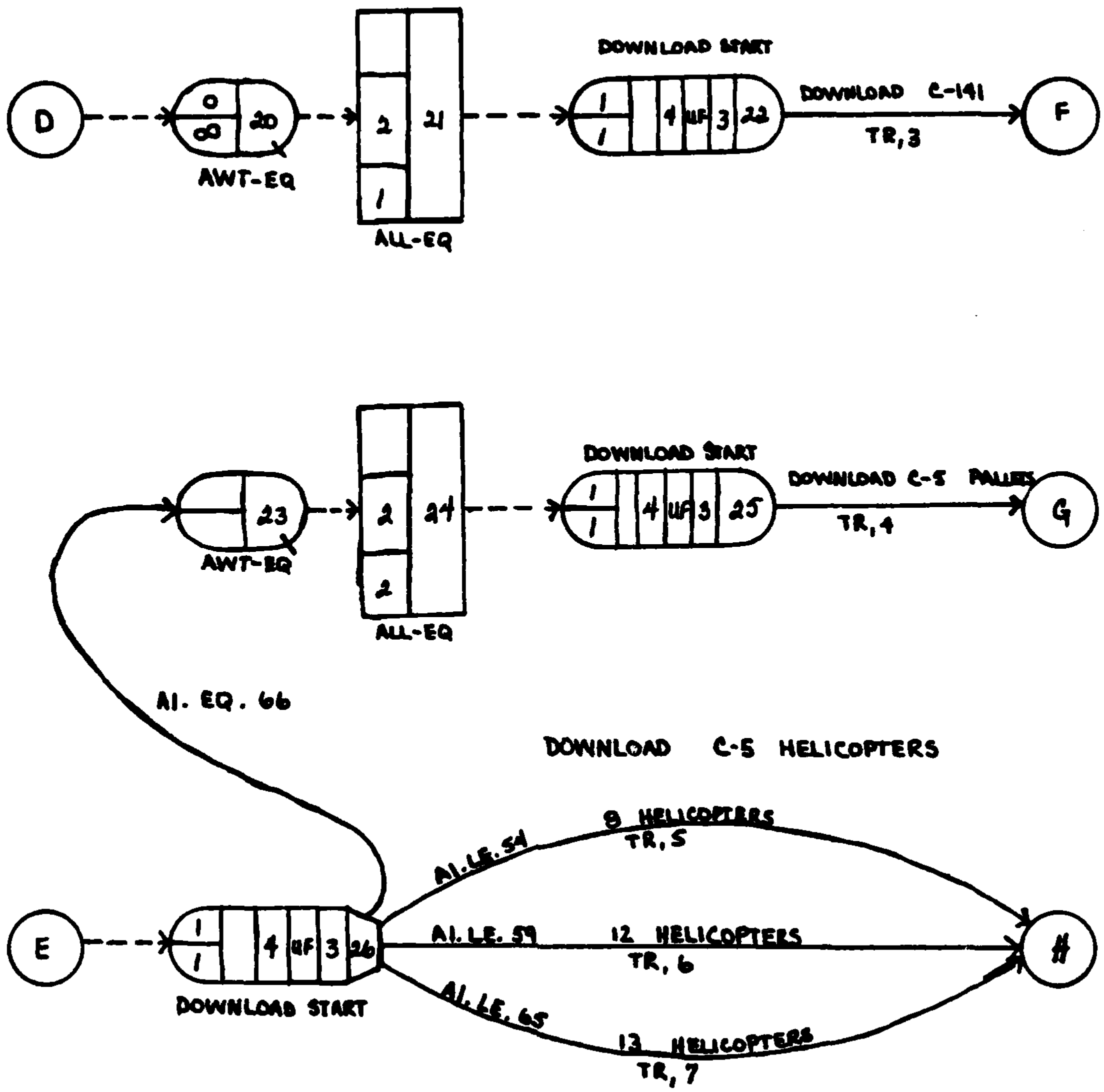


Figure C-13

Download Aircraft

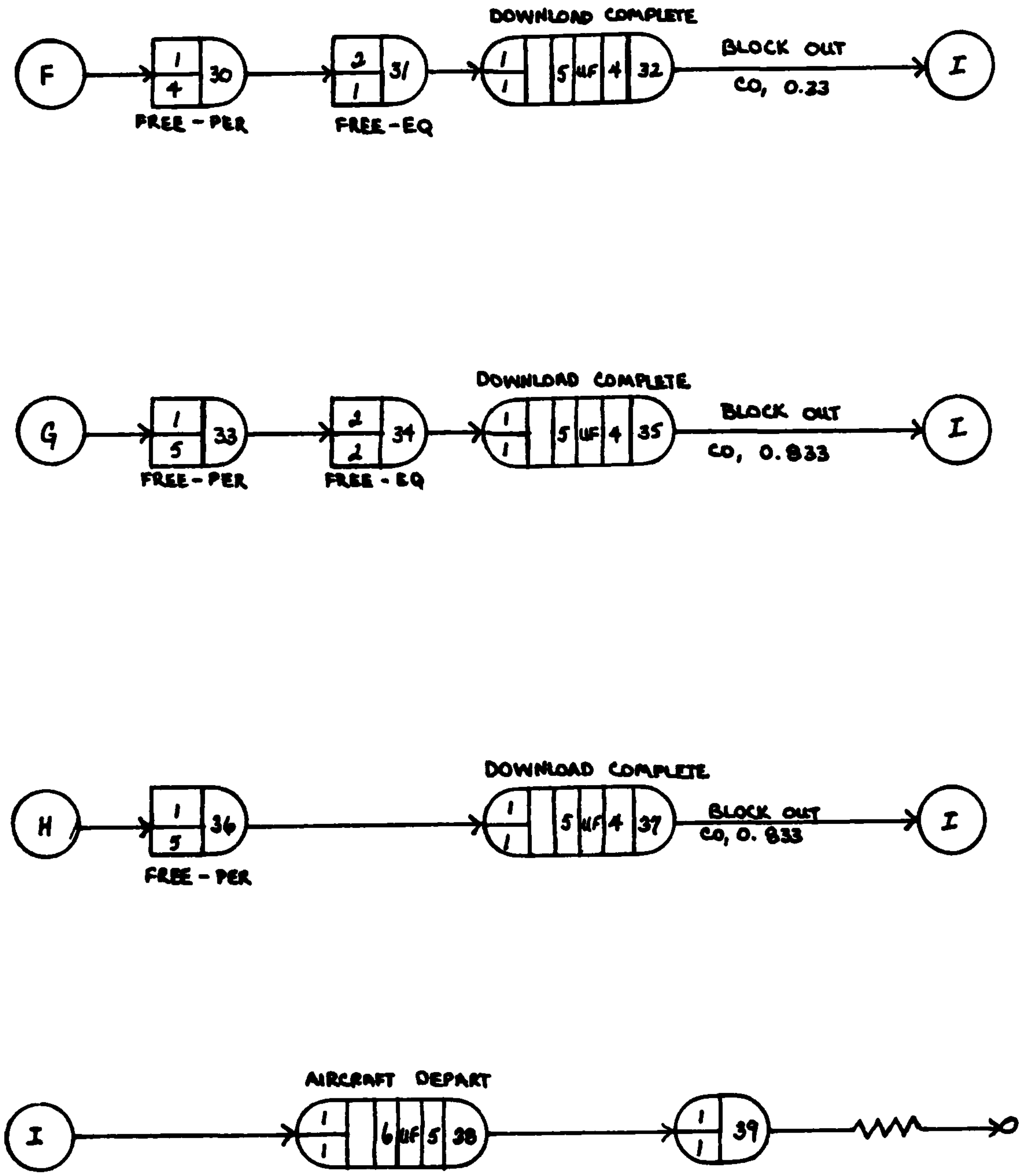


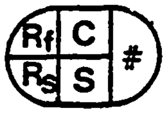
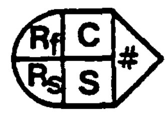
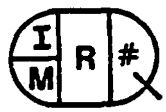
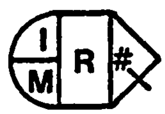
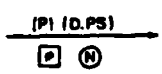
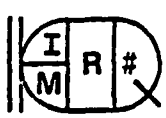
Figure C-14

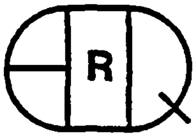
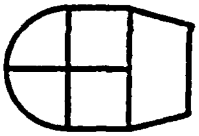
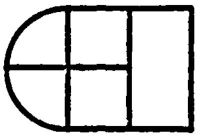
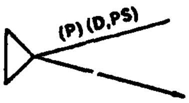
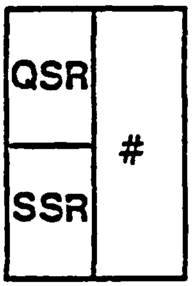
Complete Download / Release Resources

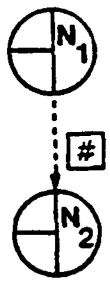
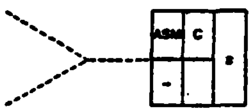
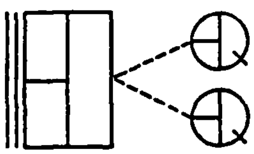
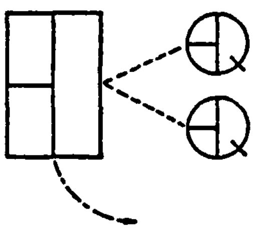
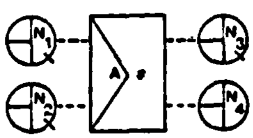
APPENDIX D

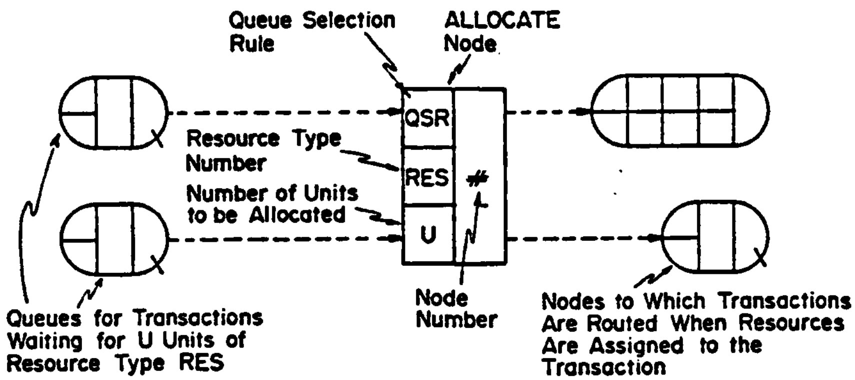
NETWORK SYMBOLOGY

The following symbols have been reproduced from Pritsker's text on modelling and analysis of systems by using Q-GERT networks (25).

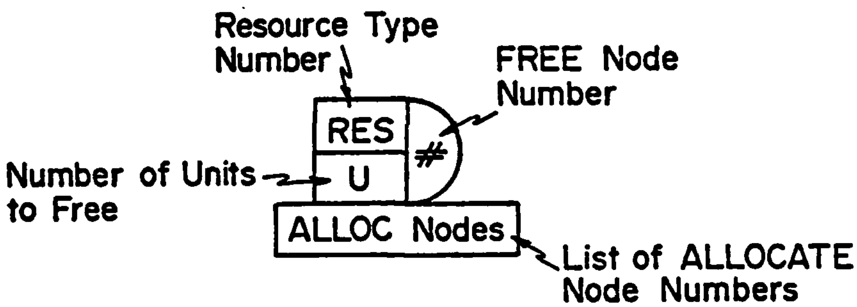
Symbol	Concept Definition
 	R_f is the number of incoming transactions required to release the node for the first time. R_s is the number of incoming transactions required to release the node for all subsequent times. C is the criterion for holding the attribute set at a node. S is the statistics collection type or marking. # is the node number.  indicates deterministic branching from the node.  indicates probabilistic branching from the node.
 	I is the initial number of transactions at the Q-node. M is the maximum number of transactions permitted at the Q-node. R is the ranking procedure for ordering transactions at the Q-node. # is the Q-node number.
	Pointer to a source node or from a sink node.
	P is the probability of taking the activity (only used if probabilistic branching from the start node of the activity is specified). D is the distribution or function type from which the activity time is to be determined. PS is the parameter set number (or constant value) where the parameters for the activity time are specified. $\boxed{\#}$ is the activity number N is the number of parallel servers associated with the activity (only used if the start node of the activity is a Q-node).
	Routing of a transaction that balks from a Q-node. This symbol can not emanate from a regular node.
	Blocking indicator (only used with Q-nodes that can force preceding *service* activities to hold transactions because the Q-node is at its maximum capacity).

