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AN INVESTIGATION OF PRODUCTIVITY MEASURES FOR THE PEACETIME MAC--ETC(U)
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AN INVESTIGATION OF PRODUCTIVITY MEASURES FOR THE PEACETIME MAC AIRLIFT SYSTEM USING SYSTEM SIMULATION.

THESIS

AFIT/GST/OS/80M-3 Philip A. Richard
Capt USAF

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ducted with a simulation model of a portion of the MAC airlift system. Results from this experiment indicate that an activity index like departure reliability does not track system output, and, consequently, should not be regarded as a measure of system productivity. A set of productivity ratio indices was computed using the model input/output data from the system simulation. By emphasizing the relationship between output and input these ratio indices highlight system productivity and enable the MAC Commander or the airlift managers to make appropriate decisions regarding system productivity. In addition, productivity ratio measures have the potential for improving contingency planning by providing planners the ability to relate required output capacity to needed input resources, and also to determine output capacities constrained by input resources.

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AN INVESTIGATION OF PRODUCTIVITY MEASURES FOR THE PEACETIME MAC AIRLIFT SYSTEM USING SYSTEM SIMULATION

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of the

Master of Science

by

Philip A. Richard, B.S.

Capt USAF

Graduate Strategic and Tactical Sciences

March 1980

Preface

This research study was undertaken at the suggestion of Mr. Jim Reynolds of the Airlift Management Division, and Major "Pete" Milne of the Operations Research Division, Headquarters Military Airlift Command, Scott AFB, Il. Their perception of the problem went beyond mere dissatisfaction with departure reliability as the MAC measure of merit and helped to establish the tone of this study effort.

I have found the area of productivity particularly relevant and applicable to MAC. By getting our focus off the details of activities and onto system output we can hope to improve not only our peacetime productivity but also our wartime preparedness and contingency capability.

I am grateful for the assistance, encouragement and support provided by Colonel Charles R. Margenthaler, my thesis advisor, and Lt Colonel Thomas C. Clark, Jr., who helped me in many ways with the details of Q-GERT. I am also indebted to Lt Colonel James H. Havey for his understanding and support. Finally, I wish to express my love and appreciation for my wife, Denise, whose love and continual support, not to mention diligent work in typing this manuscript, have made this thesis as well as my stay here at AFIT a particularly rewarding experience.

Philip A. Richard

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Abstract

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AN INVESTIGATION OF PRODUCTIVITY MEASURES FOR THE PEACETIME MAC AIRLIFT SYSTEM USING SYSTEM SIMULATION

I Introduction

The mission of the Military Airlift Command (MAC), broadly stated, is to develop and maintain "in a constant state of readiness" an airlift system capable of responding expeditiously to any contingency airlift requirement, but especially strategic mobility. (Ref 1:1) To accomplish this, MAC operates a fleet of jet transport aircraft including 70 wide-bodied C-5s whose theoretical maximum capacity is some 100 tons and practical capacity 50 tons, and 234 C-141s, whose maximum capacity is some 30 tons. MAC also maintains a network of aerial ports and support bases throughout the United States, Europe and the Pacific. MAC is "manned at a level and exercised at an appropriate peacetime flying rate to insure the success of (this) airlift system. The peacetime use of the airlift system creates a by-product of airlift that is applied to satisfy (the Department of Defense (DOD)) airlift requirements." (Ref 2:1)

The term "by product" stresses that routine peacetime airlift is not the principal mission of MAC. Rather, because a certain amount of flying must be done to maintain crew proficiency as well as to exercise the maintenance and aerial port capacities of the system, the airlift capability produced is incidental.

While this peacetime "by-product" airlift is incidental to training, in the strictest sense, it is a valuable and needed service made available to DOD users either through direct funding as for Joint Chiefs of Staff (JCS) sponsored exercises and Joint Airborne and Air Transportability Training (JA/ATT) or through the Airlift Service Industrial Fund (ASIF), in broad service type groups or accounts: 1) the Special Assignment Airlift Mission (SAAM), and 2) Channel Traffic. The SAAM account provides for unique mission requirements or unusual airlift support needs, whereas, the Channel mission provides recurring support for overseas logistics functions and DOD installations.

TABLE 1-1

MAC Channel Military Capability and Utilization
(Ton-Miles in Millions) (Ref 16:1)

	Ton-Mile Capability	Actual Ton-Mile Requirement	Capability Utilization
1974	1853.6	1056.1	.57
1975	1802.3	967.5	.54
1976	1680.0	921.4	.55
1977T	418.4	196.5	.47
1977	1916.6	788.6	.41
1978	1763.0	778.2	.44
1979 (Projected)	1742.4	778.0	.45

While even peacetime aircraft utilization rates produce significant airlift capability this capability is not entirely productive. Table 1-1 lists ton-mile capabilities and actual ton-mile requirements for Fiscal Years 1974 through 1978 with budget projections for 1979. These capability figures represent what the airlift (force) fleet engaged in the Channel airlift mission could have transported if fully utilized. The actual requirements are what was actually transported for various DOD users. Note that these figures do not include SAAM, JAAT or Aeromedical Evacuations since these three mission areas are managed differently than the Channel mission. While the MAC airlift system is primarily poised in readiness for contingency airlift support the system does provide a valuable commodity. Furthermore, when this airlift commodity is not available to DOD customers they must turn to other transportation sources, even commercial air transport, to meet their needs. It is conceivable that a marginal improvement in MAC airlift system productivity would attract more DOD cargo in turn improving ASIF returns. Airlift ton-miles represent only a small portion of total DOD transportation requirements. Thus by making a larger portion of DOD cargo available for air transportation utilization of MAC capacity would not necessarily threaten commercial cargo contracts. There are many reasons why MAC peacetime airlift capacity is not more fully utilized and why the ASIF is often in deficit, however, at least part of the reason is that the productivity of the airlift system is not being totally harnessed.

At the present time system performance is measured by departure reliability primarily and by cargo age secondarily. Departure reliability is an indication of how well the individual flying units are at meeting flying schedules. The departure reliability index is computed as the ratio of successful on time departures (that is, departures within some interval defined about the scheduled mission take-off time) to the number of scheduled departures. The cargo age is a measure of how long cargo items remain in some portion of the MAC airlift system. The system-wide cargo age or "pipeline" time is measured from the time an item is consigned to MAC for delivery until the time that the user actually takes delivery of the item at the destination port. (Ref 21: i; Ref 22: 3) From the unit commander's point of view the departure reliability index measures how well the unit is able to marshall its resources to successfully execute a flying schedule. This reliability index lends itself to the way pre-mission activities follow one another from aircraft generation, to fueling and cargo loading, aircrew preflight and actual mission departure. Generally, late departures are further identified by assigning responsibility for the late departure to one of the major unit functional areas, specifically, Operations, Maintenance, Transportation or other support area. The local unit's cargo age, or "port hold" time includes port processing time and awaiting transportation time. The local port hold time is a representation of how fast cargo goes through the local port "system".

There are perceptions that these measures do not portray the whole system productivity/performance picture. Firstly, departure reliability measures an activity only--that of departing on time. This measure does not capture the impact on other system components. Secondly, there may be an actual conflict between measuring and emphasizing on-time departures on one hand and trying to improve total system productivity on the other. Thirdly, this departure reliability index and even port hold times are not used by the airlift managers and schedulers to allocate airlift support but rather port level measures and user established frequency levels. (Ref 14:8) What is needed then is some manner of gauging the airlift system's condition as well as response to specific management actions and decisions.

This thesis proposes to consider and develop an approach to the measure of performance for the peacetime airlift force. Since, as stated above, the mission of MAC is to prepare and be ready to provide contingency airlift support, the primary measure of performance for MAC is whether this goal of readiness and responsiveness is being met. This is largely a judgemental question based on the commander's assessment. Rather than attempt to address this overwhelming question this thesis aims at illuminating a more day-to-day problem encountered by airlift managers and unit commanders, that of measuring the productivity of peacetime airlift. The idea being that if productivity can be measured and the relevant factors can be understood, then the Commander of MAC can manage the system to enhance its productivity. A further limitation on the scope of the study is that only Channel mission productivity is investigated here. The Channel mission is the most open-ended of the three ASIF accounts. With both the JA/ATT and the SAAM accounts the users contract and pay for a dedicated capability, whereas reimbursement for Channel mission support is only for the actual capability used. Consequently, there is more room for productivity management in the area of Channel mission support. It is with these limitations, then, that this study is undertaken.

Methodology and Research Design

This study consisted of two separate phases. The first phase, or literature search, delved into the background of the problem itself and attempted to answer a number of questions: Why is the measure of productivity a problem in MAC? What has been done to measure MAC system productivity? What ideas have been developed concerning productivity in general and productivity measurement in particular? The results of this literature search are presented in Chapter II--System Productivity.

The second phase of this study consisted of system simulation experiments. The research design for these experiments consisted of answering the questions: What is going to be measured? How is it going to be measured? From Beer (Ref 7) we find that one way to establish system controls is to determine the factors that affect productivity most. Shannon explains that "Most systems operate according to the Pareto principle, that in terms of performance and effectiveness there are a few significant factors and many insignificant ones. In fact, the rule of thumb is that in most systems 20% of the factors will account for 80% of the performance, whereas the other 80% of the factors contribute the remaining 20% of the performance. Our problem is to decide which are the significant few." (Ref 40:153-154)

In line with this then a computer simulation model of the airlift system was defined and developed using Q-GERT techniques and computer codes. In his work on productivity (discussed in Chapter II) Paul Mali asserts that productivity is a relationship between system input and system output. Consequently, the model was designed with a view to relating particular system output levels of ton-miles, "pipeline" time, and departure reliability to system inputs such as flying hours, maintenance and port man hours and fuel. This effort is detailed in Chapter III--System Structural Model. To determine the significant factors and significant interactions a number of experiments were conducted consisting of operating the model with different combinations of factor levels. The particular experiments conducted are described in Chapter IV--Experimental Design. The results of each experiment were then analyzed for factor significance and interaction significance. The analytical techniques are described in Chapter IV, and the results are discussed in Chapter V--Experimental Results.

Thesis Report Organization

This report is organized as such. Chapter I--Introduction discusses the problem under study and the method employed to study it. Chapter II--System Productivity presents background material on the problem as well as on possible solutions. Chapter III--System Structural Model describes the airlift system computer simulation model used, how it was developed, the system assumptions made, the parameters used and the language employed. Chapter IV--Experimental Design discusses the experiments that were conducted using the system simulation model as well as the approach used to analyze the results. Chapter V--Experimental Results presents the results and analysis of the experiments described in Chapter IV. Finally, Chapter VI--Conclusions and Recommendations lists a number of conclusions derived from the observations in Chapter V, some recommendations for applications of the productivity measures described, and some recommendations for further study.

II System Productivity

Productivity is a concept that can have many different meanings. Basically, productivity is defined as: "The efficiency with which economic resources (men, materials and machines) are employed to produce goods and services." (Ref 46:332) That is, productivity is not merely production but production and resource consumption taken together. Two men are tasked to haul certain items on foot, one man is equipped with a shopping bag, the other with a wheelbarrow with a capacity of one-half cubic yard. If the task is to haul a couple loaves of bread the shopping bag is well suited and actually more efficient than the wheelbarrow. Both men are also capable of hauling a given amount of dirt, but the man with the wheelbarrow in hauling more than the gentleman with the shopping bag with essentially the same effort is being more productive. Now the man with the shopping bag could conceivably pile one-half yard of sand into, and out of, his shopping bag and try dragging it, but then the spillage and destruction to the bag would detract from his overall effectiveness. Consequently, then, productivity is related both to efficiency, as well as, effectiveness. In more complex situations involving many people, an extensive inventory of equipment and supplies, and a large budget productivity involves many kinds of inputs and many kinds of outputs. These inputs and outputs depend on an extensive set of interrelationships. Clearly, in such situations and organizations productivity is a system phenomenon. The parts interact to produce and this interaction must be exploited to increase output while maintaining control over inputs. Discussed in this chapter are the idea of a system, what it is and how MAC airlift is a system. Also covered is productivity in general, and system productivity in particular.

System Concept

The concept of a system can have many different manifestations. To some it is an array of mechanical or electronic components which has a well-defined function and observable process. To others "system" denotes a biological entity, which has unique powers of growth and reproduction. Still others perceive "system" as a mere interplay between conceptual entities as a system of equations. These examples of "system" understanding bespeak more an analytical framework than a truly "system" framework. Current thinking on "system" as exemplified by the General System Theory (GST) can trace its origins to a biological/organismic outlook. Bertalanffy, an early developer of GST, propounded that "In contrast to physical phenomena, like gravity and electricity the phenomena of life are found only in individual entities called organisms. Any organism is a system, that is, a dynamic order of parts and processes standing in mutual interaction." (Ref 39:9)

Furthermore, systems manifest certain characteristics (Ref 39:13-14):

1) interrelationships and interdependence of objects, attributes and events.

2) Holism, that is, the system is a unit rather than a

mere assemblage of constituent parts.

3) goal-seeking--the interaction of parts leads to a final result.

4) inputs and outputs--systems depend on inputs to generate the activity that results in goal attainment. Furthermore, all systems produce some kind of output.

5) transformation--all systems transform inputs into outputs in some way.

6) entropy or thermodynamic disorder--this is a pathologic characteristic of a rundown system as brought about by lack of input, information or formal organization.

7) regulation--interacting components of a system must be regulated in some fashion to insure goal attainment--this regulation includes the establishment of objectives, norms, plans and systems of control.

8) hierarchy--systems are generally comprised of several smaller sub-systems.

9) differentiation--specialized units in complex systems perform specialized functions.

10) equifinality--in open systems a particular final state can be attained from different starting points and by different paths.

In general then the main thrust of the systems outlook is that systems, and in particular organizations, are viable because of the characteristics outlined above. To effectively control an organization, then, these system characteristics must be considered and taken advantage of, not ignored and circumvented.

The MAC Airlift System

How, then, is the MAC airlift system a system? The MAC airlift system can be depicted in a number of schematic fashions. Figure 2-1 represents the MAC airlift system, at a very macro-level, as comprising of inputs, activities and services peculiar to MAC, and outputs. The dotted line serves as a boundary indicator between the airlift system over which MAC exerts direct control and the environment over which direct control, as opposed to mere influence, is minimal. Note that

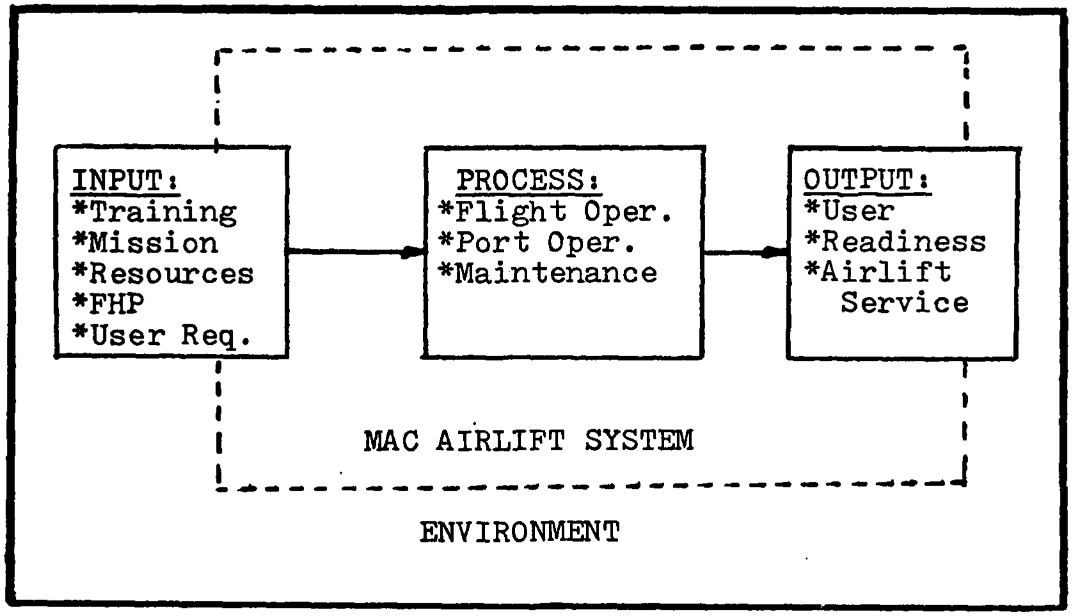


Fig 2-1 Input-Output Model of MAC Airlift System

a portion of the input and output blocks are depicted as part of the environment, this suggests interfaces with other systems, users, logistics, transportation, and so forth. The input block to the MAC system consists of, but is not limited to, readiness training requirements and goals, user airlift requirements, and the funds to accomplish these. The MAC airlift system contained within the borders consists of the personnel, capital equipment, supplies, funds, and organization needed to convert the inputs into desired outputs, thereby attaining its goal. The peculiar processes by which the MAC airlift system converts inputs into outputs includes flying aircraft, repairing and maintaining aircraft, operating an aerial port. The outputs of the MAC airlift system consist of a state of readiness, determined by both the availability and sustainability of airlift forces, and cargo tonnages and passengers moved in response to specific user requirements.

Figure 2-2 is an attempt to depict the airlift system, in particular the area within the borders of figure 2-1, with a causal loop diagram, as consisting of discrete components and activities interconnected and interrelated by flows (arrows) of material funds, personnel, requirements, information and so on. In general, a positive sign (+) indicates a direct correspondence between the two connected components, that is, an increase in one results in an increase in the other. Conversely, a negative sign (-) indicates an inverse relationship, an increase in one resulting in a decrease in the other.

Referring to Figure 2-2: The airlift system is set in motion by the requirement for readiness which generates flying training requirements. Airlift capacity generated by this training is programmed through ASIF at scheduling/programming which balances and coordinates training requirements and user airlift needs. Operations and logistics are related through the flying hour program. This program is an allotment of flying hours, actually the wherewithal to accomplish a specified number of flying hours including crew salaries, maintenance facilities and personnel, port facilities and manning, and the organization with which MAC must accomplish

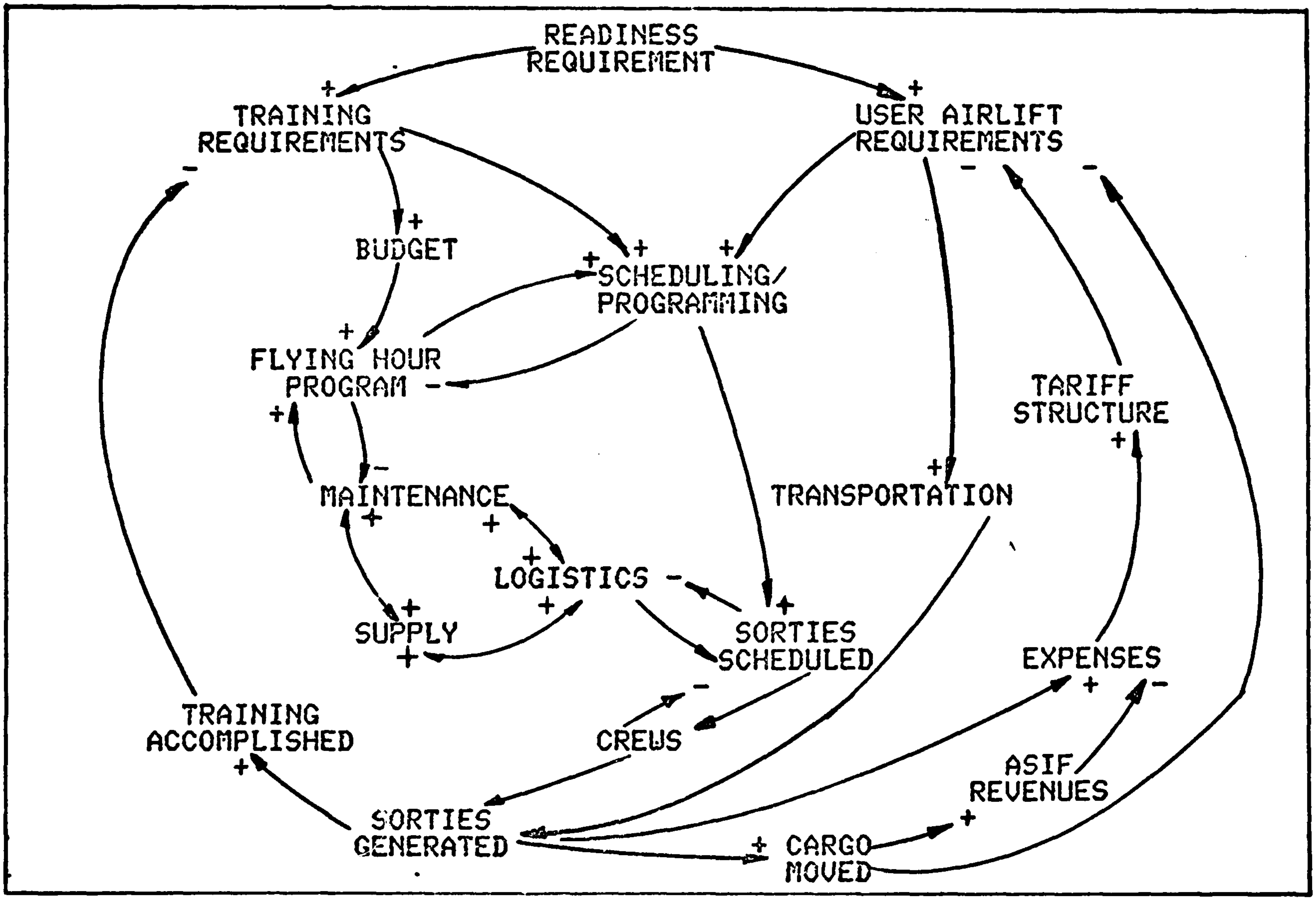


Figure 2-2 Causal Loop Diagram of Peacetime MAC Airlift System

its mission. When the scheduling operation schedules a mission, a demand is made on transportation, logistics, and on operations. As mission demands are made in each of these functional areas as the sorties actually depart there is marginally less capability to meet further demands. Demands must balance with capabilites. As the sorties actually depart and the missions operate, costs in terms of fuel, crew per diem, and labor man-hours are accrued. As cargo is moved ASIF revenues are generated to offset costs. Periodically ASIF revenues and expenses must be reviewed to set appropriate tariff rates. Excessively high tariffs act as disincentives to customers. As missions are completed training is accomplished which decreases the total training requirements. The only completely exogenous element is the readiness requirement. Training and user airlift requirements are partly conditioned by the system output. For the most part, then, the system establishes its performance levels. As various parts of the system are "speeded" up the other parts of the system must respond. When there is a lag or discrepancy in some part of the system the entire output is affected. Productivity is related to how well the interaction is managed and exploited. The existence of a tariff structure relating only to costs and revenues with no feedback for improved controls and management can drive this system to even less productivity. That is less ton-mile or poorer pipeline performance at the same level of input.

Table 2-1 tabulates several examples from the MAC airlift system of each of the systems characteristics.

TABLE 2-1

Examples of Systems Characteristics in MAC Airlift System

	GST Systems Characteristics	Examples from MAC Airlift System
1.	Interrelationship and Interdependence of Components	MAC organization, command and control
2.	Holism	MAC single manager of airlift resources
3.	Goal-seeking	Readiness, User Satisfaction
4.	Inputs and Outputs	AFM 2-21, AFM 3-21, AFR 23-17, DOD airlift requirements/readiness, ton-miles cargo, passenger-miles, user satisfaction, ASIF revenues
5.	Transformation	Cargo and passengers are moved from one place to another
6.	Entropy	Decrease in user demand due to high tariffs, budget cutback, organizational breakdown.
7.	Regulation	UMMIPS standards. MAC and AF series regulations governing every aspect of MAC activity
8.	Hierarchy	MAJCOM headquarters, Numbered Air Force, chain of command
9.	Differentiation	functional areas, operations, transpor-

TABLE 2-1 (continued)

	tation, logistics, plans
10. Equifinality	MAC offers many airlift services: Channel, Special Assignment Airlift Mission, Joint Airborne Airlift Training

Productivity

As delineated above every system in general and the MAC airlift system in particular, is characterized by among other things, a transformation of inputs into outputs and and by goal-seeking behavior. Corporate manufacturing systems employ manufacturing processes to transform inputs of raw materials into outputs of usable goods so as to meet a goal of customer satisfaction and profit generation. At some points in its development an organization becomes concerned with increasing its output and thus goal satisfaction while lowering resource consumption and utilization. What is being sought in this endeavor is higher productivity.

Paul Mali has written an excellent book on the subject of productivity (Ref 26) and in particular on the subject of managing productivity. He describes current productivity at large as being in a state of crisis and that the productivity management environment itself has changed considerably because of a change in human expectations, technology, and accountability.

In his investigations Mali has identified some twelve causes for the current productivity crisis, however, the number one cause he cites is the "shocking wastes of resources result(ing) from (an) inability to measure evaluate, and manage the productivity of a growing white-collar force." (Ref 26:25) The other eleven causes deal with the gamut of human motivational problems, government intrusion and overregulation, and the rapid obsolescence of skills and practice brought about by technological change. Table 2-2 summarizes these

TABLE 2-2 Causes and Effects of the Productivity Crisis (Ref 26:26)

Disruptive Trends	Productivity Action Factors	Effects on Productivity	Potential Organizational Problems
1. Emerging new work force	White-collar workers	Creates evaluation and managing difficulties	Waste of human resources
2. Increasing compensation without equal productivity.	Rewards	Pushes wages and prices up.	Escalation of inflation
3. Developing superorganizations.	Complexities	Decision making and resource accountability	Slow down in reaction time and muddling of resource use
4. Drive toward organizational expansion	Growth	Adding staff reduces productivity.	Soaring costs
5. Rising number of affluent workers.	Affluent attitudes	Changes traditional reasons for working	Low motivation
6. Growing deficiency of materials	Scarcity	Disrupts plans and schedules	Late deliveries
7. Difficulties in cooperation and coordination	Conflicts	Produces unresolved disagreements	Uncoordinated organization
8. Inhibiting effects of antiquated and inadequate laws	Laws and regulation	Increases disruptive legislative intrusions	Excessive and costly constraints
9. Work processes becoming restrictive	Specialization	Produces routine and boring work	Worker dissatisfaction
10. High cost for use of technology	Rapid changes	Affects existing capital investments	Reduction of new opportunities
11. Increasing desire for time off	Leisure	Creates need for discretionary time	Disruption of work commitments
12. Accelerating knowledge	Information	Makes practices outdated	Obsolescence of skills

twelve causes.

Fortunately, Mali perceives a solution to the problems. He asserts that the productivity crisis can be resolved by the development of a productivity management ethic and discipline, which he describes in three parts: 1) a basic conceptual framework of organizationsl productivity, 2) productivity as a synergistic or system-process, 3) 10 principles of developing the productivity discipline.

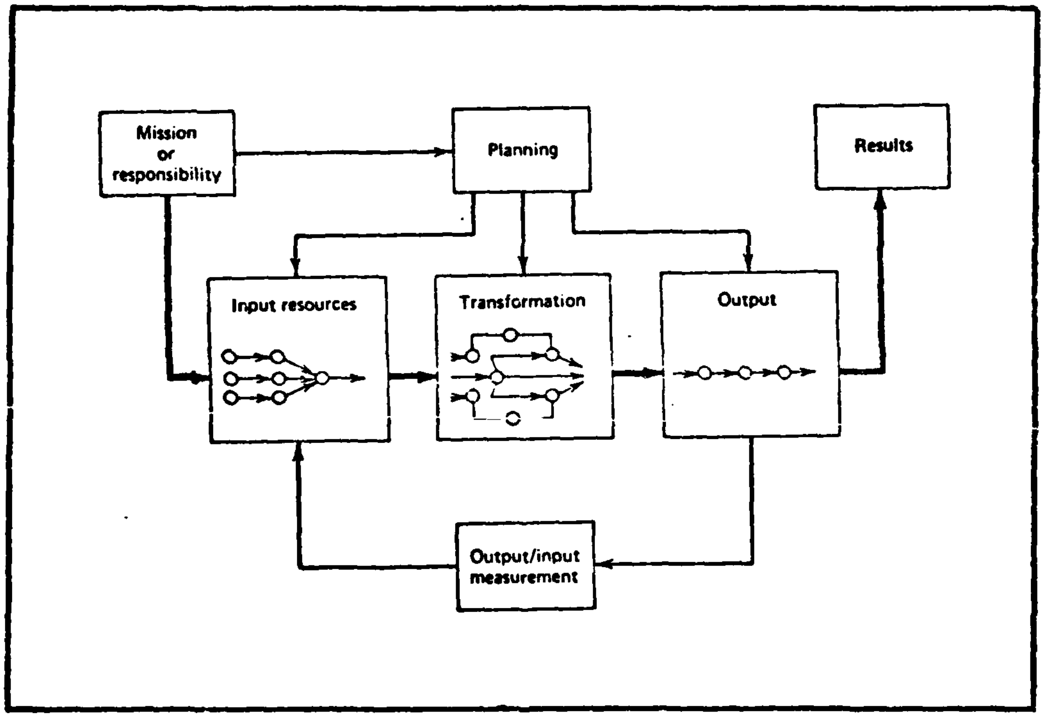


Figure 2-3 The Productivity Process (Ref 26:40)

In his conceptual framework of productivity Mali asserts that productivity is attained by taking action to achieve it: "Productivity in an organization is a managed process that identifies and relates all the events and activities necessary to accomplish productivity objectives. It deliberately seeks an efficient way to transform or convert resources into results." (Ref 26:45) This process is illustrated in Figure 2-3. Note that this diagram is effectively an enhancement of the first diagram of the MAC airlift system in Figure 2-1 to which planning and measuring functions have been added. From the diagram the process starts with a mission statement or objective definition. This action then leads to a master plan for operating the organization and to identification of inputs to the system. Planning delineates where the resources come from, how they are transformed by the organization and what form the output will take. The measurement cycle is an integral part of the system and acts as a feedback loop.

An important aspect of productivity, according to Mali, is that it is synergistic, that is, systemic. By synergism is meant the phenomenon that occurs when the well-ordered components of a system produce a result that is more than the mere assembly of the parts. Furthermore the organization of the system provides an infrastructure which enables the system to accomplish and produce at a level not possible by any one component or mere combination of components. Consequently, then the productivity that a system strives for must consider this synergism. Why? "Unused capacity, stored potential or low level of effectiveness are released or greatly enhanced when the parts or factors of the synergistic phenomena are made to work well." (Ref 26:54) Mali has identified some thirty factors at four different levels of directness which affect productivity. Table 2-3 summarizes these findings.

The way these factors interact and impact may vary from organization to organization. Furthermore, changes in factors at lower levels affect productivity by altering factors at levels just above them; and so on. Operating something like

TABLE 2-3

Levels of Factors Effecting Productivity (Ref 26:54)

Level	Effect on Productivity	
4	Most Direct ↑	Effectiveness and efficiency
3		skills, motivation, methods, costs
2		leadership, experience, climate, incentives, schedules, organizational structure, technology and materials
1	↓ Least Direct	abilities, style, training, knowledge, physical conditions, unions, social awareness, aspiration levels, processes, job design, goals, policies, R&D, plant and equipment, standards and quality.

the wheels of an odometer.