Symbol	Concept	Definition
	Value Assignment	A is the attribute number to which a value is to be assigned; if A+ is specified, add value to attribute A; if A– is specified, subtract value from attribute A. D is the distribution or function type from which assignment value is to be determined. PS is the parameter set number.
	Queue Ranking	R is the ranking procedure for ordering transactions at the Q-node. R can be specified as: F → FIFO; L → LIFO; B/i → Big value of attribute i. S/i → Small value of attribute i. If i= M, ranking is based on mark time.
	Conditional, Take-First Branching	 indicates conditional-take first branching from the node.
	Conditional, Take-all Branching	 indicates conditional-take all branching from the node.
(C) (D,PS)	Condition Specification for Branch	C is the condition specification for taking the activity (see Table 5-1).
	Attribute Based Probabilistic Branching	If P<1.0, P is the probability of taking the activity. If P≥1, P is an attribute number.
	Selector node or S-node	QSR is the queue selection rule for routing transactions to or from Q-nodes (see Table 5-2). SSR is the server selection rule for deciding which server to make busy if a choice exists (see Table 5-3). # is the S-node number.

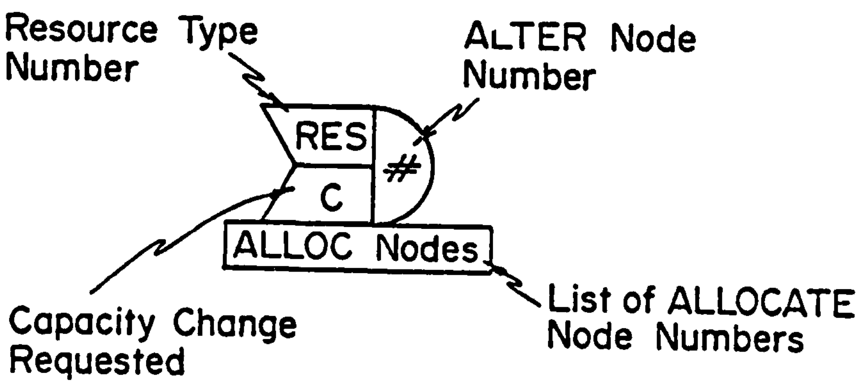
Symbol	Concept	Definition
	Nodal Modification	# is the activity number causing nodal modification. N_1 is the node number to be replaced when activity # is completed. N_2 is node number to be inserted when activity # is completed.
	Routing Indicator	Routing indicator for transaction flow to or from Q-nodes to S-nodes or Match nodes
	Assembly by S-nodes	ASM is the queue selection rule that requires transactions to be assembled from two or more queues.
	Blocking	Blocking at an S-node.
	Balking	Balking from an S-node.
	Match Node	# is the match node number. Transactions are routed from N_1 to N_3 and N_2 to N_4 when a match occurs. A is the attribute number on which the match is to be made



Queue Selection Rule
ALLOCATE Node
QSR
Resource Type Number
RES
#
Number of Units to be Allocated
U
Queues for Transactions Waiting for U Units of Resource Type RES
Node Number
Nodes to Which Transactions Are Routed When Resources Are Assigned to the Transaction



Resource Type Number
FREE Node Number
RES
#
Number of Units to Free
U
ALLOC Nodes
List of ALLOCATE Node Numbers



Resource Type Number
ALTER Node Number
RES
#
C
ALLOC Nodes
Capacity Change Requested
List of ALLOCATE Node Numbers

APPENDIX E

SIMULATION PROGRAMS

The following programs were written for use on the AFIT Harris Computer System with a VULCAN operating system. To execute the programs on the Harris system, use the following:

For the terminal service simulation programs, execute the programs in batch using the command

IJ, lfn

where lfn is a local file containing the following information:

```
$JOB,jn,Qualifier,User Number,Parameters
AS 20=lfn(for output)
QGERT.XU,lfn(QGERT Program),lfn(FORTRAN)
```

where jn is the designated job name with lfn (output) defined as the local file designated to receive the output.

For the ramp operations simulation programs, execute the programs in batch using the command

IJ, lfn

where lfn contains the following information:

```
$JOB,jn,Qualifier,User Number,Parameters
AS 20=lfn(output)
QGERT.U,lfn(QGERT),lfn(FORTRAN)
```

Some items within the programs must be changed to run the program on other systems. For example, the variable names may have to be shortened.

```
SIMULATION PROGRAM (Q-GERT BASED)                    PAGE #   1

GEN,REUSCHE,STREAM TEST,4,18,1982,,2,66,,2,(14)7,(17)1,1*E*E4*
SEE,7,36912258/N*
RES,1/PERSONNEL,00,16,37,50,81,103,121*
RES,2/EQUIPMENT,9,32,75,105,124*
SOU,1,0,1,A*
REG,2,1,1,F*
REG,3,,1,A*
REG,4,,1,F*
REG,5,,1*
REG,6,,1*
REG,7,,1*
REG,10,,1*
REG,11,,1,A*
REG,12,,1,F*
REG,13,,1*
REG,14,,1*
QUE,15/ANT-SUP*
ALL,16,,1,10,15/17*
REG,17,,1*
FRE,18,,1,10,16,-1*
REG,30,,1,F*
QUE,31/ANT-FL,(10)32*
ALL,32,,2,1,31/34*
REG,34,,1,P*
QUE,35/ANT-MEGH,0,3,(7)36,(10)
REG,36,,1*
ALL,37,,1,2,35/38*
REG,38,,1*
FRE,39,,1,2,37,50,103,121*
FRE,40,,2,1,75,32,124,105*
QUE,41,(6)S/M*
REG,42,,1,F*
ALL,50,,1,1,41/51*
REG,51,,1,F*
REG,52,,1,P*
REG,53,,1*
REG,54,,1*
FRE,55,,1,1,50,37,103,121*
REG,60,,1,F*
REG,61,,1,F*
QUE,62/MAR-PLT,(10)65*
QUE,63/MAR-LHS,(10)65*
QUE,64/MAR-SHS,(10)65*
SEL,65/SEL-LD,ASM,,S/M,,62,63,64*
REG,66,1,1*
REG,67,3,3*
REG,68,2,2*
REG,70,,1,F*
REG,71,8,8*
REG,72,12,12,*
```

```
SIMULATION PROGRAM (Q-GERT BASED)                    PAGE #   2

REG,73,13,13*
QUE,74/ANT-FL,(10)75*
ALL,75,,2,2,74/77*
REG,76,36,36*
REG,77,,1*
QUE,80/ANT-SUP,(10)81*
ALL,81,,1,2,80/82*
REG,82,,1,F*
FRE,83,A,1,2,75,81,103,121*
QUE,84/ANT-ACA,0,,,,,(10)96*
FRE,85,,2,2,75,105,124*
SOU,90,0,1,F*
REG,91,1,1,A*
REG,92,,1,F*
QUE,93/ANT-PKG*
QUE,94/ANT-PKG*
QUE,95/ANT-LD,0,2,D,S,8,(10)96*
SEL,96,ASM,,8/4,,95,84*
REG,97,1,1,A*
REG,100,1,1,(7)8/4*
REG,101,,1,F*
QUE,102/ANT-LDC,(10)103*
ALL,103,,1,4,102/104*
QUE,104/ANT-EQP,(10)105*
ALL,105,,2,1,104/106*
REG,106,,1*
REG,107,,1*
QUE,108,,,*
SIV,109/C141-DP,,1,(6)1*
FRE,110,,2,1,75,105*
FRE,111,,1,4,121,103,81*
REG,116,1,1*
QUE,120/ANT-LDC,(10)121*
ALL,121,,1,5,120/122*
REG,122,,1,F*
QUE,123/ANT-EQP,(10)124*
ALL,124,,2,2,123/125*
REG,125,,1*
QUE,126/ANT-LD,*
FRE,127,,2,2,75,124*
FRE,128,,1,5,121*
SIV,129/CS-DEPT,,1,,1*
REG,134,1,1,A*
SOU,140*
ALT,141,0,1,13*
ALT,142,0,1,19*
ALT,143,0,1,32*
ALT,144,0,1,-32*
ALT,145,0,1,32*
ACT,1,1,CO,.25,1/GEN-LD,(9)A1.LT.66*
```

Figure E-1

Terminal Service Simulation Program

```
SIMULATION PROGRAM (Q-GERT BASED)                    PAGE #   3

ACT,1,2*
ACT,1,15,(9)A1.EQ.1*
ACT,2,3,(9)A1.LE.50*
ACT,2,10,UF,1,(9)A1.GE.51*
ACT,3,3,CO,0.018,2/GEN-PCS,(9)A2.LE.5*
ACT,3,4*
ACT,4,5,(9)A2.EQ.1*
ACT,4,6,(9)A2.LT.5*
ACT,4,7,(9)A2.GE.5*
ACT,5,30*
ACT,6,30*
ACT,7,30*
ACT,10,11*
ACT,11,11,CO,0.16,2/GEN-PCS,(9)A4.LT.A2*
ACT,11,12,UF,2*
ACT,12,13,(9)A1.EQ.7*
ACT,12,14,(9)A1.GE.4*
ACT,13,30*
ACT,14,30*
ACT,17,18,CO,12.5*
ACT,17,15,CO,12*
ACT,140,141*
ACT,141,142,CO,3*
ACT,142,143,CO,9*
ACT,143,144*
ACT,144,145,CO,12*
ACT,145,144*
ACT,30,31,(9)A1.LT.2*
ACT,30,31,(9)A1.GE.7*
ACT,30,34*
ACT,34,35,(8).1*
ACT,34,42,(8).9*
ACT,36,42*
ACT,38,39,UF,4*
ACT,39,42*
ACT,42,40,(9)A1.LT.2*
ACT,42,40,(9)A1.GE.7.0*
ACT,42,41*
ACT,40,41*
ACT,51,52,(9)A5.EQ.1*
ACT,51,54,(9)A5.EQ.2*
ACT,52,53,AT,3,(8).1*
ACT,52,54,AT,3,(8).9*
ACT,53,51,AT,7,3/COR-DIS*
ACT,54,55*
ACT,55,60*
ACT,60,61,(9)A1.LT.4*
ACT,61,62,(9) A1.EQ.1*
ACT,61,67,(9)A1.EQ.2*
ACT,61,68,(9)A1.EQ.3*
```

```
SIMULATION PROGRAM (Q-GERT BASED)                    PAGE #   4

ACT,67,65*
ACT,68,64*
ACT,65,66,,,4/ASM-LD*
ACT,66,80*
ACT,60,70,(9)A1.GE.4*
ACT,70,71,(9)A2.LE.8.5*
ACT,70,72,(9)A2.LE.12.5*
ACT,70,73,(9)A2.LE.13.5*
ACT,70,76,(9)A2.LE.36.5*
ACT,76,74*
ACT,71,77*
ACT,72,77*
ACT,73,77*
ACT,77,80*
ACT,82,83,AT,7,(9)A1.EQ.2*
ACT,82,83,AT,5,(9)A1.NE.2*
ACT,83,84*
ACT,83,85,(9)A2.EQ.1*
ACT,90,90,AT,5,(9)T.LT.5.0*
ACT,90,91,AT,5,(9)T.GE.5.0*
ACT,91,91,AT,5,(9)A6.LE.49*
ACT,91,92,(9)A6.LE.50*
ACT,91,97,(9)A6.EQ.50*
ACT,92,93,(9)A6.LE.50*
ACT,92,94,(9)A6.GE.51*
ACT,97,97,AT,7,(9)A6.LE.65*
ACT,97,92,(9)A6.LE.66*
ACT,93,95,CO,0.25,5/PK-AC*
ACT,94,95,CO,0.5,5/PK-AC*
ACT,96,100,,,6/ART-LD*
ACT,100,101*
ACT,101,102,(9)A6.LE.50*
ACT,106,107,AT,7,12/TR-CGO*
ACT,107,108,AT,7*
ACT,108,116,CO,0.2,10/LD-PAX*
ACT,116,109,CO,0.33*
ACT,116,110,CO,0.1*
ACT,116,111,AT,7*
ACT,101,120,(9)A6.GE.51*
ACT,122,123,AT,7,(9)A6.EQ.66*
ACT,122,125,AT,5,13/TR-CGO*
ACT,125,126,AT,7,14*
ACT,126,134,CO,0.4,12/LD-PAX*
ACT,134,127,CO,0.1,(9)A6.EQ.66*
ACT,134,128,AT,7*
ACT,134,129,CO,0.633*
PAR,1,0.083,0.05,0.15,(7)1*            11
PAR,2,0.15,0.1,0.2,(7)2*               11
PAR,3,0.1,0.05,0.2,(7)3*               11
PAR,4,0.2,0.15,0.25,(7)4*              11
```