Finally, Mali rounds out his plan for developing the "productivity discipline" by describing his "principles of productivity growth" (Ref 26:62-73). Of particular interest and applicability to the MAC airlift system are:

--principle of ratio time measurement.
--principle of expectancy alignment.
--principle of worker accountability.
--principle of focus.
--principle of continuance.
--principle of resource priority.

The principle of ratio time measurement states that "Productivity is more likely to improve when expected results are measured and made greater in the same time frame that expected resources are measured and made less." (Ref 26:62)

Measurement here is the key. Mali asserts that if a phenomena can be measured it can, also be controlled and manipulated. No goal of productivity management is to increase output with a decrease in input. If productivity is expressed as a ratio of output to input then productivity increases it output increases and input decreases, stays level, or even increases but at a lower rate. Productivity still increases if total output decreases where input also decreases but at a higher rate.

Mali's principle of expectancy alignment asserts that "the greater the alignment of employee expectancies (needs) with organizational objectives (targets), the greater the motivation to accomplish both." (Ref 26:65) Along the same vein the principle of worker accountability states that "accountability for productivity is more likely to happen when employees understand, participate in, and are held responsible for productivity objectives, measurements, and evaluation." (Ref 26:65) At the very bottom of any effort to change an organization consideration must be given to the people involved. These persons are often viewed as the obstacles to ultimate productivity when in fact they are the most flexible and promising resource an organization has. Productivity management should hinge on personnel involvement and commitment.

The principle of focus is that "the greater the focus toward productivity objectives on a time scale, the greater the likelihood of achieving these objectives." (Ref 26:66). The stunning accomplishments of the Manhattan Project and of the manned space program came about because of this principle. Lately, public concern over energy shortages and prices has led to a concerted investigation of options to conserve energy, to tap alternate energy sources, and to alter our consciousness of energy problems. Similarly, when productivity becomes the "only game in town" interest and creative solutions inevitably follow.

The principle of continuance states that "productivity tends to continue when achieving an objective does not incapacitate or destroy any of the factors which produced it." (Ref 26:70). Fundamental to Mali's development of productivity is its systemic nature. Because of the interconnection and interdependence of the elements of a viable system it is impossible to modify one part of the system without also affecting the rest of the system. If system productivity is based upon a selective process of drawing down and building up the components of a system then the continued productivity of the system cannot be assured. At some point entropy, thermodynamic disorder, will bring the system to a halt.

Finally, and probably most importantly is the principle of resource priority which is that "productivity increases when objectives for productivity set the priorities for resource allocation." (Ref 26:73). In every organization there is some resource that acts as a constraint on the operation so that the resource must be carefully managed in order to optimize benefits and attain organizational goals. How these resources are meted out to various projects and objectives should be a measure of what the expected or perceived benefit of the objective is. Since an organization logically pursues greater benefits then resources must be allocated to produce this greatest benefit. A simple and straightforward measure of agreement between marginal benefit return of an objective and its resource allocation is the rank-order correlation. (Ref 26:73):

$$\rho = 1 - \frac{6 \sum d^2}{N(N^2 - 1)} \qquad (1)$$

where ρ is the rank-order correlation, and d is the difference between the benefit priority of an objective and its resource allocation priority, and N is the total number of objectives considered.

The benefit priority of an objective may be determined by marginal analysis of an operation or by consulting a panel of experts. Similarly, the resource allocation priority of an objective can be determined by observing the actual process or by having a panel assign a value. Observing a value directly in an actual operation or determining one democratically or arbitrarily depends on whether one is evaluating an ongoing operation or planning a future operation.

The other four principles of productivity growth are: principle of shared gain, principle of creating potential productivity and principle of work justice, and finally the principle of elasticity. While these four principles are notable in themselves they were not deemed to have the same direct applicability to the MAC airlift system.

How then do the other principles apply to the MAC airlift system? The principle of ratio time measurement speaks of increasing output and the same terms that input is decreased to insure productivity growth. It has been the MAC experience, discussed briefly at the end of this chapter, that productivity enhancements dealt with either input or output at any given time and then only one aspect of the input or output. Consequently, when the results fell short of expectations interest waned. What was overlooked was the synergism of the productivity effort. Various factors of input and output work in concert to produce noticeable productivity gains.

The principle of expectancy alignment and the principle of worker accountability have direct application to the MAC airlift system. Because of the nature of military service personnel turn-over is relatively high, resulting generally in low experience. Furthermore, when low morale is coupled to this, productivity can be expected to suffer. Consequently, an enlightened review of personnel policies is important not only for the stability of the military force but also for the productivity of the military work force. Additionally, the involvement and encouragement of personnel participation in productivity enhancement, as through the suggestion program, can achieve both worker satisfaction and increased system productivity.

The principle of focus is not new to the airlift system. The traditional emphasis on departure reliability as a measure of performance has resulted in remarkable efforts on the part of every functional area of the airlift system to improve that reliability index. Consequently, it is to be expected that if a concerted and coordinated effort is made to stress productivity enhancement that the results will follow.

The principle of continuance is of particular importance and applicability to the peacetime MAC airlift system. It has been observed that with the emphasis on departure reliability a considerable effort is made to improve the reliability standing. At times this effort has included circumventing the actual operational process when a problem arose to insure that at least the index itself would not be adversely affected. For example, last minute scheduled departure changes would be made to make up for a maintenance abort. While such an effort might be appropriate for a departure reliability indexed operation the same effort would not be appropriate in a productivity based operation. Productivity enhancement would demand that the effort and resources be allocated where the maximum productivity could be realized. A short term gain in the productivity index caused by "juggling" the operation could well manifest itself at some other point in the system as a net loss.

Similarly, the principle of resource priority is critical to MAC airlift system productivity. If one considers flying hours as MAC's principal resource, being comprised of fuel allocations, as well as maintenance, port and operations (crew) man-hours, then how these flying hours are allocated to various objectives, missions in this case, determines the net productivity of the airlift system. While it is true that the primary mission of MAC is to insure readiness to meet contingency airlift requirements and that raw flying hours can be translated into crew aging and thus readiness, DOD also depends on the MAC airlift system to provide a transportation service. Consequently, when that service capability is not available DOD agencies contract other transportation means to fulfill their requirements. This translates to paying for the same transportation twice because the airlift capability is not available where it is needed when it is needed for whatever reason. An airlift system oriented to productivity enhancement and improvement would seek out an optimum or, at least more satisfying allocation of its resources.

If it can be said that Mali's treatment of the theoretical basis of productivity and productivity improvement is complete then his treatment of the practical aspects of productivity is even more so. As has been observed and iterated above one of the principal causes of the productivity crisis in Mali's view, has been the inability to properly measure productivity. Therefore, it should not be surprising to realize that central to productivity improvement is measurement: "To be effective any system of productivity requires evaluation--evaluation readily understood, simple to implement, easy to administer, and clearly cost effective. This means that the evaluation system must have a basis of measurement that must be agreed upon and designed into the system for evaluation to work." (Ref 26:78)

To be sure productivity measurement is not easy, as Mali points out (Ref 26:79-80). For one thing simple measures tend to oversimplify the actual processes and dynamism in a system. A measure of productivity is important not just for indicating whether productivity has advanced or retreated but also why. Furthermore, if productivity has advanced, a good measure should help an organization capitalize on the process. If a retreat in productivity has occurred, appropriate measures help to locate problem areas and to reverse the situation. What is needed then is not a measure but several measures for different functional areas as well as for various levels of management. Another problem described is that measurement is generally appended to an operation rather than incorporated into the operations. Consequently, such measures offer excellent hindsight if not foresight. Still another difficulty in measuring is the all encompassing breadth of productivity and objective descriptions, such as cost-effective, responsive, "lean and mean", high "teeth or tail" ratio and so forth. While such expressions conjure up any number of salutory images of a system, in particular a military system, deciding whether a system has accomplished any of this is another matter. Measures should be unambiguous and unequivocal. Objectives and goals should also be stated in terms of concrete measures as well, for example, a ton-mileage increase of five percent this year, and so on. Another area that makes measuring productivity difficult is the tendency to focus in on activities rather than results. Any operation is comprised of several activities. Involvement with all of these bogs a system down in meaningless trivia. In many MAC offices piles of computer print-out detail a myriad of activity discrepancies and problems. The more important question of what substantive effect these anomalies have on overall output is often overlooked. A measure needs to be results oriented. Finally, traditional productivity measures have tried to emphasize the highest levels of aggregation, the most macro of levels, rendering the measure quite useless for lower organizational echelons. Measures, then, should be appropriately scaled to the level at which they will be used.

Mali then describes several forms that productivity measures may take including productivity ratios, total factor productivity indices, use of management by objectives, and the use of productivity checklists, and productivity audits. The ratio measures involve identifying the critical outputs and inputs of a system and computing the ratio of outputs to inputs. The total factor productivity index can be expressed either as total output over total input or as a total productivity link series, given by (Ref 26:93):

$$\text{Total Productivity link series} = \sum_{n=1}^{k} \left[\frac{P_1}{R_1} + \frac{P_2}{R_2} + \frac{P_3}{R_3} + \ldots \frac{P_k}{R_k} \right] \qquad (2)$$

where P is the productivity of a particular functional area and R its particular resource allocation.

In other words, the link series measure is a linear combination of disparate productivity measures and is useful in comparing index values with a given base value. The measurement of productivity using management of objectives (MBO) is known, if not necessarily appreciated, in the military services. At its basis MBO involves establishing concrete performance goals for each functional area and each level down to each individual and then observing how these specific objectives are attained. The difficulties associated with defining precise benchmarks for every job probably result more from a lack of experience with the method than any other factor. The use of checklists is a well established practice in the Air Force particularly in flight operations and in maintenance. The development of checklists delineating specific actions and responsibilities for each position is the basis of this approach. The productivity audit is "a process of monitoring and evaluating organizational practices to determine whether functional units, programs, and the organization itself are utilizing their resources effectively and efficiently to accomplish objectives." (Ref 26:132)

Up to this point the concepts and principles of systems theory and productivity improvement and the manner in which these describe the MAC peacetime airlift system have been reviewed. Additionally, the approach to productivity improvement as developed by Paul Mali was described together with its implication for the MAC airlift system. What follows is a discussion of the efforts and recommendations that have actually been made to measure and improve MAC peacetime airlift system productivity.

MAC Airlift System Productivity

The trend of the MAC Airlift System Productivity has been the topic of much discussion and study. This section of Chapter II briefly discusses the productivity constraints encountered by MAC operations and reviews some of the studies undertaken to improve MAC productivity. As described already in Chapter I the airlift capability of the MAC airlift system in ton-miles is derived as a by-product from MAC readiness training requirements. These requirements, comprise the Flying Hour Program, and reflect the raw flying hours to allow every crew member to accomplish specific training events as well as to experience a certain level of flying calculated to age them. This "aging" process is a critical factor in the development and training of aircrews to insure safe operation. Consequently, the flying hour requirements are established on more than just the absolute minimum number of hours needed to accomplish specific training events. The productivity of the MAC airlift system hinges on the effectiveness and efficiency with which these flying hours are generated and utilized.

The management of this flying hour generation at utilization cycle occurs at different levels. Essentially, the flying hours are generated at the wing level while they are scheduled or utilized at Major Command level. That is, the wing is responsible for transportation and logistic support resources to "produce" flying hours. The operations resources include aircrews, operations support staff personnel. The maintenance resources include maintenance man-hours performing scheduled and unscheduled maintenance and scheduled periodic inspections, equipment and tool resources and vehicle resources. The transportation resources include port dock and warehouse facilities, port man-hours to process cargo including receiving, documenting, writing, marshalling, palletizing and uploading, and vehicle resources including 463L Material Handling Equipment (MHE) utility vehicles, and associated maintenance and POL costs. The logistic support resources include capital equipment including the aircraft themselves, supply stockage, and supply man-hours to manage and operate the supply system including receiving, inspecting and documenting supply items, reparable assets control, and supply warehousing facilities. Added to this are the other support functions which serve as infrastructure to the entire process. It should be obvious that Figure 2-2 barely scratches the surface in depicting the interaction of components in the MAC airlift system.

Actual management actions in each of the functional areas decribed above rely on the information derived from specifically tailored performance or effectiveness measures. A variety of performance measures is used in the "Commander's Management Information Summary" a volume of data on various aspects of MAC operations published by Headquarters MAC. In this volume operations focuses on departure reliability, that is, getting the aircraft airborne on time. Maintenance, while also concerned with departure reliability, is more concerned with maintenance man-hours per flying hours and unscheduled maintenance man-hours to scheduled or total maintenance man-hours. Transportation is concerned with the level of cargo in the port awaiting transportation, port processing times and port holding times. Logistics supply support is concerned with a host of measures that track documentation errors, delinquencies in receiving reparable assets from base repair facilities and various stockage rates. Obviously, the idea of an aggregated measure of productivity index is buried in considerable detail.

The utilization of MAC's flying hour capability is performed at Headquarters MAC and at the Numbered Air Force Headquarters. Headquarters Military Airlift Command (HQMAC) assumes the responsibility of programming or allocating the flying hours to various mission areas and functional areas. The Numbered Air Force's concern themselves with developing a workable schedule and workflow for all of the wings directly subordinate to them. It is in the process of implimenting these schedules that the Wings generate the flying hours as described above.

The chief tool used by HQMAC in programming the flying resources is actually a budgeting process. Since 1958 MAC (then MATS, Military Air Transport Service) has provided airlift service through the Airlift Service Industrial Fund (ASIF). The industrial fund was a management process devised by DOD to insure effective and equitable management of resources and industrial-type services used by several branches in DOD. Narragon and Neil have compiled a thorough analysis of the Transportation Industrial Funds in their report for The Logistics Management Institute (Ref 28).

The HQMAC flying hour programming cycle begins with the identification of training requirements in flying hours which become the airlift resource when transformed by the airlift system. Next, projected DOD requirements for passenger and cargo airlift also expressed in flying hours, are obtained. Additionally, JCS sponsored exercises, as well as Joint Airborne and Air Transportability Training (JA/ATT) requirements are identified in flying hours. Then the programming and allocation begins, once the proper deductions have been made for direct training requirements. This amounts to some 25% of the total flying hours [some 117,374 flying hours (Refs 16-20) was projected for direct training in FY 1980]. These direct training requirements as well as the JCS exercises and JA/ATT missions will generate no by-product airlift. Consequently, funding is direct for these three categories of flying-hours. What is left at this point [260,281 flying hours projected for FY 1980 (Refs 16-20)] is programmed through the ASIF. There are two categories of services in ASIF--Channel Mission and Special Assignment Airlift Missions (SAAM). The Channel Mission consists of securing logistic support service to overseas bases. The frequency for this service is based either on a validated frequency basis, that is, a minimum frequency established on the basis of collateral requirements including national policy and morale as well as the primary basis of logistic support need, or requirements basis which reflects actual support needs. Reimbursement for Channel service is on a ton-mile basis for cargo or a set fee for passengers. The SAAM consist of unique airlift requirements and amount to chartering an airplane for a length of time. Presidential support missions and some disaster relief support missions are examples of SAAMs. Reimbursement for a SAAM is on the basis of a flat hourly fee based on aircraft operating costs. Rate structures are established to recapture expenses of operating the fleet. There is no incentive or attempt to make a profit.

While the ASIF was established as a means of managing industrial type service effectively the ASIF structure has had a pejorative effect on MAC productivity. Several features of the ASIF plan, including the validated frequency Channel missions over non-productive routes, make the MAC system inefficient. Consequently, when tariff rates are established to balance revenues and expenses the impact of inefficient utilization of Channel service results in rates which cannot compete with surface transportation rates, particularly ships. Service transportation managers are then disinclined to ship by air, leading to even poorer utilization overall and thus a recurrence of the initial problem (Ref 28: 30).