Figure E-1 (cont)

Terminal Service Simulation Program

```
PAR,5,0.3,0.2,0.5,(7)6*
PAR,6,0.65,0.3,1.0,(7)5*                    11
PAR,7,0.5,0.33,0.66,(7)6*
PAR,8,0.8,0.45,1.15,0.0,7*
PAR,9,1.167,0.95,1.25,(7)4*
PAR,10,1.00,0.75,1.5,(7)8*                  U1
PAR,11,2.75,2.5,3.5,(7)9*                   U1
PAR,12,4.25,4.1,4.4,(7)10*
PAR,13,0.15,0.1,0.2,(7)2*
PAR,14,0.2,0.15,0.25,(7)4*
PAR,15,0.15,0.10,0.20,(7)2*                 A1
PAR,16,0.10,0.05,0.20,(7)3*                 A1
PAR,17,0.65,.30,.95,(7)5*
PAR,18,1.00,0.75,1.5,(7)8*                  S1
PAR,19,0.225,0.15,0.30,(7)2*                I2
PAR,20,0.15,0.075,0.30,(7)3*                I2
PAR,21,0.30,0.225,0.375,(7)4*               I2
PAR,22,0.225,0.15,0.30,(7)2*                I2
PAR,23,0.125,0.075,0.225,(7)1*              I2
PAR,24,0.75,0.45,1.5,(7)5*                  I2
PAR,25,0.125,0.075,0.225,(7)1*              A2
PAR,26,0.225,0.15,0.30,(7)2*                A2
PAR,27,0.150,0.075,0.30,(7)3*               A2
PAR,28,0.750,0.450,1.5,(7)8*                S2
PAR,29,1.25,.75,1.5,(7)7*                   S2
PAR,30,1.5,1.25,2.225,(7)8*                 S2
PAR,31,.50,.375,.75,(7)8*                   U2
PAR,32,1.375,1.25,1.75,(7)9*                U2
PAR,33,1.25,.9375,1.74,(7)8*                U2
PAR,34,3.4375,3.125,4.375,(7)9*             U2
VAS,1,1,IN,1,2,CO,0*
VAS,2,2,CO,0*
VAS,3,2+,CO,1*
VAS,5,1,CO,1,3,TR,2,2,CO,0*
VAS,6,1,CO,2,3,TR,4*
VAS,7,1,CO,3,3,TR,3*
VAS,10,4,CO,0*
VAS,11,4+,CO,1*
VAS,13,3,TR,2*
VAS,14,3,TR,4*
VAS,30,4,UF,11*
VAS,41,5,CO,0*
VAS,51,5+,CO,1*
VAS,52,7,TR,5*
VAS,53,3,UF,12*
VAS,66,1,CO,1*
VAS,71,2,CO,0*
VAS,72,2,CO,0*
VAS,73,2,CO,0*
VAS,76,2,CO,1*
```



```
VAS,77,1,CO,2*
VAS,82,5,TR,18,7,TR,17*
VAS,83,3,UF,8*
VAS,90,6,CO,0,5,TR,9*
VAS,91,6,IN,1,7,TR,12,5,TR,9*
VAS,92,1,UF,18,2,UF,16,4,UF,5*
VAS,93,1,CO,1,4,CO,10*
VAS,94,1,CO,2,4,CO,10*
VAS,95,4,UF,6*
VAS,96,6,IN,1*
VAS,97,7,TR,12,6+,CO,1*
VAS,106,7,TR,13*
VAS,107,3,UF,7,4,UF,9,7,TR,10*
VAS,108,4,UF,10,5,UF,19*
VAS,109,3,UF,3,4,UF,14*
VAS,116,7,TR,1*
VAS,122,5,TR,6,7,TR,1*
VAS,125,1,UF,13,3,UF,3,4,UF,9,7,TR,11*
VAS,126,4,UF,10,5,UF,17*
VAS,128,4,UF,15*
VAS,129,4,UF,14*
VAS,134,7,TR,7*
FIN*
```

Figure E-1 (cont)
Terminal Service Simulation Program

```
      SUBROUTINE UI
C
C
      COMMON/OUTPUT/TARRAV(100),TACPOS(100),TACBLK(100),TUPLDS(100),TUPL
     +              DC(100),TACBLKD(100),TACULS(100),TACBU(100),TACULC(1
     +              00),A7(100)
      COMMON/PAY/A1,A2,A6,TRU
C
C
C*********************************************************
C*                                                       *
C*                INITIALIZE VARIABLES                   *
C*                                                       *
C*********************************************************
C
        N=0
      A1=GATRB(1)
      A2=GATRB(2)
      A6=GATRB(6)
C
      IF (NRUN.EQ.1) THEN
        DO 1000,I=1,34
          CALL CPTR(I)
1000    CONTINUE
      ELSE
      CONTINUE
      ENDIF
C
      DO 200,I=1,100
        TARRAV(I)=0.00
        TACBLK(I)=0.00
        TACPOS(I)=0.0
        TUPLDS(I)=0.00
        TUPLDC(I)=0.00
        TACBLKD(I)=0.00
        TACULS(I)=0.0
        TACBU(I)=0.0
        TACULC(I)=0.0
200   CONTINUE
C
      RETURN
      END
C
C
      FUNCTION UF(IFN)
C
      COMMON/QVAR/NDE,NFTBU(500),NREL(500),NRELP(500),NREL2(500),NRUN,
     +            NRUNS,NTC(500),PARAM(100,4),TBEG,TNOW
C
      COMMON/OUTPUT/TARRAV(100),TACPOS(100),TACBLK(100),TUPLDS(100),TUPL
```

Figure E-1 (cont)

Terminal Service Simulation Program

```
     +              DC(100),TACBLKO(100),TACULS(100),TACBU(100),TACULC(1
     +              00),A7(100)
C
      COMMON/PAY/A1,A2,A6,TRU
C
      A1=GATRB(1)
      A2=GATRB(2)
      A3=GATRB(3)
      A=GATRB(5)
      A6=GATRB(6)
      B=GATRB(7)
C
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19) IFN
C
C***************************************************************
C*                                                             *
C*              DETERMINE TYPE OF CARGO                        *
C*                                                             *
C***************************************************************
C
1     CONTINUE
      IF(A1.LE.54) THEN
        CALL PATRB(8.0,2)
      ELSEIF(A1.LE.60) THEN
        CALL PATRB(12.0,2)
      ELSEIF(A1.LE.65) THEN
        CALL PATRB(13.0,2)
      ELSE
        CALL PATRB(36.0,2)
        CALL PATRB(7.0,1)
      ENDIF
      UF=0.0
      RETURN
C
C*******************************************************************
C*                                                                 *
C*              ASSIGN CARGO ATTRIBUTES                            *
C*                                                                 *
C*******************************************************************
C
2     CONTINUE
      IF(A2.EQ.36) THEN
        CALL PATRB(7.0,1)
      ELSEIF(A2.EQ.8) THEN
        CALL PATRB(4.0,1)
      ELSEIF(A2.EQ.12) THEN
        CALL PATRB(5.0,1)
      ELSEIF(A2.EQ.13)
        CALL PATRB(6.0,1)
      ENDIF
```

Figure E-1 (cont)

Terminal Service Simulation Program

```
      UF=0.0
      RETURN
C
C*************************************************************
C*                                                          *
C*               ASSIGN ACTIVITY TIMES AND                  *
C*                WRITE RANDOM NUMBER DEVIATES              *
C*                TO A FILE                                 *
C*                                                          *
C*************************************************************
C
3     CONTINUE
        WRITE(20,'("1",3X,F6.4)') B
      RETURN
C
4     CONTINUE
      IF(A1.EQ.1.OR.A1.EQ.7)THEN
        UF=TR(14)
      WRITE(20,'("14",3X,F6.4)') UF
      ELSEIF(A1.GE.4) THEN
        UF=TR(15)
        WRITE(20,'("15",3X,F6.4)') UF
      ELSEIF(A1.LT.4) THEN
        UF=TR(16)
        WRITE(20,'("16",3X,F6.4)') UF
      ENDIF
      RETURN
C
5     CONTINUE
        TARRAV(A6)=TNOW
        UF=0.0
      RETURN
C
6     CONTINUE
        TACPOS(A6)=TNOW
        UF=0.0
      RETURN
C
7     CONTINUE
        WRITE(20,'("13",3X,F6.4)')B
      RETURN
C
8     CONTINUE
      IF (A1.EQ.2) THEN
        WRITE(20,'("17",3X,F6.4)') B
      ELSE
        WRITE(20,'("18",3X,F6.4)') A
      ENDIF
      UF=0.00
      RETURN
```

Figure E-1 (cont)

Terminal Service Simulation Program

```
C
9       CONTINUE
          TUPLDS(A6)=TNOW
          UF=0.0
        RETURN
C
10       CONTINUE
          TUPLDC(A6)=TNOW
          UF=0.0
        RETURN
C
11      CONTINUE
        IF(A1.EQ.1.OR.A1.EQ.7) THEN
          WRITE(20,'("2",3X,F6.4)') A3
        ELSEIF(A1.EQ.2.OR.A1.GE.4) THEN
          WRITE(20,'("4",3X,F6.4)') A3
        ELSEIF(A1.EQ.3) THEN
          WRITE(20,'("3",3X,F6.4)') A3
        ENDIF
        RETURN
C
12      CONTINUE
          WRITE(20,'("5",3X,F6.4)') B
        RETURN
C
13      CONTINUE
          WRITE(20,'("6",3X,F6.4)') A
        RETURN
C
14      CONTINUE
          TACBLKO(A6)=TNOW
          IF (A6.EQ.66) THEN
            TRU=TIRU(1)
              WRITE(20,'("50",3X,F10.5)') TRU
              WRITE(20,'("60",3X,F10.4)') TACBLKO(66)
              WRITE(20,'("70",3X,I3)') NRUN
              WRITE(20,'("00    000")')
           ENDIF
          UF=0.0
        RETURN
C
15      CONTINUE
          WRITE(20,'("7",3X,F6.4)') B
        RETURN
C
16      CONTINUE
          IF (A1.LE.50) WRITE(20,'("9",3X,F6.4)')A
        RETURN
C
17      CONTINUE
```

Figure E-1 (cont)