Studies and recommendations in this area of airlift system productivity have fallen into two principal areas: 1) creation of greater airlift requirements by removal or reduction of tariff disincentives, 2) enhancement of mission or sortie productivity. Narragon and Neil (Ref 28) have reviewed several proposals made over the years to remove ASIF disincentives to more product employment of airlift capability. These have included rate stabilization, token tariff rates, flooring of funds, and direct funding. Some efforts have been made to establish rate stabilization and opportunities for token tariffs. The case for flooring of funds and direct funding seems harder to make since both can be demonstrated to cause other problems in the general DOD transportation system. The General Accounting Office has also studied the problem from a costs versus revenue standpoint and recommended that tariffs be made to more closely reflect expenses. As indicated above this would introduce an economic disincentive to the use of airlift. Another important area of study has dealt with the validated frequency Channel mission, particularly when mission scheduling is driven by the minimum frequency rather than actual movement requirements. The constraints on many of these validated frequency missions are collateral to airlift management and involve morale, power projection and foreign policy.

The other area of study has emphasized mission/sortie productivity. Studies of this type have been performed by Lockheed, HQMAC/DO, Operation and HQMAC/XPSR, Studies and Analysis-Operations Research. These three are discussed in the Airlift Management Procedures Study (AMPS) published by HQMAC/XPSR in 1972 (Ref 23). The Lockheed study emphasized the need to better utilize aircraft cabin space by improving the design of pallet loads. Their study pointed out that a survey indicated that poor management practices allowed too many inefficient palletized loads be uploaded in C-141 aircraft. Their proposed solution was to more closely monitor pallet capacity utilization. The MAC/DO study conducted in the early 1970s assailed the emphasis placed on effectiveness performance measures, in particular departure reliability, to the detriment of other important measures, in particular airlift efficiency. The study proposed the implementation of a deliberate aircraft delay when the delay would mean greater payloads. The proposal was based on an analysis of payload and mission efficiency factors and involved several interesting mathematical relationships and decision graphs. The emphasis of the AMPS was again on the exclusion of efficiency considerations when measuring MAC performance. The study findings were never formally implemented by MAC.

A more recent investigation of sortie productivity has looked into the relationship between port levels and capacity utilization, the greater of volume capacity or weight capacity utilization. The report findings and recommendation (Ref 27) reflect a nonrigorous analysis of such factors as selectivity and the time-series nature of cargo generation. Basically, the report identifies a direct relationship between port levels and capacity utilization and between day of the week of mission operation and capacity utilization. This latter finding reflects weekend cargo policies, wherein few cargo deliveries are made on weekends so that port levels are drawn down over the weekends resulting in low port levels and lower capacity utilization at the start of the new week. The report was hastily accomplished but did point up an area that might be successfully exploited for productivity gains.

Outside of the MAC community other studies have been made to enhance MAC productivity. In particular, several Army studies conducted during the late 1960s and early 1970s. These involved the Routine Economic Airlift (REAL) study which proposed to identify whole new classes of air-eligible cargo. The aim was to associate an equipment item's overseas stock priority with a tariff rate ceiling. Thus a particular item or group of items could be shipped by air if the tariff charged was less than or equal to this maximum tariff value. The idea was that various savings could be realized in crating and packing certain items for sea shipment if they were sent by air. It was hoped that implementation of the proposal would lower overseas stock levels and thus DOD equipment investment by lowering the "pipeline" time for more classes of equipment. This "pipeline" concept is a measure of the time an item spends in a particular transportation system from the time the item is received for shipment to the time it is consigned to the receiver at destination. Another Army idea that has received continued study has been the Air Line of Communication (ALOC) concept. Again, by relying on the more rapid shipment times available with an air transportation system the Army could alter overseas logistics policies to take advantage of the shorter "pipeline" time. One of the more persuasive criticisms of the ALOC concept speculates on the possible impact on the ALOC of airlift emergencies or contingencies. With lower stock levels, accommodated by the availability of rapid and responsive airlift, the Army could find itself in a desperately short position if an emergency diverted airlift away from the ALOC.

The 1973 oil embargo brought to MAC a new-found fuel conservation concern. A study was conducted of fuel conservation techniques. The study was particularly concerned with highlighting the problem for aircrews responsible for fuel planning.

A new study program undertaken by MAC in 1974 promises to provide a methodology for evaluating MAC system performance and productivity over the long range. The study program, entitled Military Airlift Command Resource Optimization (MACRO), employs an extensive simulation model to model and characterizes the effects on the MAC airlift system in peacetime or wartime of any of numerous system factors. The model employs a micro-perspective and considers resource interactions and constraints at a very detailed level. Effectively by modeling "reality" the program aims to elicit a response about any aspect of the MAC airlift system, present or future within twenty-four hours. The program is currently still under development with an initial capability predicted for late 1980.

Summary

This chapter has developed the background to the thesis study. Entitled "System Productivity" the chapter has discussed the systems concept and its characteristics, as well as, their application to the MAC airlift system. System productivity as embodied in the work by Paul Mali was discussed. System productivity is the result, it was found, of the rich interactions of a system. Consequently, productivity is necessarily a system response. Productivity improvement takes a concerted and committed effort. Basic to any productivity management effort is a means of measuring productivity. These means must make the productivity processes transparent to management inspection, so that problem areas can be worked out and particularly productive interactions enhanced and exploited. The means of measuring productivity may be broken down into five areas: 1) ratio measures of system output to input; 2) total factor indeces, particularly useful in comparing a given year with a base year, 3) management of productivity by objective, 4) productivity checklists, and 5) productivity audits.

Next, the MAC airlift system productivity environment was discussed. MAC airlift capability is essentially a by-product of readiness training. What is not needed for direct training or JCS exercises and Joint Training is made available to DOD customers through the ASIF. Because of the mechanics of the ASIF MAC finds itself in a constrained market. Low operations efficiency coupled with a tariff rate structure that is high when compared to alternate surface transportation means has resulted in many customers being driven to surface transportation--further aggravating the situation.

The constrained productivity of MAC has been the subject of several studies including several that aimed to remove ASIF disincentives in order to attract more customers. A number of studies by MAC and Lockheed to improve sortie productivity by better utilizing pallet capacity and by waiting for cargo. A recent study suggests a relationship between mission efficiency and port levels.

A number of Army studies have attempted to identify classes of cargo for economic routine airlift, while other Army studies have proposed an ALOC system aimed at reducing overseas stock levels and thus costs.

The most recent addition to the productivity study effort has been MACRO. The aim of the undertaking is to capture MAC airlift system dynamics through computer simulation modeling and to use this facility to answer questions about the MAC system. From the title of the program the optimization of resource allocation promises to impact productivity of the MAC system.

III SYSTEM STRUCTURE

Discussed in this chapter is the principal tool used in the investigation of productivity measures, an airlift system simulation. Part of the problem discussed in Chapter I is the reliance of departure reliability as a measure of system performance. The objective of the simulation model is to illustrate: 1) that departure reliability is not a measure of productivity and that it does not reflect many of the forces acting in the airlift system, and 2) that relatively simple and straightforward ratio measures of productivity can be developed, which can impart more knowledge about the system's dynamics and capabilities. With this objective in mind the model was designed to behave as a portion of the MAC airlift system in such a way that productivity could be measured as different ratios of output to input. The output of the MAC system model is ton-miles, pipeline times, and departure reliability. Input to the model system consists of maintenance man hours, port man hours, flying hours, and fuel. The scope of the model is limited to the United States to Europe Channel missions. This was done so that sufficient detail could be captured about the interaction between operations maintenance and transportation/aerial port. The assumption here is that the manner in which inputs are transformed into outputs in a portion of the MAC system is essentially the same process for the entire MAC system but on a larger scale. What can be concluded, then, from looking at a sufficiently well-represented portion of the system can also be concluded about the MAC system at large. Sections in this chapter include Simulation Rationale, Model Assumptions and Limitations, Determination of Model Parameters, Q-GERT Approach, Model Output, and Model Verification and Validation.

Simulation Rationale

The overall objective of the study is to develop a method and an approach to measuring performance, in particular productivity, of the MAC peacetime airlift system. Beer in his essay on "Control Systems" asserts that system measures are suggested by "The most important features of the system." (Ref 7:153) That is, key features which enhance or retard productivity. Then features can be identified from experience and observation as well as from a concerted investigation of system factors and interactions. This investigation can consist of evaluating actual system inputs and outputs using statistical significance testing techniques. However, the MAC airlift system is a large enterprise and obtaining comprehensive data can be a colossal task. Additionally, as Easterfield suggests, "The origin and meaning of any figures found in firms should be scrutinized very carefully before they are used for purposes other than those for which they were intended." (Ref 12:41) That is to say input and output figures may appear to indicate one thing but may actually relate to some other perspective because of the way in which they were defined, calculated and reported. To insure validity and consistency the environment of the investigation must be carefully controlled. Unfortunately, the MAC airlift system is a large system to deal with. Furthermore, to obtain particular data points tampering with the system could disrupt the very processes that are being observed. The Heisenberg principle deals with the ambiguity engendered by the disruptive effects of the act of measuring. (Ref 40:11) The use of a simulation model, however, appears to offer a reasonable compromise to experimentation with the actual MAC system itself. There are a number of advantages to using simulation to study a system. First of all, the process of reducing real system behavior to computer model system behavior imparts insight to the real system. Secondly, the computer "system" can be exercised over a wide range of conditions, not practical or possible when dealing with the real system, in order to investigate unique relationships and dynamics. Third, time frames can be greatly compressed. Long periods of time can be simulated in relatively little simulation time. (Ref 40:11-12)

Model Assumptions and Limitations

The simulation model developed here is designed to measure output and input of the MAC system. That is, the model emulates the real system in that missions are flown subject to a scheduling policy, modeled by a probability density function. The value of the model is in comparing one set of circumstances, system environment, management policy with another, not in determining "real" parameters. The model parameters are based on observation of the system and from data obtained from a month's Channel operations. The model flows aircraft and cargo through the "system" in a manner comparable to the real system. However, values for maintenance man-hours and port man-hours represent estimations of direct Channel mission support. Pipeline times are computed from simple assumptions. The value of these parameters, then, is not in comparing them with actual system parameters but in comparing them with the parameters generated by the model under a diffent set of circumstances. Figure 3-1 depicts a schematic of the model's flow. Cargo arrives to the port with a particular frequency. This frequency is one of the parameters varied to determine the effect of low port levels and selectivity. Missions are generated with a normally distributed "interarrival time" based on observation of the system and from the mission data collected. Aircraft and crews are scheduled at mission generation time with appropriate delays. There is no limitation to the number of crews or to the number of aircraft, although system parameters are based on certain assumptions about fleet size. The Channel mission is between the US port, an aggregation of Eastern MAC bases, and the European port, an aggregation of NATO installations. The mission flight time is drawn from a distribution of times representing all MAC Channel missions operating between Eastern US bases and Europe. The variation in time accounts for differences in destination as well as enroute winds. Aircraft transactions will proceed through loading with no load at all or only a partial load if the port level is low. The aircraft do not wait for cargo. The cargo waits for the aircraft. This models the aircraft capacity utilization dependence on