Terminal Service Simulation Program

```
        WRITE(20,'("11",3X,F6.4)') B
      RETURN
C
18    CONTINUE
        WRITE(20,'("12",3X,F6.4)') B
      RETURN
C
19    CONTINUE
        WRITE(20,'("10",3X,F6.4)') B
      RETURN
C
      END
C
C*******************************************************************
C*                                                                 *
C*            PRODUCE OUTPUT                                       *
C*                                                                 *
C*******************************************************************
C
      SUBROUTINE OO
C
      COMMON/QVAR/NOE,NFTBU(500),NREL(500),NRELP(500),NREL2(500),NRUN,
     +            NRUNS,NTC(500),PARAM(100,4),TBEG,TNOW
C
C
      COMMON/OUTPUT/TARRAV(100),TACPOS(100),TACBLK(100),TUPLDS(100),TUPL
     +            DC(100),TACBLKO(100),TACULS(100),TACBO(100),TACULC(1
     +            00),A7(100)
C
      COMMON/PAY/A1,A2,A6,TRU
C
C**********************************************************************
C*                                                                    *
C*                  PRINT AIRLIFT FLOW CHART                          *
C*                                                                    *
C**********************************************************************
C
      PRINT 90
90    FORMAT("1")
      PRINT 100
100   FORMAT(30X,25('-'),/,30X,'I AIRLIFT   FLOW   CHART I',/,30X,25('-'
     +),//,1X,79('-'),/,2X,'MSN',7X,'ACFT',6X,'ACFT',5X,'ACFT',5X,'ACFT'
     +,5X,'ACFT',5X,'ACFT',5X,'ACFT',3X,'GROUND',/,3X,'NO',4X,'TYPE/NO.'
     +,4X,'ARRIVE',3X,'BLOCK',4X,'AVAIL',4X,'S-UPLD',3X,'C-UPLD',4X,
     +'DEPT',4X,'TIME',/,1X,79('-'),//)
C
      N=0
      DO 110,I=1,66
        N=N+1
        GT=TACBLKO(N)-TARRAV(N)
```

Figure E-1 (cont)

Terminal Service Simulation Program

```
      IF(NRUN.EQ.1.OR.NRUN.EQ.5) THEN
      IF(N.EQ.17.OR.N.EQ.34.OR.N.EQ.51.OR.N.EQ.67)
        PRINT 90
        PRINT 100
      ENDIF
      IF(N.LE.50) THEN
      PRINT 115,N,TARRAV(N),TACPOS(N),TACPOS(N),TUPLDS(N),TUPLDC(N),
     +          TACBLKO(N),GT
      ELSE
      PRINT 116,N,TARRAV(N),TACPOS(N),TACPOS(N),TUPLDS(N),TUPLDC(N),
     +           TACBLKO(N),GT
      ENDIF
      ENDIF
115   FORMAT(1X,I3,3X,'C141/XXXXX',3X,F6.2,3X,F6.2,3X,F6.2,3X,F6.2,3X,
     +F6.2,3X,F6.2,3X,F6.2,//)
116   FORMAT(1X,I3,3X,'C-5A/XXXXX',3X,F6.2,3X,F6.2,3X,F6.2,3X,F6.2,3X,
     +F6.2,3X,F6.2,3X,F6.2,//)
110   CONTINUE
C
      PRINT 117,NRUN,TRU,TACBLKO(66)
117   FORMAT(6X,I3,/,6X,"AVERAGE PERSONNEL UTILIZATION =",1X,F10.5,/,
     +        6X,"SIMULATION COMPLETION TIME =",1X,F10.4)
C
C
C
      RETURN
      END
```

Figure E-1 (cont)

Terminal Service Simulation Program

```
RAMP OPERATIONS GERT PROGRAM                                    PAGE #   1

GEN,REUSCHE,ASE*,UFHA,6,3,27,82,,1,66,,10,F,4,6,(17)1,1*
SIN,50,1,1,5,A*
SOU,1,0,1*
RES,1/PERS,00,7,24*
RES,2/FORKLIFT,12,9,18*
REG,2,1,1,A*
REG,3,1,1,F*
REG,10,1,1*
REG,13,1,1*
REG,15,1,1,F*
REG,19,1,1*
REG,22,1,1*
REG,25,1,1,F
REG,27,1,1*
REG,28,1,1*
QUE,4/AWT-LND*
QUE,5/AWT-PRK,0,1,(7)8*
QUE,6/AWT-PERS,0,6,(7)8,,(10)7*
QUE,8/AWT-FL,(10)9*
QUE,17/AWT-FL,(10)18*
QUE,39/AWT-LND*
QUE,40/AWT-PRK,0,1,(7)8*
QUE,23/AWT-PERS,0,3,(7)8,(10)24*
ALL,7,,1,4,6/8*
ALL,9,,2,1,8/10*
ALL,18,,2,2,17/19*
ALL,24,,1,5,23/25*
FRE,11,,1,4*
FRE,12,,2,1*
FRE,20,,1,5*
FRE,21,,2,2*
FRE,26,,1,5*
ALT,34,,1,+30*
ALT,35,,1,+30*
ALT,36,,1,-30*
ALT,37,,1,+30*
ACT,1,2,CO,6*
ACT,2,15,(9)A1.LT.66*
ACT,15,2,TR,1,(9)A1.LE.50*
ACT,15,2,TR,7,(9)A1.GT.50*
ACT,2,3*
ACT,3,4,(9)A1.LE.50*
ACT,4,5*
ACT,5,6,CO,0.25*
ACT,10,11,AT,3*
ACT,11,12*
ACT,12,13*
ACT,13,28,CO,0.33*
ACT,3,39,(9)A1.GT.50*
ACT,39,40*
```

```
RAMP OPERATIONS GERT PROGRAM                                    PAGE #   2

ACT,40,23,CO,0.5*
ACT,19,20,AT,3*
ACT,20,21*
ACT,21,22*
ACT,22,28,CO,0.833*
ACT,25,17,(9)A1.EQ.66*
ACT,25,26,AT,3,(9)A1.LE.54*
ACT,25,26,AT,3,(9)A1.LE.59*
ACT,25,26,AT,3,(9)A1.LE.65*
ACT,26,27*
ACT,27,28,CO,0.833*
ACT,28,50*
ACT,1,34,CO,4*
ACT,34,35,CO,12*
ACT,35,36*
ACT,36,37,CO,12*
ACT,37,36*
VAS,2,1,IN,1*
VAS,5,2,UF,1*
VAS,40,2,UF,1*
VAS,6,2,UF,2*
VAS,23,2,UF,2*
VAS,10,2,UF,3,3,TR,11*
VAS,11,4,UF,6*
VAS,19,2,UF,3,3,TR,12*
VAS,20,4,UF,7*
VAS,25,2,UF,3,3,TR,13*
VAS,26,4,UF,8*
VAS,13,2,UF,4*
VAS,22,2,UF,4*
VAS,27,2,UF,4*
VAS,28,2,UF,5*
PAR,1,0.37,0.3,0.45*
PAR,2,.5,.4,.75*
PAR,3,1.25,1.10,1.50*
PAR,4,3.7,3.4,4.0*
PAR,5,3.7,3.4,4.0*
PAR,6,3.7,3.4,4.0*
PAR,7,1.42,1.3,1.5*
PAR,8,.25,.2,.375*                 D2
PAR,9,.625,.55,.75*                D2
PAR,10,1.85,1.7,2.0*               D2
PAR,11,.625,.6,.94*                D3
PAR,12,1.563,1.375,1.875*          D3
PAR,13,4.625,4.25,5.0*             D3
FIN*
```

Figure E-2

Ramp Operations Simulation Program

```
      FUNCTION UF(IFN)
C
      COMMON/QVAR/NOE,NFTBU(100),NREL(100),NRELP(100),NREL2(100),NRUN,
     +NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
C
      COMMON/OUTPUT/TARRAV(100),MISNUM(100),BLKINT
     +(100),STRTOL(100),ENDOL(100),DEPART(100)
C
      COMMON/PAY/K
C
      K=GATRB(1)
      A=GATRB(3)
C
      GO TO (1,2,3,4,5,6,7,8) IFN
C
1     CONTINUE
      TARRAV(K)=TNOW
      MISNUM(K)=K
      UF=0.0
      RETURN
C
2     CONTINUE
      BLKINT(K)=TNOW
      UF=0.0
      RETURN
C
3     CONTINUE
      STRTOL(K)=TNOW
      UF=0.0
      RETURN
C
4     CONTINUE
      ENDOL(K)=TNOW
      UF=0.0
      RETURN
C
5     CONTINUE
      DEPART(K)=TNOW
      IF(K.EQ.66) THEN
        TRU=TIRU(1)
        WRITE(20,'("50",3X,F10.5)') TRU
        WRITE(20,'("60",3X,F10.4)') DEPART(K)
        WRITE(20,'("70",3X,I3)') NRUN
        WRITE(20,'("00   0000")')
      ENDIF
      UF=0.0
      RETURN
C
6     CONTINUE
      WRITE(20,'("2",3X,F6.4)') A
```

Figure E-2 (cont)

Ramp Operations Simulation Program

```
        UF=0.0
      RETURN
C
7     CONTINUE
      WRITE(20,'("3",3X,F6.4)') A
        UF=0.0
      RETURN
C
8     CONTINUE
      WRITE(20,'("4",3X,F6.4)') A
        UF=0.0
      RETURN
C
      END
C
C
      SUBROUTINE UI
C
      COMMON/QVAR/NDE,NFTBU(100),NREL(100),NRELP(100),NREL2(100),NRUN,
     +NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
C
      COMMON/OUTPUT/TARRAV(100),MISNUM(100),BLKINT
     +(100),STRTDL(100),ENDDL(100),DEPART(100)
C
      COMMON/PAY/K
C
C     TARRAV = ARRIVAL TIME
C     MISNUM = MISSION NUMBER
C     BLKINT = BLOCK IN TIME
C     STRTDL = START DOWNLOAD TIME
C     ENDDL  = END DOWNLOAD TIME
C     DEPART = DEPART TIME
C
      K=GATRB(1)
C
      DO 200,I=1,100
         TARRAV(I)=0.0
         MISNUM(I)=0.0
         BLKINT(I)=0.0
         STRTDL(I)=0.0
         ENDDL(I)=0.0
200   CONTINUE
C
      RETURN
      END
C
C
      SUBROUTINE UO
C
      COMMON/QVAR/NDE,NFTBU(100),NREL(100),NRELP(100),NREL2(100),NRUN,
```

Figure E-2 (cont)

Ramp Operations Simulation Program

```
     +NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
C
      COMMON/OUTPUT/TARRAV(100),MISNUM(100),BLKINT
     +(100),STRTDL(100),ENDDL(100),DEPART(100)
C
      COMMON/PAY/K
C
      K=GATRB(1)
C
      PRINT 90
      PRINT 100
90    FORMAT('1')
100   FORMAT(30X,25('-'),/,30X,'I AIRLIFT   FLOW   CHART I',/,30X,25('-'
     +),//,1X,83('-'),/,2X,'MSN',7X,'ACFT',6X,'ACFT',5X,'ACFT',5X,'ACFT'
     +,5X,'ACFT',5X,'ACFT',5X,'ACFT',5X,'GROUND',/,3X,'NO',4X,'TYPE/NO.'
     +,4X,'ARRIVE'
     +,3X,'BLOCK',4X,'AVAIL',4X,'S-DNLD',3X,'C-DNLD',4X,'DEPT',6X,'TIME'
     +,/,1X,83('-'),//)
C
      DO 110 I=1,66
      GT=DEPART(I)-TARRAV(I)
      IF(NRUN.EQ.1) THEN
      IF (I.EQ.17.OR.I.EQ.34.OR.I.EQ.51) THEN
         PRINT 90
         PRINT 100
      END IF
      IF (I.LE.50) THEN
         PRINT 115,I,TARRAV(I),BLKINT(I),BLKINT(I),STRTDL(I),
     +   ENDDL(I),DEPART(I),GT
      ELSE
         PRINT 116,I,TARRAV(I),BLKINT(I),BLKINT(I),STRTDL(I),
     +   ENDDL(I),DEPART(I),GT
      END IF
      ENDIF
115   FORMAT(1X,I3,3X,'C141/XXXXX',3X,F6.2,3X,F6.2,3X,F6.2,3X,F6.2,3X,
     +F6.2,3X,F6.2,3X,F6.2,//)
116   FORMAT(1X,I3,3X,'C-5A/XXXXX',3X,F6.2,3X,F6.2,3X,F6.2,3X,F6.2,3X,
     +F6.2,3X,F6.2,3X,F6.2,//)
110   CONTINUE
C
      RETURN
      END
```

Figure E-2 (cont)

Ramp Operations Simulation Program

APPENDIX F

PROGRAM EXPLANATIONS

The following program coding explanations have been reproduced from Pritsker's text on modelling and analysis of systems by using Q-GERT networks (25).