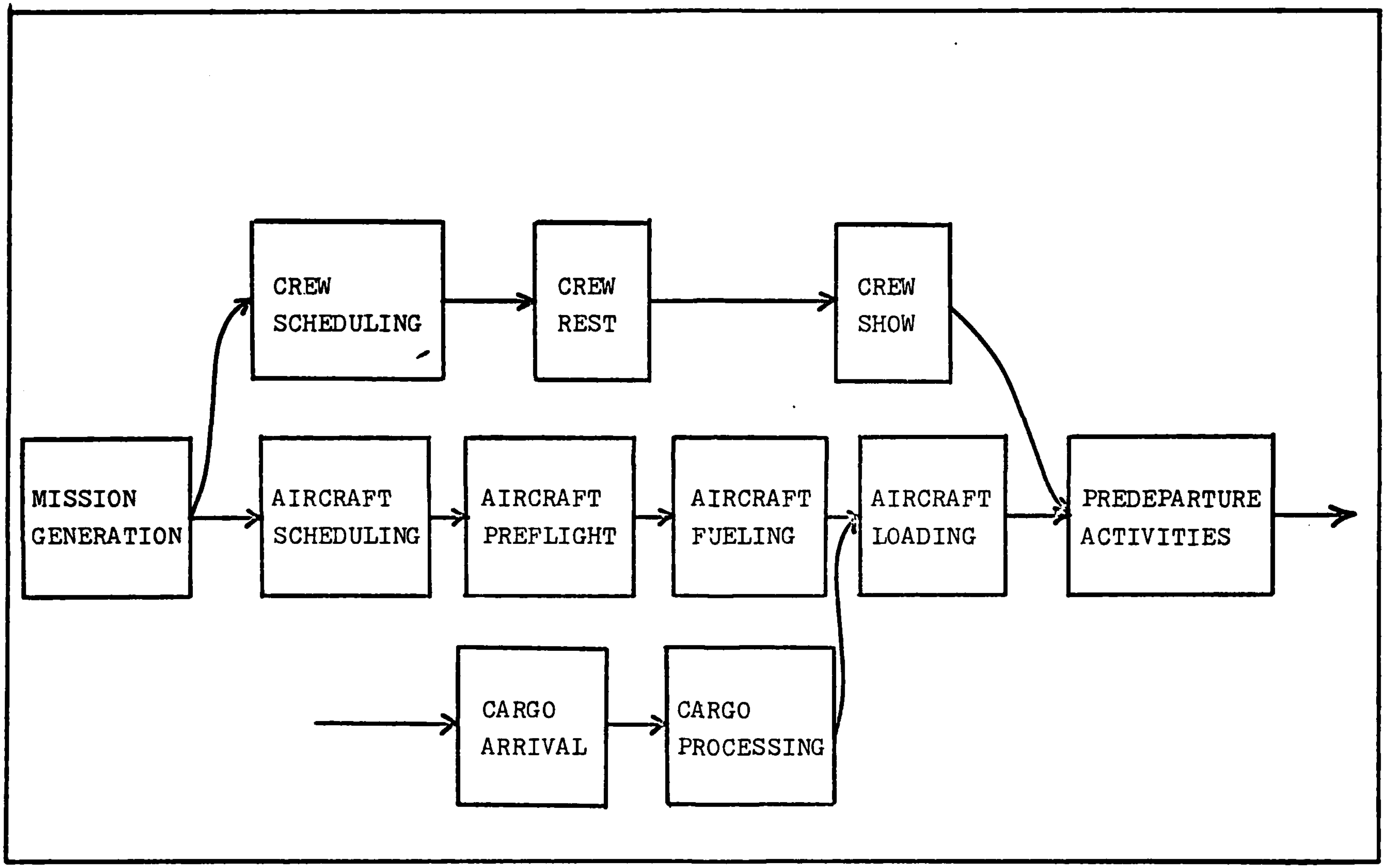


Figure 3-1 Model Mission Flow

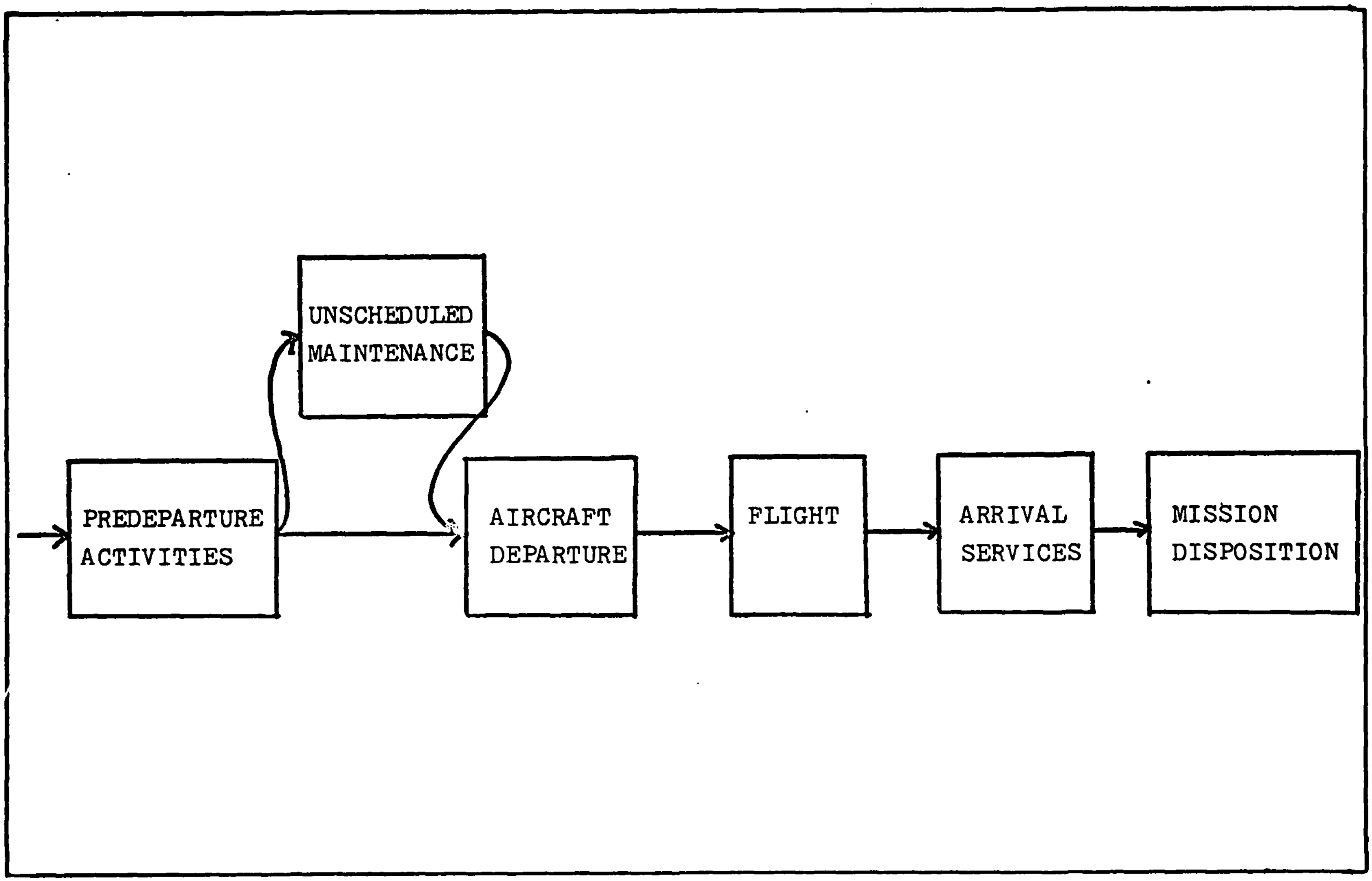


Figure 3-1 (continued)

port levels and selectivity. Furthermore, from analysis of the actual system data 66% of the total cargo was transported by C-141 and 34% of the cargo by C-5. Consequently the cargo is split up into C-141 and C-5 queues, with 66% going to the C-141s and 34% to the C-5s. Cargo arrives in discrete parcels, five of which comprise a C-141 load and nine of which comprise a C-5 load. The aircraft is subject to unscheduled maintenance due to discrepancies noted during the crew preflight. This predeparture nonscheduled maintenance rate is also one of the factors manipulated in the experiments described in Chapter IV. The manning of the system for crews and support personnel is established at an arbitrary level and does not constitute a constraint on the system in general. This reflects the policy of manning the MAC system at a high enough level to meet contingency surge requirements. Furthermore, these missions are all scheduled so that adequate support is assumed available. Once again the aim of the model is to measure input and output of the MAC system in general. There is no advantage to be gained by adding detail and refinements such as resource constraints. The same general processes are involved.

As stated above the model represents an aggregation of eastern US bases with a Channel mission to an aggregation to European bases. The level of detail is such that maintenance man-hours are sensitive to workload as are the port man-hours. The base nonscheduled maintenance rate represents a lower workload than the high nonscheduled maintenance rate and the man-hours reflect this. Similarly port man-hours depend on how much cargo needs to be processed and how many aircraft need to be loaded. By varying the factors that govern these workloads the inputs and outputs of the system vary as well.

The added detail of a day-in-the-life-of-a-man-and-a-tool-box type model would only add more bulk without necessarily adding conceptual refinement or system insight. The model is intended to measure differences in system outputs and inputs resulting from different environmental and management conditions. Exactly how all of this is brought about in the system is not at issue.

As Pritsker puts it:

> "In modeling and simulation, what is important is relative. Models are built to be explanatory devices... The purpose for which the model is built should be reflected in the amount of detail included in the model. By knowing the purpose for which a model is built, the relative worth of including specific details can be assessed. Only those elements that could cause significant differences in decision making resulting from the outputs of the model need be considered." (Ref 36:387)

Determination of Model Parameters

Model parameters were derived from system observation as a crewmember and as a Command Post duty controller, from conversations with experienced airlift personnel at HQMAC and at the MAC Airlift System Programming Office (SPO) at Wright-Patterson AFB, from data contained in AFR 76-2, Airlift Planning Factors, and, finally, from an analysis of a Military Air Integrated Reporting System (MAIRS) printout from HQMAC/DO representing thirty-days (Julian days 301 to 331 1979) of MAC Channel missions. The first two sources helped to round out the conceptual framework and to determine parameter ranges when hard data was not available. AFR 76-2 was useful in determining various aircraft capability and performance data as well as Channel route information. Finally, the actual MAIRS data were used to establish average cargo weights, departure frequencies and flight times. In using the MAIRS data all C-5 and C-141 flights operating from east coast bases to European destinations were identified. These were then taken to represent the aggregated mission data base of the "conceptual" port model. As an aid in the analysis of the MAIRS data a computer program, DATANAL, was written. The computer FORTRAN code listing and printouts are included in Appendix A. The mission parameters derived in this manner and used in the model are summarized in Table 3-1. In addition to giving average parameter values the program also computed frequency data and printed this out to give a "picture" of the general distribution of the data. All of these factors were taken into consideration in establishing the parameters and distributions used in the model.

Truck cargo unloading times on a per ton basis were derived both from Porte's study (Ref 34) and system observation. Aircraft cargo loading and unloading service times in hours per ton were determined in a similar manner. The maintenance service times are assumed to be uniformly distributed. This assumption is based on system observations, as well as, from conversations with the personnel at the MAC SPO. The fueling times are computed from AFR 76-2 information and from fueling rate capabilities obtained from the MAC SPO. The fuel planning procedures outlined in AFR 76-2, while not directive

TABLE 3-1

Simulation Parameters Derived From MAIRS Data
(US-to-Europe Missions)

PARAMETERS	C-5 Mean	C-5 Std Dev	C-141 Mean	C-141 Std Dev
Cargo Weight (tons)	27.9	6.8	15.6	5.6
Flight Time (hours)	7.6	0.4	7.3	1.2
Interdeparture Time (hours)	13.3	10.6	3.8	3.6
Cargo (tons, total for 30 days)	1592.0		3120.0	
Mission Sorties (total for 30 days)	57		200	

upon aircrews, are useful as heuristics for this type modeling. According to AFR 76-2, enough fuel must be uploaded to allow for 10% over planned flight time plus thirty minutes departure and approach and forty-five minutes holding. Fuel consumption was taken to be the average fuel consumption fibures cited in AFR 76-2, that is 2025 gallons per hour for the C-141 and 3375 gallons per hour for the C-5. Data from the SPO indicates that fueling rates are some 500 gallons per minute, or 30,000 gallons per hour, from either fueling trucks or from fuel hydrants. Consequently, the fueling service time (FST) relationships become:

$$FST_{(C-141)} = 0.0675\,[\text{Flying Time} \times 1.1 + 1.25] \quad (3)$$

$$FST_{(C-5)} = 0.1125\,[\text{Flying Time} \times 1.1 + 1.25] \quad (4)$$

Total fuel consumption is simply this fueling service time multiplied by 30,000.

The mission generation rate is based on an assumption regarding fleet size. Actual MAC operations involve many different kinds of missions so that there is no dedicated aircraft fleet for Channel. However, for the purpose of this study it was assumed that the C-141 fleet, consisting of 30 aircraft, and the C-5 fleet, consisting of 16 aircraft, were dedicated to the European Channel mission. This is based on the observation that roughly half of the total mission activity is Channel mission and that roughly half of the Channel missions are to Europe.

The mission generation rate is computed from the relation:

$$MGR = \frac{\left[\frac{\text{Simulation Period}}{UR}\right] FT}{\left[\frac{\text{Simulation Period}}{24.0}\right] FS} \qquad (5)$$

where

UR = utilization rate in hours per unit equipment aircraft per day.

FT = flying time for fleet

FS = fleet size

Since FT was observed from the MAIRS data to be a normally distributed random variable then MGR is also a normally distributed random variable with expected value given by

$$E[MGR] = \frac{24.0\ E[FT]}{(UR)\ (FS)} \qquad (6)$$

Substituting the specific values of the C-141 and C-5 fleet sizes:

$$E[MGR]_{C-141} = \frac{0.8\ E[FT \sim N(7.3,1.22)]}{UR} \qquad (7)$$

$$E[MGR]_{C-5} = \frac{1.5\ E[FT \sim N(7.6,0.45)]}{UR} \qquad (8)$$

The standard deviation of this distribution is estimated to be one-fourth of the range between the maximum value observed and the minimum value observed.

Tables 3-2 a,b, and c summarize the model parameters employed.

Model Language

To model this system the Q-GERT modeling language was

TABLE 3-2a

Aircraft Service Parameters

AIRCRAFT SERVICE/ACTIVITY TIMES	DISTRIBUTION TYPE	C-5 min	C-5 max	C-141 min	C-141 max
NON SCHEDULED MAINTENANCE:					
Engine Maintenance	uniform	0.5	3.00	0.5	1.75
Hydraulic Maintenance	uniform	0.5	2.00	0.5	2.00
Electric/Avionics Maint.	uniform	0.5	2.50	0.5	1.50
"Other" Maintenance	uniform	0.5	2.50	0.5	2.00
Preflight (Hours)	constant	6.0		3.0	
Fueling Time (Hours per flying hour)	constant	.1125		.0675	
Loading Time (Hours per ton cargo)	constant	.06		.06	

TABLE 3-2b

Cargo Service Parameters

CARGO SERVICE/ACTIVITY TIME	DISTRIBUTION	VALUE (MEAN)
Load weight (tons)	normal	$\mu = 3.12$, $\sigma = 1.12$
Truck Offload Time (hours/ton)	constant	0.16
Cargo Routing (hours)	constant	1.0

TABLE 3-2

Server Numbers

SERVICE	NUMBER OF SERVERS
Truck Offloading	10
Aircraft Fueling	10
Aircraft Loading	10

used. Q-GERT represents Graphical Evaluation and Review Technique with a capability for modeling waiting Queues. This particular language was chosen because the MAC airlift system is a queue service-queue-service type system. Since Q-GERT has an established power for handling queueing systems, its language and technique were selected. Q-GERT represents more than a language. It is also an approach to conceptualizing systems as well as simulating them.

The Q-GERT technique consists of two parts. First, the pertinent activities and servers in a system are identified. Then these system elements are represented by a Q-GERT flow diagram. This diagram includes server numbers, service rates, queue selection rules, and transaction flow information. Second, this graphical representation is translated into a series of Q-GERT instruction codes which correspond to the different kinds of nodes, service/activities, and branching options. The actual system simulation is done by the Q-GERT Analysis Program. This program uses the coded instructions to compile and analyze the network being modeled. After termination of the simulation the Analysis Program prints out an extensive list of simulation results and statistics. (Ref 36)

There are two basic symbols in Q-GERT, the node and the activity/service. The nodes represent "milestones, decision points and queues." (Ref 33:3) Generally, there are three parts to a Q-GERT node symbol: the left sector, which designates node release conditions or queue capacity information and is drawn as a hemisphere, a center sector, which may be comprised of several different boxes which determine how a transaction is treated when the node is released and a right sector which specifies branching type: queue, deterministe, probablistic, or conditional. Nodes must at least specify release conditions and branching type so that some nodes may appear without center sectors. The center sector may contain information that relates to queue discipline, statistics to be collected, how multiple transactions are to be managed, assignment of values to attributes, and so forth depending on the specific node being described and the options selected. Table 3-3 summarizes the Q-GERT symbols used in the accompanying flow chart.

Transactions which originate or pass through nodes are routed along activity branches represented by arrows drawn between nodes. An activity may represent a time delay or a service process. A time delay type activity begins when the start node is released, whereas a service type activity which emanates from a queue node, is constrained by the number of servers serving a given activity. As a result, a service type activity starts only when a server is free, subject to queue discipline and server selection constraints. Activities are labeled with time delay or service time information enclosed in parentheses. Referring to Figure 3-2, this information may specify that time delay is a constant value, (a), a sample from a probability distribution, (b), or determined by a call to a user function, (c). Additionally, activities may be labeled with a server identification number, the number of parallel servers, and stochastic or conditional se-

TABLE 3-3 Q-GERT NODE DESCRIPTION (Ref 36)

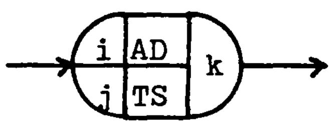
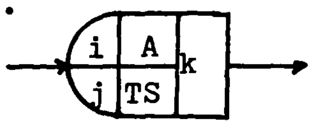
Q-GERT SYMBOL	NODE TYPE Operation Description	UNIQUE LABELS/PARTS DESCRIPTION
1. 	REGULAR	i=number to release initially j=number to release subsequently k=node number (must be unique for each node) AD=attribute designator--when more than one transaction is required to release a node this designator indicates how the attribute will be assigned. TS=transaction status--an M here indicates that time the transaction goes through the node is to be assigned to the transaction as an attribute. --and I, or B here indicates that node is to collect statistics on time since transaction was last marked (I) time since last time node was released (B)
2. 	Nodes with conditional branching--selects and schedules all activities that meet condition.	

TABLE 3-3 (continued)

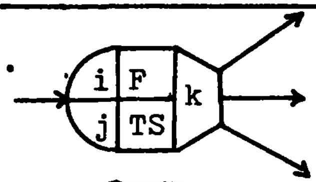
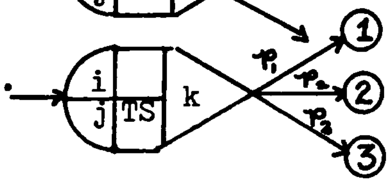
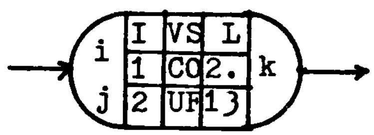
Q-GERT SYMBOL	NODE TYPE Operation Description	UNIQUE LABELS/PARTS DESCRIPTION
3. 	Selects only the first activity that meets condition.	
4. 	Node with Probablistic Branching	Transaction sent to 1 with probability p_1 to 2 with probability p_2 to 3 with probability p_3.
5. 	Node with attribute value assignment	I=attribute number to which value is to be assigned. VS=source from which value is ti be taken. CO=indicates a constant value specified by SP is to be assigned. IN=indicates an incremental number will be assigned. UF=indicates a call to a User Function will supply value additionally. VS may be other letter to specify various standard statistical distribution. L=Parameter set.