Fields*

1	2	3	4	5	6	7	8	9	10
REG or SOU	Node number	Initial number to release [1]	Subsequent number to release [∞]	Branching (D,P,F,A) [D]	Marking (M) [M if SOU, no M if REG]	Choice criterion (F,L,S,B) [L]/ Attribute [M]			
SIN or STA	Node number/ label	Initial number to release [1]	Subsequent number to release [∞]	Branching (D,P,F,A) [D]	Statistics desired (F,A,B,I,D) [F]	Upper limit of first cell [N]	Width of histogram cell [N]	Choice criterion (F,L,S,B) [L]/ Attribute [M]	
QUE	Node number/ label	Initial number in queue [0]	Capacity of Q-node [∞]	Branching (D,P) [D]	Ranking (F,L,S,B) [F]/ Attribute [M]	Block or node number for balkers (B) [balkers destroyed]	Upper limit of first cell [N]	Width of histogram cell [N]	Following S-nodes or match nodes or allocate nodes
SEL	Node number/ label	Queue selection rule [POR]	Server selection rule [POR]	Choice criterion (S, B) [B]/ Attribute [M]	Block or node number for balkers (B) [balkers destroyed]	Associated Q-nodes	(Repeats of Field 7)		
MAT	Node number	Matching attribute	Q-node/ Routing node	(Repeats of Field 4)					
SEE	Stream number	Seed[0]/ Initialization (I, N) [N]		(Repeats of Fields 2 and 3)					
VAS	Node number	Attribute number [1]	Distribution type (CO)	Parameter set [0]		(Repeats of Fields 3, 4 and 5)			
PAR	Parameter set number	Parameter 1 [0]	Parameter 2 $[-10^{20}]$	Parameter 3 $[10^{20}]$	Parameter 4 [0]	Stream number [10]			
ACT	Start node	End node	Distribution or function type [CO]	Parameter set or constant [0.0]	Activity number/ label	Number of parallel servers [1]	Probability or attribute number or order [.5]	Condition code [N,L,R] I=start node	
MOD	Activity number	Node out	Node in		(Repeats of Fields 3 and 4)				
TRA	Node number/ subnetwork ID		(Repeats of Field 2)						

* Default values are given in brackets [ ]. If no default is indicated, data for the field is required. Options for a field are given in parentheses ( ). A slash (/) and dashed line indicate the field may contain two entries where the slash and second entry are optional.

GEN - general project information

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	GEN	(Required)	= 'GEN'	8101
2	Analyst name	Alpha field (up 12 significant characters)	12 blanks	If present, first character must be alphabetic (only first 12 characters are processed)	102
3	Project name or number	Alpha field	12 blanks	(see previous field)	103
4	Month	Integer	1	Integer between 0 and 12	104
5	Day	Integer	1	Integer between 0 and 31	105
6	Year	Integer	2001	Integer between 1970 and 2001	106
7	Number of STAtistics nodes	Integer	0	Integer between 0 and maximum number of nodes	107
8	Number of SINk nodes	Integer	0	Integer between 0 and maximum number of nodes	108
9	Number of SINk node releases to end a run	Integer	value in Field 8	Integer	109
10	Time to end one run of the network	Real	1.E20	Positive real	110
11	Number of runs of the network	Integer	1	Positive integer	111
12	Indicator for output reports in addition to the final summary report	First Run, Each Run, Cumulative & Each Run, Summary Only	First	= 'F' or 'E' or 'C' or 'S'	112
13	Time from which statistics will be kept on each run	Real	0	Non-negative real	113
14	Maximum number of attributes with each transaction flowing through the network	Integer	0	Non-negative integer	114
15	Run number for beginning of event tracing	Integer	0→no tracing	Integer between 0 and value of Field 11	115
16	Run number for ending of event tracing (this run will be traced)	Integer	Value of Field 15	Integer between value of Field 15 and value of Field 11	116
17	Run number for beginning of nodal tracing	Integer	0→no tracing	Integer between 0 and value in Field 11	115
18	Run number for ending of nodal trace (this run is traced)	Integer	Value in Field 17	Integer between value in Field 17 and value in Field 11	116
19	Indicator that only input cards with errors are to be listed	Errors only All cards	All input cards listed	= 'E'	119
20	Execution option	E1 — No execution E2 — No execution if any input discrepancies E3 — No execution if fatal input discrepancy	E3	= 'E1', 'E2', 'E3', or 'E4' (E4 — Echo suppressed)	120
21	Largest node number defined by user. (Specify only when including subnetworks.)	Integer	MXNOD	Integer	
22	Largest activity number defined by user. (Specify only when including subnetworks).	Integer	MXNPO	Integer	

RES - *resource* type definition

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card Type	RES	(Required)	= 'RES'	8000
2	Resource Number/	Integer	(Required)	Nonnegative integer ≤ MXRES	8002
	Label	8 characters	Blanks		
3	Number of units of this resource type available	Integer	1	Positive Integer	
4-13	Resource ALLOCATE nodes to be polled when resource is freed	Integer	No ALLOCATE nodes associated with resource definition	Integer between 1 and maximum number of nodes	

SEE - Random number *seed* initialization (required only if seed values or reinitialization of seed values are desired)

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card Type	SEE	(Required)	= 'SEE'	8009
2	Stream Number	Integer	MXSTR=10	Positive Integer less than or equal to MXSTR	702
3	Random Number seed for stream specified in previous field/	Integer	Internal seed value	Integer	
	Reinitialization of stream	I→*I*nitialize seed to same value for each run N→*N*o resetting of seed	N		
4-21	Repeats of *Fields* 2 and 3.				

TRA - nodal *trace* Only one TRA card is permitted. If subnetwork nodes are to be traced, the TRA card must follow the ESN card associated with the subnetwork containing the node definition.

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	TRA	(Required)	= 'TRA'	8000
2	User-defined node numbers to be traced/	Integer	No user-defined nodes are to be traced	Integer and less than 50 nodes to be traced	1402
	Subnetwork ID number	Integer	No ID number		
3-49	Repeats of Field 2				1403

REG-*reg*ular node description or *SOU*-*sou*rce node description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	*REG* or *SOU*	(Required)	= 'REG' or 'SOU'	8000
2	Node number	Integer	(Required)	Integer between 1 and maximum number of nodes	8002
3	Initial number of incoming transactions to release the node.	Integer	1 if *REG* 0 if *SOU*	Non-negative integer (0 if and only if *SOU*)	8003
4	Subsequent number of incoming transactions to release the node (after the first release)	Integer (to specify infinite, use default)	Infinite	Positive integer	8003
5	Output characteristics of node	*P*robabilistic *D*eterministic *F*irst (conditional, take first) *A*ll (conditional, take all)	Deterministic	= 'P', 'D', 'F', or 'A'	205
6	Indicator that this node is to mark	*M*ark	M if SOU... No M if REG	= 'M'	206
7	Criterion for associating an attribute set with a transaction passing through a node/	Hold the attribute set of the transaction arriving *F*irst *L*ast or hold attribute set of the transaction with the *S*mallest value in a given attribute *B*iggest value in a given attribute	*L*ast	= 'F', 'L', 'S', or 'B'	207
	If *S*mall or *B*ig specified, the number of the attribute to be used or 'M' for mark time	Integer or 'M'	*M*ark Time	Integer between 1 and maximum number of attributes specified for a transaction or 'M'	7207

QUE - queue node description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	QUE	(Required)	= 'QUE'	8000
2	Node number/Label for output identification	Integer /8 characters	(Required)/ Blanks	Integer between 1 and maximum number of nodes	8002
3	Initial number in queue	Integer	0	Non-negative integer	403
4	Maximum number permitted in queue	Integer (to specify infinite, use default)	Infinite	Non-negative integer	404
5	Output characteristics of node	*D*eterministic *P*robabilistic	*D*eterministic	= 'P' or 'D'	205
6	Ranking procedure for Q-node/	*F*IFO-first in-first out *L*IFO-last in-first out *S*mall value first (based on attribute value) *B*ig value first (based on attribute value)	*F*IFO	= 'F', 'L', 'S', or 'B'	406
	For Q-nodes ranked by *S*mall or *B*ig, the number of the attribute on which the ranking is based	*Integer* or *M*ark Time	*M*ark Time	Integer between 1 and maximum number of attributes or 'M'	7207
7	Balking or blocking information	*B*locking or Integer = node number to which balkers are sent	Balkers are lost to system	= 'B' or integer between 1 and maximum number of nodes	407 8407 8408 8409
8	The upper limit of the first cell for the histogram to be obtained for this node.	Real or 'N'	N → no reporting of statistics	Real or 'N'	
9	The width of each cell of the histogram. Each histogram contains 20 cells.	Real or 'N'	N → no reporting of statistics	Positive Real or 'N'	
10-31	Selector nodes or the MATCH node on output side of Q-node (if any) (but not if a service activity emanates from the Q-node) When more than one S-node is specified, the order of appearance in these fields determines the priority given to the associated S-nodes.	Integer	No S-node or MATCH node node on output side of Q-node	Integer between 1 and maximum number of nodes	8410 8411

ALL - *all*ocate node description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	ALL	(Required)	= 'ALL'	8000
2	Node number	Integer	(Required)	Integer between 1 and maximum number of nodes	8002
3	Queue selection rule	3 character ID from list of queue selection rules (Table A1)	POR	= 3 character ID from Table A1	503
4	Resource number	Integer	1	Integer between 1 and max. number of resources	
5	Resource units required by waiting transactions at associated Q-nodes	Integer	1		
6	Q-node in which transaction is waiting for resources/	Integer	(At least 1 required)	Integer between 1 and maximum number of nodes	
	Node number to which transaction is to be routed when resources are allocated	Integer	No routing	Integer between 1 and maximum number of nodes	
7-16	(Repeats of Field 6)				

FRE - *fre*e node description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	FRE	(Required)	= 'FRE'	8000
2	Node number	Integer	(Required)	Integer between 1 and max. number of nodes	8002
3	Output characteristics	P, D, F, A	D	= 'P', 'D', 'F', or 'A'	
4	Resource number	Integer or Ak where k is an attribute number	1		
5	Resource units to be freed	Integer or Ak where k is attribute number	1		
6-15	ALLOCATE nodes in the order to be polled to allocate freed resource units	Integer	Use ALLOC list given in RES card for resource number	List of ALLOC nodes concatenated to list provided unless a negative value is given after list	

ALT - *alter* node description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	ALT	(Required)	= 'ALT'	8000
2	Node number	Integer	(Required)	Integer between 1 and max. number of nodes	8002
3	Output characteristics	P, D, F, A	D	= 'P', 'D', 'F', or 'A'	
4	Resource number	Integer or Ak	1		
5	Resource units to be freed	Integer or Ak	1		
6–15	ALLOCATE nodes in the order to be polled to allocate freed resource units	Integer	Use ALLOC list given in RES card for resource number	List of ALLOC nodes concatenated to list provided unless a negative value is given after list	

SEL - *sel*ector node description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	*SEL*	(Required)	= 'SEL'	8000
2	Node number/Label for output identification	Integer/8 characters	(Required)/ Blanks	Integer between 1 and maximum number of nodes	8002
3	Queue selection rule	3 character ID from list of queue selection rules (Table A1)	*POR*	= 3 character ID from Table A1	503
4	Server selection rule	3 character ID from list of server selection rules (Table A1)	*POR*	= 3 character ID from Table A1	504
5	For assembly nodes (field 3 = ASM), criterion for associating an attribute set with a transaction passing through the node/	Hold attribute set with the *S*mallest value in a given attribute *B*iggest value in a given attribute	*B*iggest	= 'S' or 'B'	207
	For assembly nodes (field 3 = ASM), the number of the attribute to be used or 'M' for mark time	Integer or M for *M*ark Time	*M*ark Time	Integer between 1 and maximum number of attributes for this simulation or 'M'	7207
6	Balking and blocking information	*B*locking or Integer = node number to which balkers are sent	Balkers are lost to system	= 'B' or integer between 1 and maximum number of nodes	407 8407 8409
7-16	Q-nodes associated with this selector. (Up to 10 fields may be entered.) When more than one Q-node is specified, the order of appearance in these fields determines the preferred order for selecting Q-nodes.	Integer	(At least one required)	Integer between 1 and maximum number of nodes	8507

SIN - *si*nk node description or *STA* - *sta*tistics node description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	SIN or STA	(Required)	= 'SIN' or 'STA'	8000
2	Node number/Label for output identification	Integer/8 characters	(Required)/ Blanks	Integer between 1 and maximum number of nodes	8002
3	Initial number of incoming transactions to release the node	Integer	1	Positive integer	8003
4	Subsequent number of incoming transactions to release the node (after the first release)	Integer (to specify infinite, use default)	Infinite	Positive integer	8003
5	Output characteristics of node	*P*robabilistic *D*eterministic *F*irst (conditional, take *first*) *A*ll (conditional, take all)	*Deterministic*	= 'P', 'D', 'F', or 'A'	206
6	Statistical quantities to be collected	*F*irst (time of first release) *A*ll (time of all releases) *B*etween (time between *releases)* *I*nterval (time interval from *most recent marking of transaction to release of this node)* *D*elay (delay from first ar-*riving transaction until the node is released)*	*F*irst	= 'F', 'A', 'B', 'I', or 'D'	306
7	The upper limit of the first cell for the histogram to be obtained for this node. The first cell of the histogram will contain the number of times the statistic of interest at this node had a value less than or equal to the value given in this field.	Real or 'N'	N → no reporting of statistics	Real or 'N'	
8	The width of each cell of the histogram. Each histogram contains 20 cells. The last cell will contain the number of times the statistic of interest at this node had a value greater than the upper limit of the first cell (Field 7) plus 18 x cell width (Field 8).	Real or 'N'	N → no reporting of statistics	Positive real or 'N'	
9	Criterion for associating an attribute set with a transaction passing through a node /	Hold the attribute set of the transaction arriving *First* *Last* or hold attribute set of the transaction with the *S*mallest value in a given attribute *B*iggest value in a given attribute	*Last*	= 'F', 'L', 'S', or 'B'	206
	If *Small* or *Big* specified, the number of the attribute to be used or 'M' for mark time	Integer or *Mark Time*	*Mark* Time	Integer between 1 and maximum number of attributes specified for a transaction or 'M'	7207

ACT - Activity description

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card Type	ACT	(Required)	= 'ACT'	9000
2	Start node	Integer	(Required)	Number of an existing node	9002
3	End node	Integer	(Required)	Number of an existing node (not an assembly node)	9003
4	Distribution or function type	2 character ID chosen from list of distribution types (Table A1)	*CO*	= 2 character ID from Table A1	1004
5	Parameter set number or value of constant	Integer or Real	0.0		1005
6	Activity number/	Integer	System-assigned	Integer between 0 and maximum number of activity numbers	1006 9006 9106
	Label for server identification	8 characters	Blank		
7	The number of servers represented by this branch	Integer	1	Non-negative integer	1007 9007
8 or	Probability (only applicable if start node has 'P' branching or start node is a SELector using RPS rule)	Real number between 0. and 1. or attribute number where probability is stored	0.5	Real number between 0. and 1. or non-negative integer	1008 9008
8	Order of testing conditions (only applicable if start node has 'F' branching* or start node is a SELector using POR rule**)	Non-negative number (integer or real)	*0* (= conditions tested in order of input	Non-negative number	9008
9	Condition code (only applicable if start node has 'F' or 'A' branching)	See Condition Codes List***	Start node released (Ni.R).	.	1009 9009 9010 9011

* For each activity emanating from a start node with F (conditional, take first) output, an order value should be specified. When the start node is released, conditions on associated branches will be tested in ascending order (low values first) based on this value.

** The "preferred order" for selection from free servers is ascending order (low value first) based on this value.

*** Condition codes allowed are:

T.ℛ.V	Time .ℛ. Value
T.ℛ.Ak	Time .ℛ. Attribute k
Aj.ℛ.V	Attribute j.ℛ.Value
Aj.ℛ.Ak	Attribute j.ℛ.Attribute k

where ℛ=(LT;LE;EQ;NE;GT; or GE)

Ni.R	Node i Released
Ni.N	Node i Not Released
NAj.R	Node Aj Released
NAj.N	Node Aj Not Released

PAR - *parameter set description*

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	PAR	(Required)	= 'PAR'	8000
2	Parameter set number	Integer	(Required)	Integer between 1 and maximum number of parameter sets	8902
3	Parameter 1	Real	0.	Real	903
4	Parameter 2	Real	-10^{20}	Real	903
5	Parameter 3	Real	10^{20}	Real	903
6	Parameter 4	Real	0.	Real	903
7	Random Number Stream	Integer	MXSTR=10	Integer	903

VAS - value assignments to attributes of transactions

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	VAS	(Required)	= 'VAS'	8000
2	Node number at which assignment is to be made	Integer	(Required)	Integer between 1 and maximum number of nodes	8802 8812
3	Number of the attribute to which the assignment is to be made	Integer	1	Integer between 1 and maximum number of attributes	8803
4	Distribution or function type for the assignment	2 character ID chosen from list of distribution types (Table A1)	*CO*	= 2 character ID from Table A1	804
5	Parameter set number for the assignment	Integer or Real	0.0	Integer or Real	805
6-26	(Repeat Fields 3, 4, and 5 to specify up to 7 additional assignments. Use only 1 *VAS* input card for each node at which assignments take place)				806 8807

FIN - finish of all networks

Field Number	Description	Value	Default	Editing	Associated Errors
1	Card type	*FIN*	(A blank card may be used in lieu of *FIN* card)	Blank card or = 'FIN'	1301 8000

APPENDIX G

VALIDATION INFORMATION

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS MILITARY AIRLIFT COMMAND
SCOTT AIR FORCE BASE, ILLINOIS 62225

20 MAY 1982

REPLY TO ATTN OF: TRPP (Maj Borin, 638-2951)

SUBJECT: Validation Information

TO: AFIT/LS
ATTN: Captains Ruesche and Wasem

1. Your terminal service model substantially reflects actual deployment operations and the concept of operations in current OPlans. The following suggestions are not essential to achieve accurate results, but will more closely reflect current plans and operations.

2. AFR 76-6, Movement of Units in Air Force Aircraft, is a joint regulation which accurately describes the functions performed by the unit and DAG/MCC and the functions performed by the aerial port unit (ALCE). A few of the functions listed in your Table 3-1 are not performed by the aerial port (i.e., weighing, correct discrepancies, load set up, etc.).

3. UFBCE is a AFRES/ANG UTC which exactly matches the UDL of the reserve aerial port flights. It is designed for an operations comprised of both unit deployments and resupply (i.e., pallet buildup/breakdown, truck loading, warehousing, etc.).

4. UFBCF is an old UTC which was used to task Mobile Aerial Port Squadrons and includes both airland and airdrop capability. This UTC is no longer used.

5. All aerial port personnel and equipment UTCs were completely redesigned in 1981 and are reflected in MANFOR/LOGFOR documents dated after 15 Feb 82.

6. Onload UTCs normally used in current plans are shown at Attachment 1. Fleet Service and vehicle maintenance UTC are not normally used for routine deployment operations. Loadmaster UTCs are only used for heavy, sustained air flows to ensure that marshalling yard activities do not impede the airlift schedule. A typical MOG of 3, 2 shift package would be UFBJB, UFBBX, UFBMF and UFBK3.

7. The MOG is an aerial port working MOG used to indicate the number of aircraft that can be simultaneously serviced. It is not a parking MOG. Therefore, aircraft should not be kept from blocking in just because the aerial port MOG has been reached. The aircraft will park and wait for an aerial port team to become available.

8. UTCs shown in Attachment 2 are used primarily in the objective area and provide a combined capability for unit reception, resupply, theater airlift operations and airdrop operations. UFBCD consisting of 47 personnel is now used in place of UFBCF to task active MAPS. This UTC represents 25% of an active MAPS; hence, each MAPS can deploy four UFBCDs.

GLOBAL IN MISSION — PROFESSIONAL IN ACTION

9. UTCs shown on Attachment 3 are used at major APOEs and APODs to provide the full range of aerial port services associated with a large air terminal. Fleet service and vehicle maintenance UTCs are the same as shown on Attachment 1.

10. The equipment UTCs you requested are at Attachment 4.

11. Reference your para 2.

a. UTCs are a little large for unit deployment. MOG of 9 (UFBBU X 3) is extremely heavy. This level of activity is rarely reached in an actual operation. Normal MOGs are between 1 and 5.

b. Onload times look good; off-load times look too long - specifically C-141 and C-5 pallet rates. Suggest 30 minutes for C-141 and 75 minutes for C-5 pallets.

c. Off-load personnel allocation ok; onload - suggest using UTCs on attachment 1. Spot checks and inspections by loadmasters (UFBQ_); Setups and load teams by load teams (UFBB__; Supervision/ATOC by supervisory UTCs (UFBJ_); pax processing by passenger UTCs (UFBM_).

d. Ok, except unit or DAG does much of this work. See AFR 76-6.

e. Onload outputs look good; off-load outputs look too long.

f. No change. Designed for average mix, Unusual onload (i.e., 5 C-5s, no no C-141s) will have tailored aerial port package.

g. Depends on how specific you want to get. Typical functions are:

(1) Verify number of seats available.

(2) Verify with DAG number of pax planned for load.

(3) Make adjustments when required.

(4) Assemble passengers.

(5) Check manifest.

(6) Perform head count.

(7) Brief pax.

(8) Escort to aircraft.

(9) Brief loadmaster.

(10) Load pax.

(11) Return to marshalling area.

(12) Find slots for pax dropped from pre-planned load.

12. If you need further information, please contact HQ MAC/TRP. Please send us a copy of the final thesis.

FOR THE COMMANDER IN CHIEF

[illegible]

L[illegible] G. [illegible], Col, [illegible]
D[illegible] Resources
[illegible]

4 Atch
1. Unit Move Operations
2. Aerial Port Unit Deployments
3. APOE/APOD Operations
4. Equipment UTCs

Thesis Authors' Note: Attachment 4 was not included in this thesis as it was not reproducible.