TABLE 3-3 (continued)

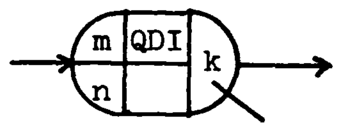
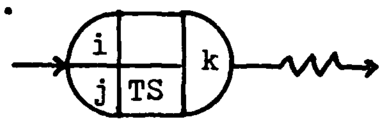
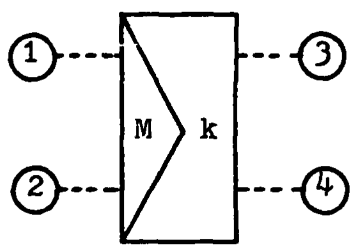
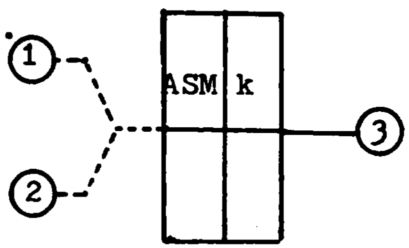
Q-GERT SYMBOL	NODE TYPE Operation Description	UNIQUE LABELS/PARTS DESCRIPTION
6. 	QUEUE NODE may also employ probablistic branching values may be assigned to attributes from here as well.	m=number in queue initially. n=capacity of queue node waiting line. QDI=queue discipline indicator. F=first come first served.
7. 	SINK NODE transactions are destroyed when node releases--can be used to collect statistics.	TS=type of statistic to be collected. I=time from marking of transaction (system time) B=time between node releases.
8. 	MATCH NODE holds up transactions in 1 and 2 until there is a transaction in each of 1 and 2 with the same value of attribute M then these are routed to the same or different nodes.	

TABLE 3-3 (continued)

Q-GERT SYMBOL	NODE TYPE Operation Description	UNIQUE LABELS/PARTS DESCRIPTION
9. 	SELECT NODE routes transactions from input queues to service queues.	ASM=indicates that a transaction is to be taken from each input queue before one transaction is routed.

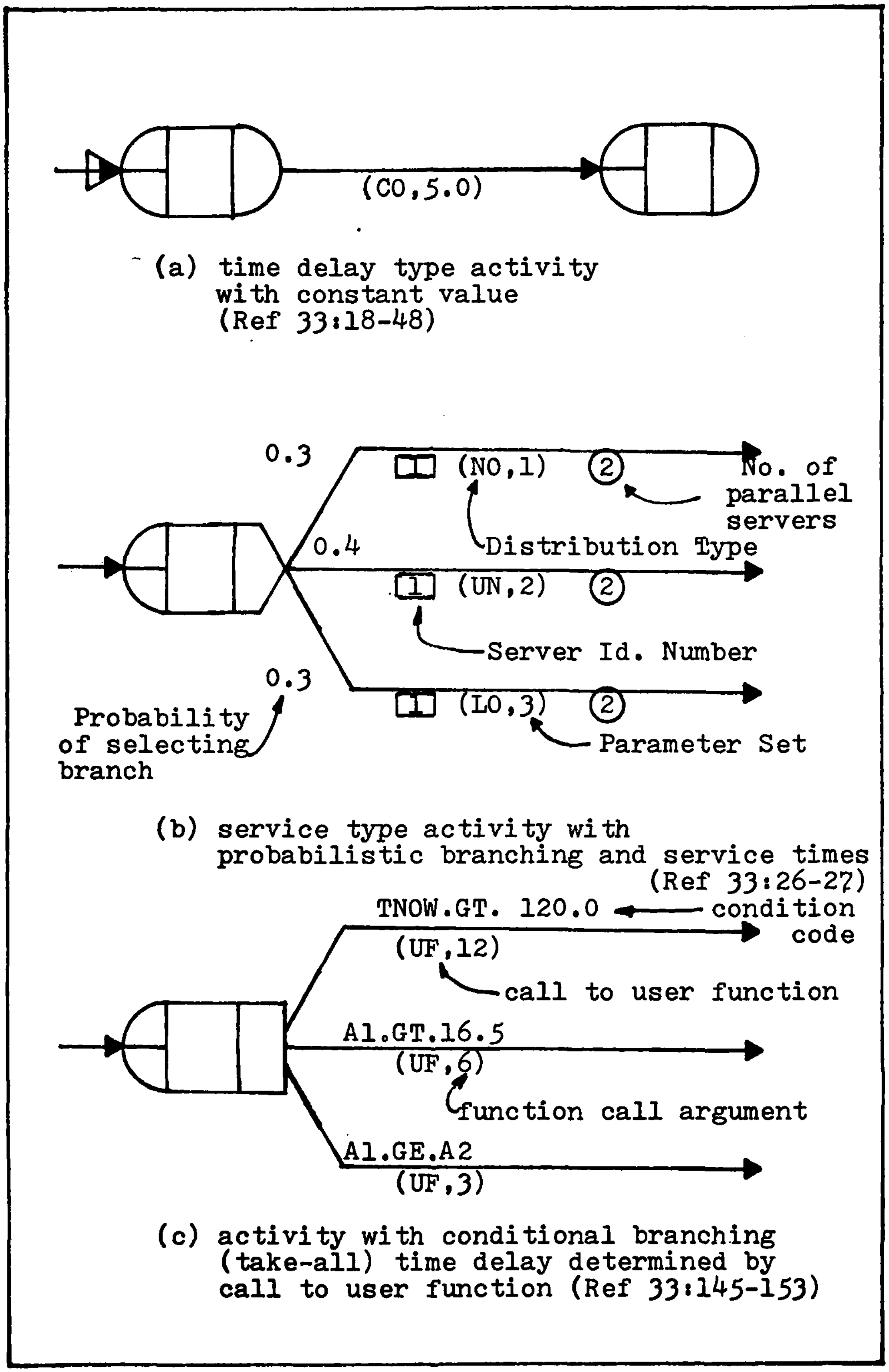


Figure 3-2 Q-GERT Activity Types

lection information. Stochastic selection information is provided on all activities that emanate from any probabilistic node. This information consists of a number between 0 and 1 which characterizes how often a particular activity is selected in a random sampling, Figure 3-2 (b). Of course the sum of the probabilities of all branches coming from a particular probabilistic node must be one. Conditional selection information consists of a FORTRAN type IF selection statement, Figure 3-2 (c).

Figure 3-3 is a presentation of the Q-GERT network using the symbols just described. The flow of transactions and parameters used together with the word picture presented above should serve to clarify the approach taken to model the MAC airlift system. In addition, the Q-GERT coding that corresponds to this network is included in Appendix B.

While Q-GERT is a powerful language, that is, capable of capturing a wide range of behavior with minimal coding, special action must be taken to extend the flexibility of the technique. This is provided for with the inclusion of FORTRAN coded program inserts. There are three basic program inserts: FUNCTION UF (IFN), SUBROUTINE UI, and SUBROUTINE UO. FUNCTION UF uses a computed GO TO statement to branch control to different areas of the function. Calls to FUNCTION UF(IFN) may be made at an attribute assignment or at activity scheduling.

Besides returning a value for the activity or for an attribute the call may also serve to initiate other activities. This effort is facilitated by the provision of Q-GERT sub-

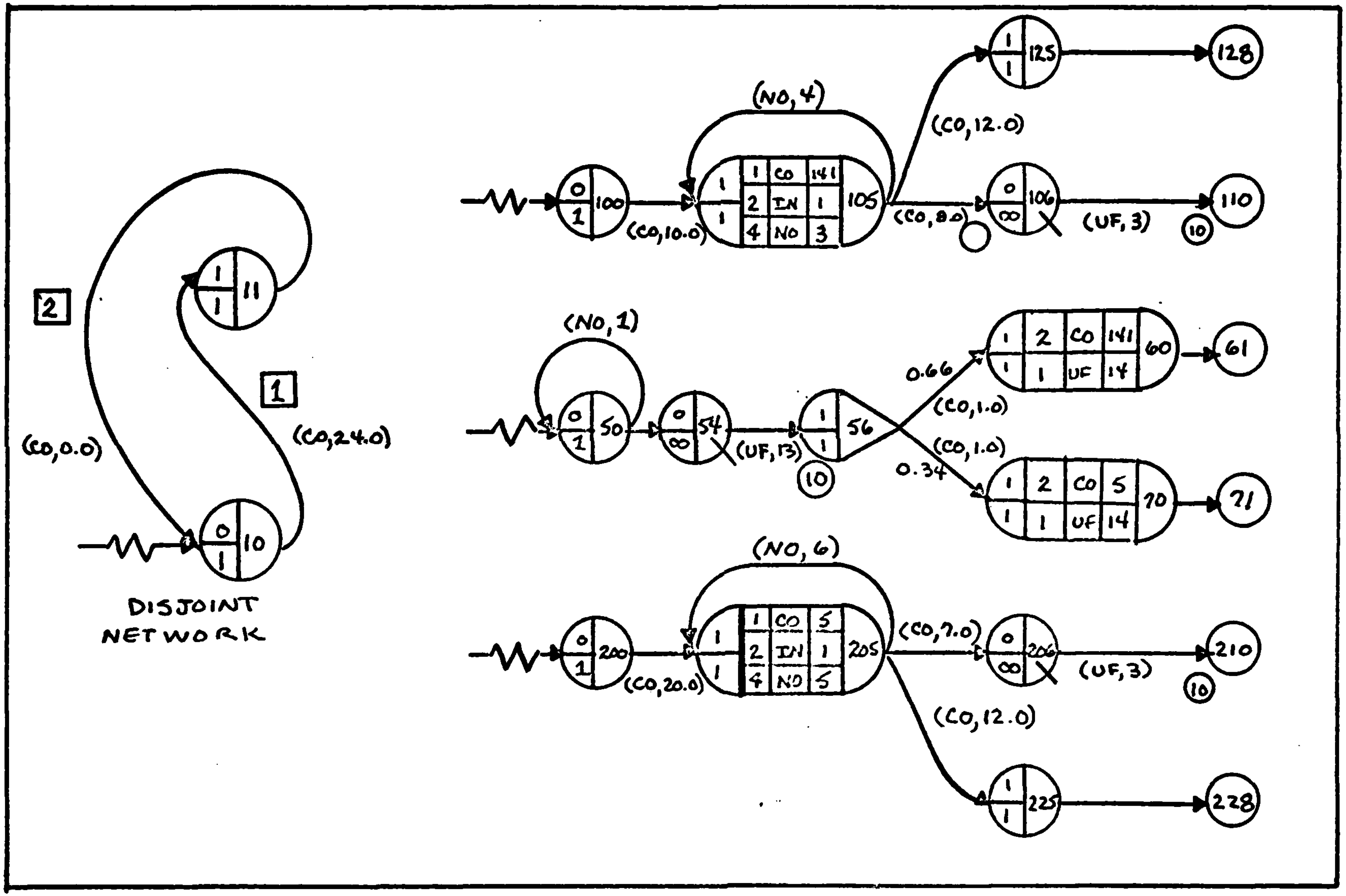


Figure 3-3 Q-GERT Network Representing MAC Peacetime Airlift System

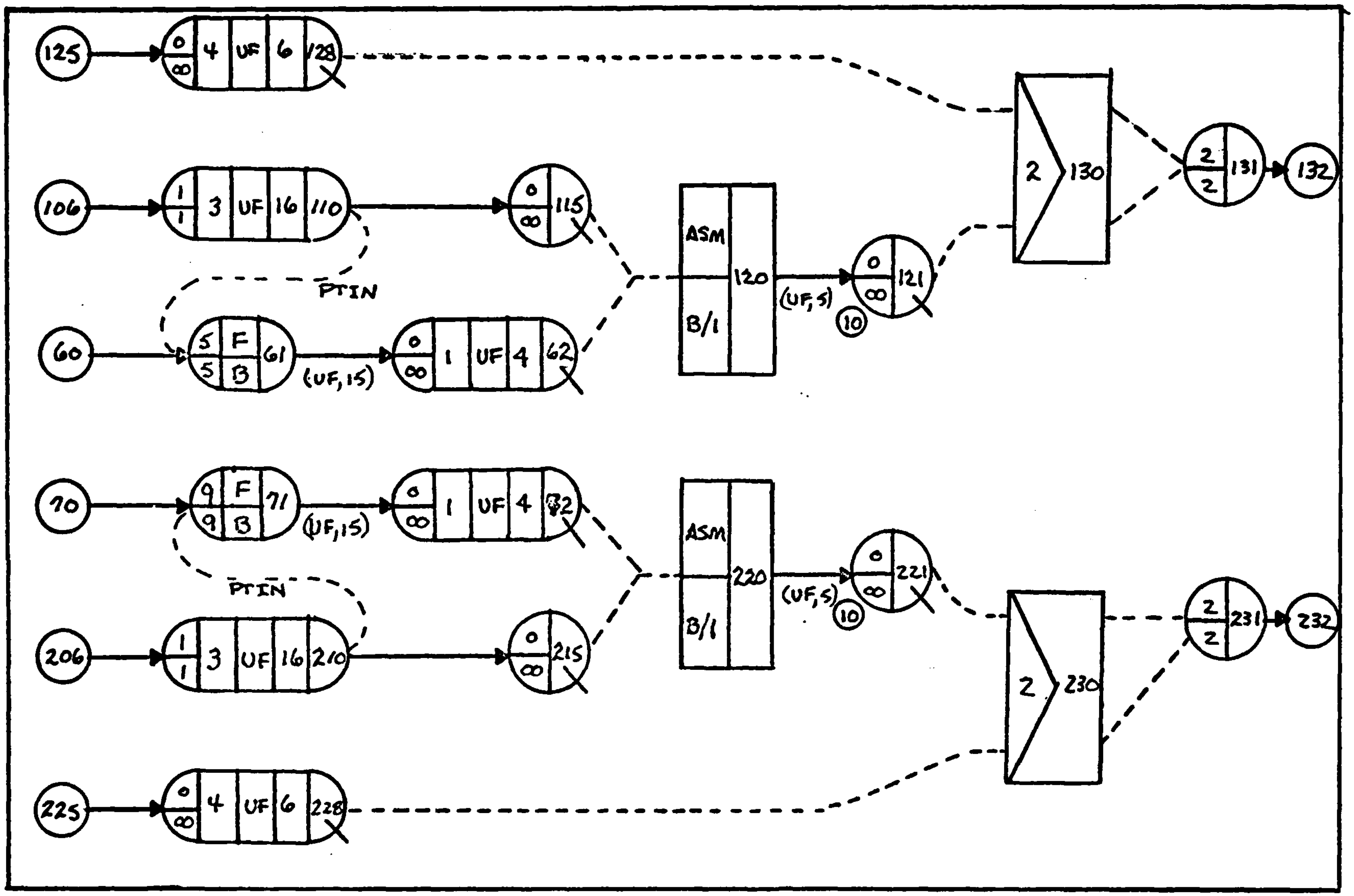


Figure 3-3 (continued)