3

UNIT MOVE OPERATIONS

WORKLOAD MOG	WORKLOAD SHIFT	SUPERVISION	LOAD TEAMS	PAX SERVICE	FLEET SERVICE	VEHICLE MAINTENANCE	LOADMASTER	LOADING EQUIP	FLEET EQUIP
1	1	UFBJA	UFBBR	UFBMA	UFBN1	UFBNH	UFBQ1	UFBK1 (UFBLV)	UFBK5
1	2	B	S	B	2	M	2	1	5
2	1	A	S	C	1	H	3	2	5
2	2	B	U	D	2	M	5	(UFBLW) 2	5
3	1	A	T	B	1	H	4	3	5
3	2	B	X	F	2	M	8	3	5
4	1	A	U	D	1	H	5	4	5
4	2	B	Y	H	2	M	9	4	5
5+		UFBJE							UFBK6

AERIAL PORT UNIT DEPLOYMENTS

WORKLOAD S/T Per Day	MOG	PERSONNEL	EQUIPMENT		
125	4	UFBCD	UFBLX	) Deployment) Theater	Active (25% of MAPS)
175	5	UFBCE	UFBLY	) Reception,) Theater	Reserve
350	10	UFBCB	UFBLZ	) Airlift	"
175	5	UFBCA	UFBL3	) Strategic)	"
350	10	UFBCG	UFBL5	) Operations	"

APOE/APOD OPERATIONS

CARGO WORKLOAD	CARGO SERVICES PERSONNEL	CARGO SERVICES EQUIPMENT	RECOUPMENT	VEHICLE DISPATCH	PASSENGER WORKLOAD	PAX SERVICE
50 S/T per day	UFBB1	UFBL1	UFBP1	UFBV1	1,000 PAX per day	UFBMJ
100	2	2	UFBP1	2		
200	3	3	2	4	1,600	K
300	4	4	3	5		
400	5	5	4	6	2,000	L
500	6	6	5	7		
600	7	7	6		4,000	
700	8	8	UFBP8			M
800	9	9	UFBP8			

5 May 1982

Hq MAC/TRP
Attn: Colonel Dumont
Scott AFB, Ill. 62225

1. Attached is information that was extracted from Chapter 3 of our thesis. The information deals with the development of the terminal service simulation models which we have completed and have computerized. We are now at the validation and verification stage in which we verify the accuracy of the model (technically and as it approximates real life). We feel you and your staff are in the best position to validate the parameters and realism of the models we developed.

2. All attached appendicies are interrelated and should be reviewed as a whole before evaluating the parts. The following questions deal with the appendicies, and are provided to assist and guide you and your staff in the validation process. Don't hesitate, however, to cover any other areas which you feel we have missed.

1) Are the scenarios (Appendix A) realistic? What changes can you suggest to make the simulation more realistic or provide better information?

2) Do the parameters (Appendices B1 and 2) provide an accurate estimation of the times necessary to complete the activities described? Please keep in mind that we are dealing with aggregates thus our parameters should reflect the total time necessary to complete the activity per piece, load or aircraft.

3) Are the personnel allocations (Appendix B3) accurate? Are too many or too few personnel resources allocated to the tasks identified? Are there any tasks which are not covered? Note we are dealing in aggregates thus our parameters may include individual steps with the activities identified.

4) Are the networks as described (Appendices C and D) an accurate representation of the way the Mobile Aerial Ports would be expected to operate in wartime/contingency operations?

5) Do the outputs (Appendix F) accurately reflect what you'd expect to happen given the scenarios? Are any of the results unreasonable? If so, why?

6) Are any manpower changes made to any UTC's if the airlift flow is comprised of a mixture of C141's and C5's? C5's only? C141's only?

7) Should manpower for passenger loading/offloading be specifically identified for each load, or can a general deduction of resources be accomplished at the start of the onload/offload, to take into account the personnel needed to sheppard the passengers?

3. We will appreciate any and all comments you have as they will assist in improving the accuracy of our thesis. Additionally, we would appreciate copies of equipment UTC's which may be applicable to our model so that we may realistically allocate equipment. If you or your staff have any questions we can be reached through our thesis advisor, Major Tom Harrington (Transportation Program Manager), AV 785-4149. A second copy of the attachments are provided so that they may be annotated and returned with any other comments you may have.

4. We thank you in advance for you and your staff's assistance and support.

Michael A. Reusche, Captain, USAF
Graduate Student, Transportation

Vaughn D. Wasem, Captain,USAF
Graduate Student, Transportation

1 atch (2 copies)
Thesis Validation Information

Authors' Note: Only attachment F was included with this letter. All other attachments are included in the thesis as figures, tables or in other appendices.

AIRLIFT FLOW CHART

Legend:

MSN NO- Mission Number

ACFT BLOCK- Aircraft Block-In time as provided by the simulation.

ACFT AVAIL- Time aircraft is available to the load crews. Since we have not simulated maintenance, the time available will equal the block time.

ACFT S-UPLD- Aircraft Start Upload

ACFT C-UPLD- Aircraft Complete Upload

ACFT DEPT- Aircraft Simulated Airborne

NOTE: This computer prepared chart depicts the simulated handling of the scenario previously depicted using the UTC UFBCF. This flow chart is for aircraft onload and ties into cargo processing.

UFBCF

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-UPLD	ACFT C-UPLD	ACFT DEPT	GROUND TIME
1	C141/AAAAA	5.84	6.09	6.09	6.24	7.19	7.72	1.88
2	C141/AAAAA	6.47	6.72	6.72	6.89	7.81	8.34	1.87
3	C141/AAAAA	7.03	7.28	7.28	7.43	8.33	8.86	1.84
4	C141/AAAAA	7.62	7.87	7.87	8.02	9.09	9.62	2.00
5	C141/AAAAA	8.24	8.49	8.49	8.62	9.83	10.36	2.12
6	C141/AAAAA	8.92	9.17	9.17	9.34	10.27	10.80	1.88
7	C141/AAAAA	9.48	9.73	9.73	9.85	10.86	11.39	1.91
8	C141/AAAAA	10.11	10.36	10.36	10.51	11.68	12.21	2.10
9	C141/AAAAA	10.80	11.05	11.05	11.20	12.10	12.63	1.83
10	C141/AAAAA	11.53	11.78	11.78	11.91	13.02	13.55	2.02
11	C141/AAAAA	12.14	12.39	12.39	12.55	13.43	13.96	1.82
12	C141/AAAAA	12.80	13.05	13.05	13.21	14.38	14.91	2.11
13	C141/AAAAA	13.41	13.66	13.66	13.82	14.79	15.32	1.90
14	C141/AAAAA	14.09	14.34	14.34	14.51	15.78	16.31	2.22
15	C141/AAAAA	14.78	15.03	15.03	15.14	16.26	16.79	2.02
16	C141/AAAAA	15.51	15.76	15.75	15.95	17.08	17.61	2.10

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-UPLD	ACFT C-UPLD	ACFT DEPT	GROUND TIME
17	C141/AAAAA	16.07	16.52	16.52	16.69	17.31	17.84	1.77
18	C141/AAAAA	16.88	16.95	16.95	17.06	18.04	18.57	1.69
19	C141/AAAAA	17.38	17.63	17.63	17.78	19.09	19.62	2.25
20	C141/AAAAA	18.09	18.34	18.34	18.48	19.48	20.01	1.92
21	C141/AAAAA	18.75	19.00	19.00	19.15	20.19	20.72	1.97
22	C141/AAAAA	19.37	19.62	19.62	19.78	21.10	21.65	2.28
23	C141/AAAAA	19.96	20.21	20.21	20.36	21.30	21.83	1.87
24	C141/AAAAA	20.63	20.88	20.88	21.04	22.01	22.54	1.91
25	C141/AAAAA	21.24	21.49	21.49	21.65	22.60	23.13	1.89
26	C141/AAAAA	21.88	22.13	22.13	22.30	23.34	23.87	1.99
27	C141/AAAAA	22.50	22.75	22.75	22.93	24.01	24.54	2.03
28	C141/AAAAA	23.11	23.36	23.36	23.49	24.77	25.30	2.19
29	C141/AAAAA	23.78	24.03	24.03	24.19	25.41	25.94	2.16
30	C141/AAAAA	24.40	24.65	24.65	24.83	25.82	26.35	1.94
31	C141/AAAAA	25.03	25.28	25.28	25.41	26.59	27.12	2.09
32	C141/AAAAA	25.70	25.95	25.95	26.13	27.18	27.71	2.01
33	C141/AAAAA	26.40	26.65	26.65	26.78	27.80	28.33	1.93

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-UPLD	ACFT C-UPLD	ACFT DEPT	GROUND TIME
34	C141/AAAAA	27.05	27.30	27.30	27.46	28.36	28.89	1.84
35	C141/AAAAA	27.74	27.99	27.99	28.12	29.12	29.65	1.91
36	C141/AAAAA	28.36	28.61	28.61	28.76	29.80	30.33	1.97
37	C141/AAAAA	29.06	29.31	29.31	29.46	30.46	30.99	1.94
38	C141/AAAAA	29.74	29.99	29.99	30.14	31.08	31.61	1.88
39	C141/AAAAA	30.37	30.62	30.62	30.75	31.93	32.46	2.09
40	C141/AAAAA	31.01	31.26	31.26	31.43	32.50	33.03	2.02
41	C141/AAAAA	31.55	31.80	31.80	31.95	33.16	33.71	2.16
42	C141/AAAAA	32.15	32.40	32.40	32.55	33.65	34.18	2.03
43	C141/AAAAA	32.81	33.06	33.06	33.20	34.45	34.98	2.17
44	C141/AAAAA	33.41	33.66	33.66	33.81	34.89	35.42	2.01
45	C141/AAAAA	34.04	34.29	34.29	34.43	35.31	35.84	1.80
46	C141/AAAAA	34.75	35.00	35.00	35.15	36.16	36.69	1.94
47	C141/AAAAA	35.43	35.68	35.68	35.83	37.09	37.62	2.19
48	C141/AAAAA	36.10	36.35	36.35	36.51	37.65	38.18	2.08
49	C141/AAAAA	36.77	37.02	37.02	37.16	38.01	38.54	1.77
50	C141/AAAAA	37.36	37.61	37.61	37.75	38.95	39.48	2.12

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-UPLD	ACFT C-UPLD	ACFT DEPT	GROUND TIME
51	C-5A/AAAAA	37.56	37.66	37.86	38.43	41.42	42.86	5.30
52	C-5A/AAAAA	41.62	42.12	42.12	42.59	45.65	46.86	5.26
53	C-5A/AAAAA	45.91	45.91	46.41	46.64	49.52	50.75	4.84
54	C-5A/AAAAA	50.16	50.66	50.66	51.02	53.57	54.81	4.65
55	C-5A/AAAAA	54.36	54.86	54.86	55.43	58.56	59.81	5.45
56	C-5A/AAAAA	58.86	59.16	59.16	59.67	62.27	63.50	4.64
57	C-5A/AAAAA	62.86	63.36	63.36	63.86	66.95	68.19	5.33
58	C-5A/AAAAA	67.15	67.65	67.65	68.36	71.30	72.53	5.38
59	C-5A/AAAAA	71.37	71.87	71.87	72.31	75.01	76.25	4.88
60	C-5A/AAAAA	75.69	76.19	76.19	76.80	79.82	81.05	5.36
61	C-5A/AAAAA	79.97	80.47	80.47	81.02	83.96	85.19	5.22
62	C-5A/AAAAA	84.12	84.62	84.62	85.24	87.92	89.15	5.03
63	C-5A/AAAAA	88.42	88.92	88.92	89.40	92.16	93.39	4.97
64	C-5A/AAAAA	92.61	93.11	93.11	93.54	96.50	97.73	5.12
65	C-5A/AAAAA	96.92	97.42	97.42	97.67	100.70	101.93	5.02
66	C-5A/AAAAA	101.11	101.61	101.61	101.73	104.75	105.98	4.88

AIRLIFT FLOW CHART

Legend:

MSN NO- Mission Number

ACFT BLOCK- Aircraft Block-In time as provided by the simulation.

ACFT AVAIL- Time aircraft is available to the load crews. Since we have not simulated maintenance, the time available will equal the block time.

ACFT S-UPLD- Aircraft Start Upload

ACFT C-UPLD- Aircraft Complete Upload

ACFT DEPT- Aircraft Airborne

NOTE: This computer prepared chart depicts the simulated handing of the terminal services onload, previously discussed using the UTC, UFBCE. All times are in hours plus 100'ths of an hour vice hours and minutes.