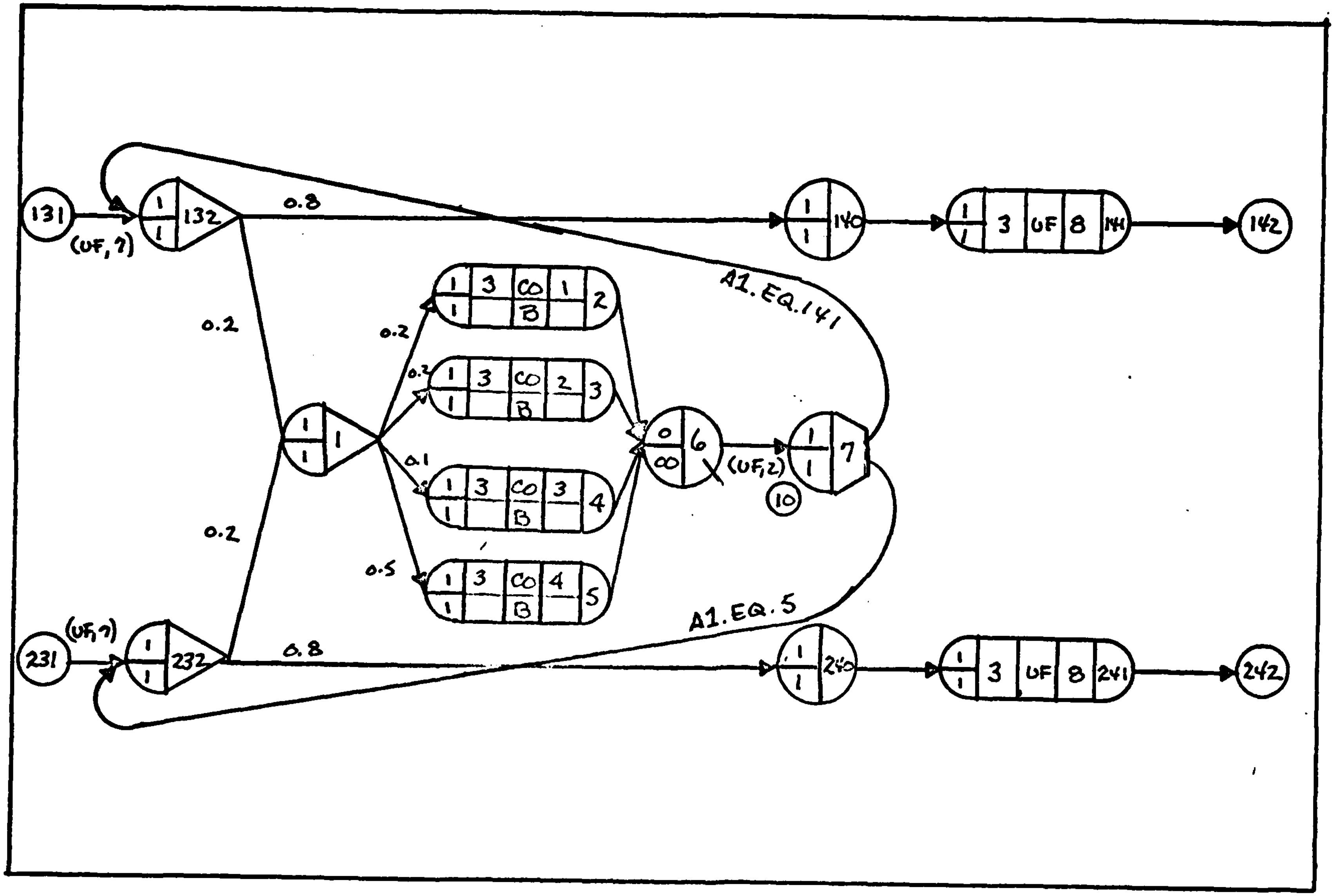


Figure 3-3 (continued)

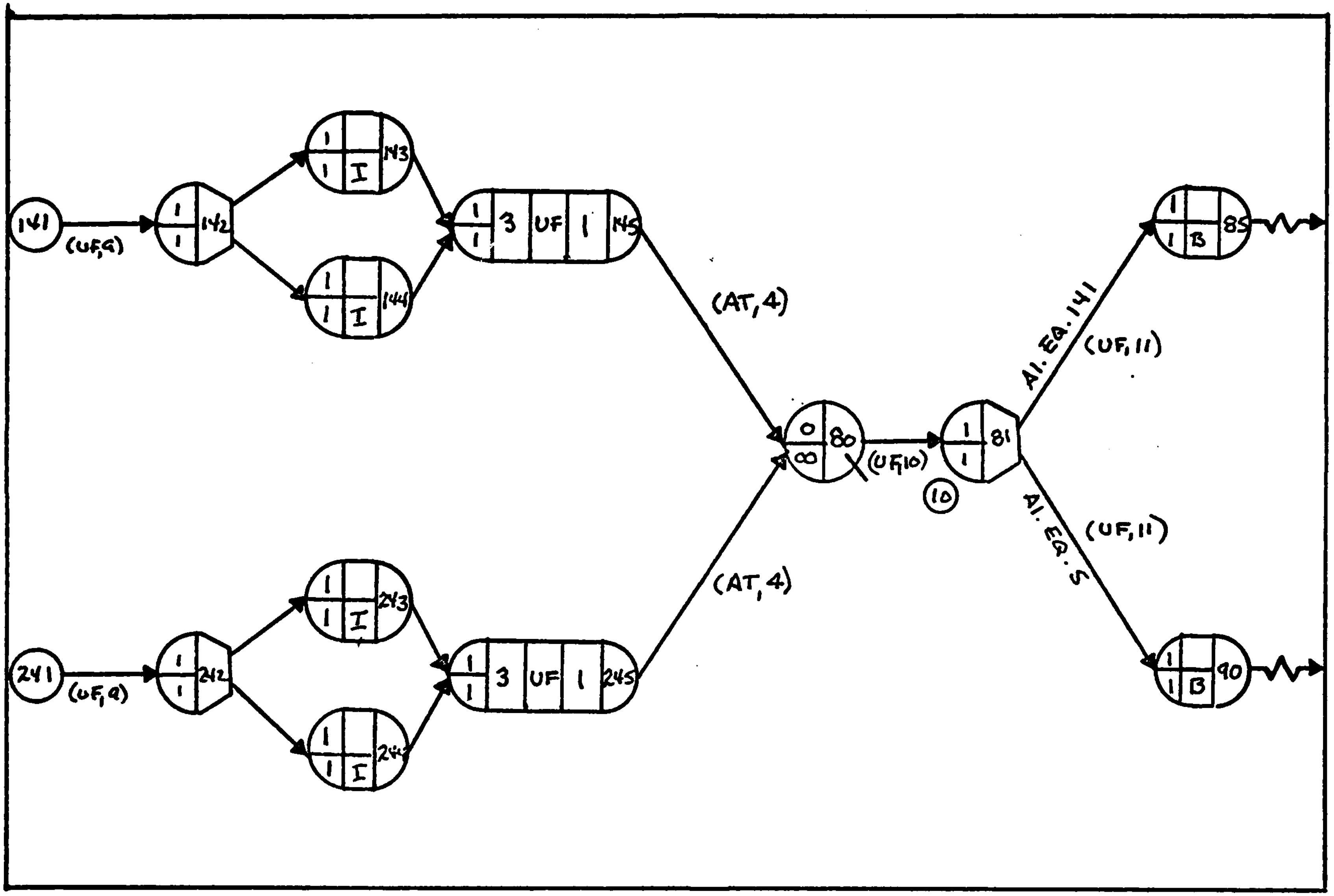


Figure 3-3 (continued)

routines. Pritsker (Ref 36:235-295) describes in detail the use of program inserts as well as of the Q-GERT subroutines. SUBROUTINE UI is a subroutine that is called by the Q-GERT Analysis Program at the beginning of an individual run. For this reason SUBROUTINE UI is used to initialize variables that will be used during a run. SUBROUTINE UO is called at the termination of a run and is employed by the analyst to output desired results and statistics. (Ref 33:253-254) Table 3-4 describes the Q-GERT variables accessed and the internal Q-GERT subroutines employed in the program inserts written.

The FORTRAN code listing for FUNCTION UF(IFN) is in Appendix C. The sixteen different sections of FUNCTION UF(IFN) are summarized in Table 3-5.

Model Output

There are two kinds of output generated by this model, the standard Q-GERT analysis program output and the user (analyst) specified output. The Q-GERT output consists of a statistical recap of all of the nodes and activities and indicates utilization of servers, average waiting time experienced in waiting queues, average between-times of statistical node releases, and so forth. The user output consists of total ton-miles, pipeline time and so forth and is described in Chapter V. Because they represent inputs to the airlift system the significant factors here are flying hours, maintenance man-hours, port man-hours, and fuel in gallons as inputs. The pertinent system output responses are departure

TABLE 3-4

Q-GERT Variable Accessed and Subroutines Used
(Ref 36)

VARIABLE/ SUBROUTINE NAME	DESCRIPTION OF VALUE OR FUNCTION	ARGUMENT LIST
GATRB(J)	Returns value of Jth attribute of transaction being processed.	J = attribute number
NO(J)	Returns random variate from normal distribution	J = parameter set
NREL (NODE)	Value either of number in queue of Q-node NODE, of remaining requirements for release of node NODE	NODE = node number of interest
NRUN	current run number	
NRUNS	total number of runs requested	
NTC(NODE)	number of transactions that have gone through node NODE since beginning of simulation	NODE = node number of interest
PATRB(ATTR,J)	assigns value of ATTR to attribute J of transaction being processed	J = attribute number ATTR = value to be assigned
PTIN (NODE, TIME, TIMEM, ATT)	puts a transaction into network at node NODE, at time TNOW+TIME, mark time is TIMEM,ATT is the attribute vector	NODE = node number of interest TIME = time delay for initiating transaction

TABLE 3-4 (continued)

VARIABLE/ SUBROUTINE NAME	DESCRIPTION OF VALUE OR FUNCTION	ARGUMENT LIST
		TIMEM = mark time of transaction ATT = attribute vector for new transaction
TMARK(IDUM)	returns TMARK as the time the current transaction was marked	IDUM = dummy argument
TNOW	current simulation time	

TABLE 3-5

FUNCTION UF(IFN) Description

IFN	CALLED AT	USE
1	Nodes: 125,225,145 and 245	Assigns value of TNOW to attribute
2	ACT,6,7	Assigns value to UF of normally distributed random variate for maintenance service type and aircraft type
3	ACT,106,110 ACT,206,210	Computer fueling time from aircraft type and flying time
4	Nodes 62 and 72	Used to pass attribute values through a SELECT Node because both transactions have unique values that must be retained. Uses aircraft type and destination
5	ACT,120,121 ACT,220,221	Takes values stored in UF 4 and assigns them to new transaction that emerges from SELECT node. Computes aircraft loading time based on load weight
6	Nodes 128 and 228	Takes crew show time to pass through MATCH node.
7	ACT,131,132 ACT,231,232	Assigns crew show time saved from UF 6 to aircraft transaction
8	Nodes 141 and 142	Used to determine departure reliability if on-time UF = 1.0, if late UF = 2.0
9	ACT,141,142 ACT,241,242	Departure release time is computed and returned in UF. If transaction is late UF = 0.0. If on-time or early aircraft is held for: UF=TMARK(FDUM)+15.5--TNOW time units

TABLE 3-5 (continued)

IFN	CALLED AT	USE
10	ACT,80,81	Computes aircraft offloading time and returns it in UF and updates aircraft arrival counters and delivery ton counters.
11	ACT,81,85	Mission report. Computes values for mission ton miles, crew day, capacity utilization, etc.
12	Node 11	Generates port report. Indicates numbers of truck arrivals and tons delivered, aircraft arrivals and tons delivered, and port level in tons.
13	ACT,54,56	Computes truck unloading time and updates truck arrivals, truck tons delivered, and port level.
14	Nodes 60 and 70	Used to accumulate load weights for C-141 and C-5 loads. Assembles 5 loads for C-141 and computes weight of 5 loads, assembles 9 loads for C-5 and computes weight. Also tallies port maintenance man hours.
15	ACT,61,62 ACT,71,72	Passes load weights computed in UF14 to the assembled load transaction which represents an aircraft "load".
16	Nodes 110 and 210	Used to simulate effect on low on hand port levels. A check is made of load queue, the assembly node is checked and dummy loads generated until the assembly node releases to the load queue.

reliability, total ton miles, and pipeline time. Maintenance man-hours are tallied in UF2, as unscheduled maintenance, as service hours times crew size where crew size for each type of maintenance work is specified in Table 3-2. Maintenance man-hours are also tallied in UF3, where fueling occurs, man-hours here is crew size times fueling time as determined above. Additionally, a constant is added to account for routine maintenance items, 3 hours for C-141s and 6 hours for C-5s. Port man-hours are tallied in UF13, UF14, UF10 and UF8. Here again man-hours are computed as either a constant value or as the product of service time and crew size. The response parameters are determined in UF11, the mission report area of FUNCTION UF, and in SUBROUTINE UO. Departure reliability is taken as the quotient of the number of releases of node 143 to the number of releases of node 145 for C-141 launch reliability and the quotient of the number of releases of node 243 to the number of releases of node 245 for C-5 launch reliability. Total ton-miles is the summation of individual mission ton-miles, both values are calculated in UF11. Mission ton-miles is computed as the product of cargo weight (attribute 6) and the distance flown. The distance flown is not as straight forward as would seem. That is, the distribution in flying time is due to the wide variety of Channel missions flown from the east coast to Europe as well as the differences in the same mission due to wind differences. Distance flown, then, is the product of flying time and block speed, where block speed is defined as the average speed of a mission from block-out, parking spot departure, to block-in, destination parking spot arrival. The longer a mission leg is, the relatively more time spent at enroute cruise speed and therefore the faster is the block speed. Equations for relating total flight time to block distance flown (BDF) were determined from a least squares fit of data in AFR 76-2 using values of 0.76 MACH enroute airspeed for C-5s and 0.74 MACH enroute airspeed for C-141s. These equations are:

$$BDF_{C-141} = [424.78 \times \text{Flying time} - 176.79 \text{ miles}] \quad (9)$$

$$BDF_{C-5} = [445.98 \times \text{Flying time} - 185.88 \text{ miles}] \quad (10)$$

Finally, pipeline time, measure of cargo time in MAC system, is measured from the time cargo arrives at the port truck terminal to the time the cargo arrives at destination. In actuality, pipeline time continues until the cargo is actually consigned to the user at destination. This was not modeled. In addition, the pipeline time is that of the oldest cargo on the aircraft, since aircraft loads are comprised of several truck loads.

Model Verification and Validation

This section describes the efforts made to establish model credibility. Model credibility is established in two steps, verification and validation. Verification is the determination that the model flow or algorithm performs as planned. That is, the values are computed as they should be and the transactions occur as they should. In essence the model does what the modeler wants it to do. The second step is considerably more difficult. Validation is the process of establishing that the model does what the real system does, that is, it behaves as the real system behaves given the conditions subsumed by the model parameters. (Ref 48:247)

Verification can be accomplished by using numerous print statements to follow a transaction along. Diagnostic outputs can also be scrutinized to insure reasonableness of results. In addition the Q-GERT Analysis Program has a "trace" option which actually prints out the flow of all transactions from node to node and along one service activity after another as determined by the network. This simplifies verification considerably.