UFBBU

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-ONLD	ACFT C-ONLD	ACFT DEPT	GROUND TIME
1	C141/XXXXX	6.00	6.25	6.25	6.25	7.94	8.27	2.27
2	C141/XXXXX	7.47	7.72	7.72	7.72	9.20	9.53	2.06
3	C141/XXXXX	8.56	8.81	8.81	8.81	10.35	10.68	2.12
4	C141/XXXXX	9.95	10.20	10.20	10.20	11.62	11.95	2.00
5	C141/XXXXX	11.33	11.58	11.58	11.58	13.10	13.43	2.11
6	C141/XXXXX	12.49	12.74	12.74	12.74	14.17	14.50	2.01
7	C141/XXXXX	13.83	14.08	14.08	14.08	15.52	15.85	2.02
8	C141/XXXXX	14.85	15.10	15.10	15.10	16.58	16.91	2.05
9	C141/XXXXX	16.09	16.34	16.34	16.34	17.72	18.05	1.97
10	C141/XXXXX	17.32	17.57	17.57	17.57	19.22	19.55	2.24
11	C141/XXXXX	18.66	18.91	18.91	18.91	20.44	20.77	2.11
12	C141/XXXXX	19.93	20.18	20.18	20.18	21.65	21.98	2.05
13	C141/XXXXX	21.23	21.48	21.48	21.48	22.97	23.30	2.06
14	C141/XXXXX	22.65	22.90	22.90	22.90	24.43	24.76	2.12
15	C141/XXXXX	23.74	23.99	23.99	23.99	25.36	25.69	1.95
16	C141/XXXXX	24.95	25.20	25.20	25.20	26.76	27.09	2.14

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-ONLD	ACFT C-ONLD	ACFT DEPT	GROUND TIME
17	C141/AAAAA	26.11	26.36	26.36	26.36	27.84	28.17	2.06
18	C141/AAAAA	27.42	27.67	27.67	27.67	29.22	29.55	2.13
19	C141/AAAAA	28.51	28.76	28.76	28.76	30.22	30.55	2.04
20	C141/AAAAA	29.79	30.04	30.04	30.04	31.49	31.82	2.03
21	C141/AAAAA	31.05	31.30	31.30	31.30	32.75	33.08	2.03
22	C141/AAAAA	32.40	32.65	32.65	32.65	34.28	34.61	2.21
23	C141/AAAAA	33.62	33.87	33.87	33.87	35.33	35.66	2.03
24	C141/AAAAA	35.05	35.30	35.30	35.30	36.76	37.09	2.04
25	C141/AAAAA	36.20	36.45	36.45	36.45	37.98	38.31	2.12
26	C141/AAAAA	37.45	37.68	37.68	37.68	39.08	39.41	1.96
27	C141/AAAAA	38.47	38.72	38.72	38.72	40.23	40.56	2.09
28	C141/AAAAA	39.75	40.00	40.00	40.00	41.42	41.75	2.00
29	C141/AAAAA	41.11	41.36	41.36	41.36	42.76	43.11	2.00
30	C141/AAAAA	42.35	42.60	42.60	42.60	44.17	44.50	2.14
31	C141/AAAAA	43.67	43.92	43.92	43.92	45.47	45.80	2.13
32	C141/AAAAA	44.77	45.02	45.02	45.02	46.57	46.90	2.13
33	C141/AAAAA	46.03	46.28	46.28	46.28	47.77	48.10	2.07

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-UNLD	ACFT C-UNLD	ACFT DEPT	GROUND TIME
34	C141/XXXXX	47.27	47.52	47.52	47.52	49.04	49.37	2.10
35	C141/XXXXX	48.50	48.75	48.75	48.75	50.22	50.55	2.04
36	C141/XXXXX	49.77	50.02	50.02	50.02	51.52	51.85	2.07
37	C141/XXXXX	51.09	51.34	51.34	51.34	52.89	53.22	2.12
38	C141/XXXXX	52.23	52.48	52.48	52.48	53.97	54.30	2.06
39	C141/XXXXX	53.56	53.81	53.81	53.81	55.17	55.50	1.94
40	C141/XXXXX	54.85	55.10	55.10	55.10	56.59	56.92	2.07
41	C141/XXXXX	56.09	56.34	56.34	56.34	57.89	58.22	2.13
42	C141/XXXXX	57.33	57.58	57.58	57.58	59.13	59.46	2.13
43	C141/XXXXX	58.49	58.74	58.74	58.74	60.23	60.56	2.07
44	C141/XXXXX	59.73	59.98	59.98	59.98	61.41	61.74	2.01
45	C141/XXXXX	61.00	61.25	61.25	61.25	62.75	63.08	2.09
46	C141/XXXXX	62.08	62.33	62.33	62.33	63.79	64.12	2.05
47	C141/XXXXX	63.38	63.63	63.63	63.63	65.13	65.46	2.08
48	C141/XXXXX	64.69	64.94	64.94	64.94	66.44	66.77	2.09
49	C141/XXXXX	65.98	66.23	66.23	66.23	67.68	68.01	2.04
50	C141/XXXXX	67.18	67.43	67.43	67.43	69.08	69.41	2.23

I AIRLIFT FLOW CHART I

MSN NO	ACFT TYPE/NO.	ACFT ARRIVE	ACFT BLOCK	ACFT AVAIL	ACFT S-UNLD	ACFT C-UNLD	ACFT DEPT	GROUND TIME
51	C-5A/AAAAA	68.52	69.02	69.02	69.02	72.99	73.83	5.30
52	C-5A/AAAAA	72.75	73.25	73.25	73.25	77.00	77.83	5.08
53	C-5A/AAAAA	76.94	77.44	77.44	77.44	80.91	81.74	4.80
54	C-5A/AAAAA	81.24	81.74	81.74	81.74	85.37	86.20	4.96
55	C-5A/AAAAA	85.43	85.93	85.93	85.93	89.54	90.38	4.95
56	C-5A/AAAAA	89.74	90.24	90.24	90.24	94.08	94.91	5.17
57	C-5A/AAAAA	93.98	94.48	94.48	94.48	98.15	98.98	5.01
58	C-5A/AAAAA	98.24	98.74	98.74	98.74	102.28	103.11	4.87
59	C-5A/AAAAA	102.51	103.01	103.01	103.01	106.76	107.60	5.09
60	C-5A/AAAAA	106.65	107.15	107.15	107.15	110.94	111.77	5.12
61	C-5A/AAAAA	110.88	111.38	111.38	111.38	115.12	115.95	5.07
62	C-5A/AAAAA	115.12	115.62	115.62	115.62	119.28	120.12	4.99
63	C-5A/AAAAA	119.29	119.79	119.79	119.79	123.30	124.13	4.85
64	C-5A/AAAAA	123.47	123.97	123.97	123.97	127.77	128.60	5.13
65	C-5A/AAAAA	127.72	128.22	128.22	128.22	131.76	132.59	4.87
66	C-5A/AAAAA	131.76	132.26	132.26	132.26	135.14	135.97	4.21

APPENDIX H

SENSITIVITY ANALYSIS

TABLE H-1

ANOVA Results 4-Way Interactions

(All Variables)

* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *

	ARU	AVERAGE RESOURCES UTILIZED
BY	UR	UPLOAD LEVEL
	IR	INSPECTION RATE LEVEL
	TR	TRANSPORT RATE LEVEL
	WR	WEIGHT RATE LEVEL
	SR	SETUP RATE LEVEL

* *

SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS			199.734	6	33.289	5918.531	0.000
UR			153.920	2	76.960	********	0.000
IR			41.806	1	41.806	7432.711	0.000
TR			2.784	1	2.784	495.012	0.000
WR			0.009	1	0.009	1.544	0.215
SR			1.215	1	1.215	216.081	0.000
2-WAY INTERACTIONS			45.020	14	3.216	571.731	0.000
UR	IR		43.806	2	21.903	3894.181	0.000
UR	TR		0.605	2	0.303	53.824	0.000
UR	WR		0.053	2	0.026	4.707	0.010
UR	SR		0.054	2	0.027	4.807	0.009
IR	TR		0.391	1	0.391	69.538	0.000
IR	WR		0.021	1	0.021	3.754	0.054
IR	SR		0.019	1	0.019	3.381	0.067
TR	WR		0.023	1	0.023	4.169	0.043
TR	SR		0.025	1	0.025	4.400	0.037
WR	SR		0.022	1	0.022	3.954	0.048
3-WAY INTERACTIONS			0.716	16	0.045	7.958	0.000
UR	IR	TR	0.363	2	0.181	32.229	0.000
UR	IR	WR	0.053	2	0.026	4.669	0.010
UR	IR	SR	0.058	2	0.029	5.183	0.006
UR	TR	WR	0.053	2	0.026	4.687	0.010
UR	TR	SR	0.049	2	0.025	4.392	0.014
UR	WR	SR	0.048	2	0.024	4.241	0.016
IR	TR	WR	0.031	1	0.031	5.540	0.020
IR	TR	SR	0.019	1	0.019	3.341	0.069
IR	WR	SR	0.023	1	0.023	4.045	0.046
TR	WR	SR	0.020	1	0.020	3.595	0.059
4-WAY INTERACTIONS			0.239	9	0.027	4.722	0.000
UR	IR WR	TR	0.052	2	0.026	4.636	0.011
UR	IR SR	TR	0.056	2	0.028	4.967	0.008
UR	IR SR	WR	0.059	2	0.029	5.228	0.006
UR	TR SR	WR	0.047	2	0.024	4.190	0.017
IR	TR SR	WR	0.025	1	0.025	4.455	0.036
EXPLAINED			245.710	45	5.460	970.783	0.000
RESIDUAL			1.091	194	0.006		
TOTAL			246.801	239	1.033		

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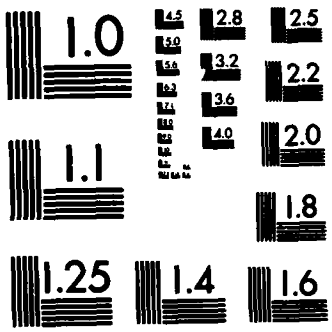
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TABLE H-2

ANOVA Results 4-Way Interactions

(Selected Variables)

* * * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * * *

ARU AVERAGE RESOURCES UTILIZED
BY UR UPLOAD LEVEL
IR INSPECTION RATE LEVEL
TR TRANSPORT RATE LEVEL
SR SETUP RATE LEVEL

SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS			199.726	5	39.945	5293.928	0.000
UR			153.920	2	76.960	*********	0.000
IR			41.806	1	41.806	5540.500	0.000
TR			2.784	1	2.784	368.992	0.000
SR			1.215	1	1.215	161.071	0.000
2-WAY INTERACTIONS			44.900	9	4.989	661.184	0.000
UR	IR		43.806	2	21.903	2902.805	0.000
UR	TR		0.605	2	0.303	40.121	0.000
UR	SR		0.054	2	0.027	3.583	0.029
IR	TR		0.391	1	0.391	51.835	0.000
IR	SR		0.019	1	0.019	2.520	0.114
TR	SR		0.025	1	0.025	3.280	0.072
3-WAY INTERACTIONS			0.489	7	0.070	9.259	0.000
UR	IR	TR	0.363	2	0.181	24.024	0.000
UR	IR	SR	0.058	2	0.029	3.864	0.022
UR	TR	SR	0.049	2	0.025	3.274	0.040
IR	TR	SR	0.019	1	0.019	2.490	0.116
4-WAY INTERACTIONS			0.056	2	0.028	3.703	0.026
UR	IR SR	TR	0.056	2	0.028	3.703	0.026
EXPLAINED			245.171	23	10.660	1412.718	0.000
RESIDUAL			1.630	216	0.008		
TOTAL			246.801	239	1.033		

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