Validation is another matter. Somehow the model results must be compared to actual system results for the same condition, that is, same value of critical input factors. To validate the model twelve runs of the network were made using the parameters and distributions derived from the MAIRS data. The Q-GERT Analysis Program printout from one of these runs is in Appendix D. Table 3-6a summarizes the input parameters. Table 3-6b summarizes the output parameters. The actual total flying hours for the activity described by the MAIRS data were 1893.2 and the actual total ton-miles were 16,044,700. Note that when the ton-mile algorithm described in (9) and (10) above is used the total ton-miles become 14,310,400. Note that the total ton-miles for the model is very sensitive to the cargo arrival rate. This is one of the factors manipulated in the experiments. Generally, the model generated output parameters compare favorably with actual system data, so that one can have reasonable confidence in the model's

TABLE 3-6a

Validation Run Input Parameters

PARAMETER	DISTRIBUTION	MEAN	SD	MIN	MAX
CASE I:					
C-5 MGR (interdeparture-hours)	lognormal	13.3	10.7	0.4	37.5
C-141 MGR (interdeparture-hours)	lognormal	3.8	3.6	0.0	15.6
CASE II:					
C-5 MGR (interdeparture-hours)	normal	13.3	10.7	0.4	37.5
C-141 MGR (interdeparture-hours)	normal	3.8	3.6	0.0	15.6
1] Cargo Arrival Rate (interarrival-hours)	normal	1.0	0.25	0.5	1.5
2] Cargo Arrival Rate (interarrival-hours)	normal	0.5	0.25	0.125	1.125
Truck Cargo Wt (tons)	normal	3.12	1.12	0.1	5.4
Predeparture Nonscheduled Maintenance Rate		0.2			

TABLE 3-6b

Validation Run Output Parameters

CASE I: [LOGNORMAL INTERDEPARTURE DISTRIBUTION]

FACTORS:	[MAIRS]	RUNS: [1]	[2]	[3]
CAR 1				
Total ton-miles ('000s)	16044.7*	7537.7	7390.6	7758.6
Total Flying Hours	1893.2	1795.4	1747.7	1897.4
C-5 Sorties	57	51	53	54
C-141	200	189	184	201
Total Cargo C-5 (tons)	1592.0	787.6	773.9	828.3
Total Cargo C-141 (tons)	3120.0	1675.1	1661.6	1718.0
Aver. Cargo C-5 (tons)	27.9	15.4	14.6	15.3
Aver. Cargo C-141 (tons)	15.6	8.9	9.0	8.5
CAR 2				
Total ton-miles ('000s)	16044.7*	11600.4	12674.5	12533.9
Total Flying Hours	1893.2	1595.4	1782.0	1697.1
C-5 Sorties	57	52	59	57
C-141 Sorties	200	164	184	171
Total Cargo C-5 (tons)	1592.0	1325.3	1554.1	1404.5
Total Cargo C-141 (tons)	3120.0	2523.1	2636.4	2708.9
Aver. Cargo C-5 (tons)	27.9	25.5	26.3	24.6
Aver. Cargo C-141 (tons)	15.6	15.4	14.3	15.8

* when ton-mile algorithms (9) and (10) were used with MAIRS flying tons total ton-miles was 14,310,400.

TABLE 3-6b (continued)

CASE II: [NORMAL DEPARTURE DISTRIBUTIONS]

FACTORS:		RUNS:		
	[MAIRS]	[1]	[2]	[3]
CAR 1				
Total ton-miles ('000s)	16044.7*	7592.6	7897.8	7959.8
Total Flying Hours	1893.2	1540.6	1594.3	1686.4
C-5 Sorties	57	45	53	51
C-141 Sorties	200	162	165	179
Total Cargo C-5 (tons)	1592.0	782.9	868.4	794.9
Total Cargo C-141 (tons)	3120.0	1720.1	1793.1	1881.4
Aver. Cargo C-5 (tons)	27.9	17.4	16.4	15.6
Aver. Cargo C-141 (tons)	15.6	10.6	10.9	10.5
CAR 2				
Total ton-miles ('000s)	16044.7*	12267.0	11957.0	12284.6
Total Flying Hours	1893.2	1674.9	1599.4	1658.8
C-5 Sorties	57	47	46	45
C-141 Sorties	200	178	170	175
Total Cargo C-5 (tons)	1592.0	1269.7	1279.4	1261.7
Total Cargo C-141 (tons)	3120.0	2759.7	2656.8	2727.8
Aver. Cargo C-5 (tons)	27.9	27.0	27.8	28.0
Aver. Cargo C-141 (tons)	15.6	15.5	15.6	15.6

* when ton-mile algorithms (9) and (10) used for actual flight times total ton-miles became 14,310,400.

ability to portray system behavior at the macro level. Further validation could be accomplished using a "Turing" approach. (Ref 48:252)

Summary

This chapter has described the system simulation model used in the study. The rationale and objectives of the simulation study were discussed. System assumptions and model limitations were presented. Next the process by which the model itself was constructed was described. This included a discussion of how parameters were determined and a description of Q-GERT terminology and symbols. Following this was a discussion of the user function/subroutine inserts, as well as, some of the computational algorithms. Finally, a brief discussion of model verification and validation was included. Verification of the model was accomplished by the use of print statements to analyze computation and output reasonableness and by the use of the Q-GERT trace feature. Validation of the model was by comparing system output parameters including flying hours, sorties generated, and ton-miles carried to actual values reported in the MAIRS data. When allowances were made for the ton-mile algorithms employed as well as the cargo arrival rate it was found that the agreement between the two sets of parameters was good so that an assumption of functional validity is not an unreasonable one. The next chapter, Chapter IV, Research Design, discusses how experiments were conducted with the system simulation and how the results of these experiments were treated.

IV Experimental Design

Chapter III discussed the system simulation model that was developed to investigate productivity measures. This chapter discusses how the system model was used and the experiments that were conducted.

Experimental Objective and Approach

The objective of the experiments was to determine which factors affect system output, as measured by ton-miles, pipeline time and departure reliability.

The simulation model of the MAC airlift system has many factors that can be independently varied. Table 4-1 lists some 24 of these factors. The list is not an exhaustive one. A two level factorial design experiment with each of these factors and all their various combinations would require 2^{24}, or nearly 17 million, computer runs. Furthermore, not all of the 2^{24} combinations are significantly different from one another. As a result, an aggregated factorial design was selected.

The three aggregate factors that were selected for the experiment were: 1) Pre-departure nonscheduled maintenance rate (PDNMR), 2) cargo arrival rate (CAR), and 3) mission generation rate (MGR). The pre-departure nonscheduled maintenance rate is defined here as the rate at which last minute aircraft discrepancies requiring maintenance are discovered during the crew's preflight of immediately before take off during engine start and taxi. With reference to the Q-GERT network, Figure 3-3, the nonscheduled maintenance rate is the

TABLE 4-1

List of Variable Factors

1. Cargo Arrival Rate
2. Aircraft/Mission Generation Rate--C-141
3. Aircraft/Mission Generation Rate--C-5
4. Pre-departure Unscheduled Mainteanace Rate--C-141
5. Pre-departure Unscheduled Maintenance Rate--C-5
6. Service Times--Truck Unloading
7. Service Times--Cargo Processing
8. Service Times--Cargo Movement
9. Service Times--Aircraft Cargo Loading/Unloading
10. C-141 Engine Maintenance
11. C-141 Hydraulic Maintenance
12. C-141 Electrical Maintenance
13. C-141 "Other" Maintenance
14. C-5 Engine Maintenance
15. C-5 Hydraulic Maintenance
16. C-5 Electrical Maintenance
17. C-5 "Other" Maintenance
18. Server Numbers (Manning) Truck Unloading Crews
19. Server Numbers (Manning) Cargo Processing Crews
20. Server Number (Manning) Engine Maintenance Crews
21. Server Numbers (Manning) Hydraulic Maintenance Crews
22. Server Numbers (Manning) Electrical Maintenance Crews
23. Server Numbers (Manning) "Other" Maintenance Crews
24. Server Numbers (Manning) Aircraft Loading Crews

fraction of the time an aircraft transaction takes the branch from Pre-departure Node 132, to Maintenance Node 1, for C-141s, or from Pre-departure Node 232 to Maintenance Node 1, for C-5s. The cargo arrival rate is defined as the speed at which cargo arrives at the port. The rate is established by setting the mean and standard deviation of the normal distribution function which governs cargo interarrival. In Figure 3-3, this cargo arrival rate corresponds to the normally distributed activity that goes from Arrival Node 50 and loops back to itself to schedule a new arrival. The mission generation rate is established by defining the mean and standard deviation for the normal distribution function which governs the time between mission generations. Referring to the same Q-GERT network the mission generation rate governs the flow of transactions from mission generation Nodes 105, for C-141s, and 205, for C-5s, back to themselves.

These three particular aggregate factors were chosen because each represents a particular stress on the system and a demand on a resource. The unscheduled maintenance rate funnels aircraft transactions through the maintenance complex causing delays and requiring manhours for service. The cargo arrival rate creates a demand on port man hours for unloading and port processing. There are also storage expenses associated with given rates of cargo, although these are not specifically modeled. The mission generation rate is a reflection of the burden placed on the maintenance personnel to generate aircraft, on the port personnel to load them, and the flight crews to fly them.

Two discrete levels for each factor, PDNMR, CAR, and MGR, were determined. Table 4-2 illustrates the parameters selected for each level of each factor.

TABLE 4-2

Simulation Experimental Parameters

FACTOR	LEVEL		VALUE				
PDNMR	1		C-5/C-141		0.2		
	2		C-5/C-141		0.5		
			mean	sigma	min	max	
CAR	1		1.5	0.3	0.375	4.5	
	2		0.5	0.1	0.125	1.5	
			mean	sigma	min	max	ute rate*
MGR	1	C-5:	6.333	7.5	0.0	30.0	1.8
		C-141:	1.825	3.0	0.0	13.0	3.2
	2	C-5:	3.8	6.75	0.0	27.5	3.0
		C-141:	1.168	2.0	0.0	9.0	5.0

* where the "ute rate" or utilization rate is as defined in Chapter III, that is, flying hours per fleet aircraft per day. In this instance the C-5 "Channel fleet" consists of 16 aircraft and the C-141 "Channel fleet" consists of 30 aircraft as determined in Chapter III.

With the factors and levels determined a series of runs was made with all possible combinations of each factor at each level. Table 4-3 depicts the run number and the level value for each factor. The same run numbers are used in reporting the results in Chapter V.

TABLE 4-3

Computer Experiment Cases

RUN #	LEVELS		
	PDNMR	CAR	MGR
1	1	1	1
2	1	2	2
3	1	1	2
4	2	2	1
5	2	1	1
6	1	2	1
7	2	2	2
8	2	1	2

It should be noted that the cases do not necessarily correspond to an actual real situation. In fact some of the cases may correspond to a pathological instance of the system, as, say, in case #8 which represents a high non-scheduled maintenance rate, a low cargo generation rate, and a high mission generation rate. One can almost visualize the confusion! This is an example of the capability of a simulation model investigating an infeasible or undesirable system condition.

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Data Analysis

Three iterations of each of the simulation runs depicted in Table 4-3 were run with a particular random number seed for each interation. The results of these runs are tabulated in Table 5-1. The data obtained from the simulation were analyzed graphically by plotting the results of each case against cases corresponding to different levels of one or other of the factors. Then productivity ratio indices were computed for each run. These were ratios of ton-miles to flying hours, and so forth. The results observed by comparing these indices are compared with the results surmised from the graphical evaluation. The data results, as well as, the graphical analysis and the analysis of indices are described in Chapter V--Experimental Results.

Summary

This chapter described the experimental design employed to exercise the simulation model. Because of the large number of discrete factors involved in the model a factorial design involving three aggregated factors, pre-departure nonscheduled maintenance rate, cargo arrival rate, and mission generation rate was selected. These three factors were chosen on the basis of their potential impact on the total system. Eight distinct cases (different combinations) of the factors were simulated. The data analysis consisted of graphical evaluation and comparison of these results with observations from comparison of productivity indices. The results of the experiment and the analysis are presented in Chapter V.

V Experimental Results

Described in this Chapter are the results of the simulation experiments that were conducted. Described in Chapter IV, the experiments were conducted in order to identify significant factor and factor interrelationships impact on total system productivity. The results of the graphical analysis of simulation results are depicted here.

Simulation Output

The output from the system simulation consisted of the Q-GERT Analysis Program statistical output, an example of which is included in Appendix D, and the user specified output, which is tabulated in Table 5-1. It should be emphasized that the maintenance man-hours and port man-hours are not illustrative of actual values. In reality there are many activities apart from direct Channel mission support that add to total man-hours. What the values in Table 5-1 represent are an estimation of direct Channel mission support man-hours. The other values represent reasonable estimations of actual system parameters within the bounds of the assumptions and objectives discussed in Chapter III.

Data Analysis

The simulation results were plotted so that the impact of each factor and factor level could be assessed. The circled number refers to the run number and is situated at the

TABLE 5-1 SIMULATION RESULTS.

RUN #	P O N M R	C A F	H G R	TOTAL TON MILES ('000S)	PIPE LINE TIME (HRS)	C5 DEPT. REL.	C141 DEPT. REL.	TOTAL DEPT. REL.	C5 SORT	C141 SORT	TOTAL MAINT. MANHOURS	TOTAL PORT MANHOURS	TOTAL FUEL (GALS) ('000S)	TOTAL FLYING HOURS
1A	1	1	1	8150.1	19.0	.966	.951	.934	104	285	2076.9	1482.4	8897.3	2908.2
1B	1	1	1	8007.7	18.1	.777	.958	.915	94	306	2156.7	1509.1	8952.3	2976.6
1C	1	1	1	7498.7	17.9	.912	.973	.957	100	289	2029.6	1425.5	8861.5	2858.5
2A	1	2	2	19551.0	19.3	.883	.962	.943	143	444	3065.9	3895.2	13189.0	4308.2
2B	1	2	2	18127.0	18.5	.910	.973	.958	132	438	2889.1	3767.4	12688.0	4200.8
2C	1	2	2	19564.0	18.5	.835	.967	.936	131	445	2931.7	3913.5	12911.0	4254.4
3A	1	1	2	9131.8	16.9	.904	.988	.967	144	428	2964.5	1745.4	12960.0	4215.1
3B	1	1	2	9404.8	16.9	.923	.971	.960	138	448	3015.6	1769.9	13207.0	4328.7
3C	1	1	2	9369.8	16.9	.860	.977	.951	128	439	2948.6	1765.5	12684.0	4162.6
4A	2	2	1	17135.0	20.7	.651	.817	.776	104	320	3054.0	3627.4	9734.8	3151.4
4B	2	2	1	15422.0	22.1	.652	.795	.761	88	282	2645.9	3478.5	8221.1	2704.9
4C	2	2	1	15422.0	22.1	.652	.795	.761	88	282	2645.9	3478.5	8221.1	2704.9
5A	2	1	1	7587.3	18.4	.611	.795	.751	93	298	2856.5	1479.8	8835.0	2871.3
5B	2	1	1	7123.1	18.6	.609	.791	.749	86	292	2715.1	1426.2	8684.5	2820.0
5C	2	1	1	7792.3	18.5	.542	.748	.697	95	290	2946.6	1483.8	8619.6	2806.9
6A	1	2	1	16317.0	21.5	.840	.983	.949	94	234	2026.6	3555.5	8845.5	2800.0
6B	1	2	1	11655.0	17.9	.739	.981	.962	23	263	1334.2	3192.2	5788.6	2099.2
6C	1	2	1	16390.0	20.9	.875	.956	.934	110	295	2172.9	3561.4	8850.0	2800.0
7A	2	2	2	18996.0	18.7	.575	.780	.739	119	479	4344.7	3863.6	13174.0	4404.4
7B	2	2	2	18279.0	19.0	.741	.793	.775	111	452	3902.0	3773.2	12303.0	4155.8
7C	2	2	2	18890.0	19.3	.560	.779	.728	122	416	3984.2	3828.5	12079.0	3966.7
8A	2	1	2	8629.6	17.2	.654	.776	.750	129	463	4246.5	1653.0	13252.0	4371.6
8B	2	1	2	9350.0	17.1	.677	.792	.760	128	489	4524.8	1726.0	13771.0	4534.8
8C	2	1	2	9441.8	17.1	.549	.795	.737	139	466	4492.7	1707.9	13520.0	4444.1

mean of the three iterations for that run. Note that the launch reliability scale has been translated in going from the base PDNMR to the high PDNMR. Also the size of the scale for launch reliability was chosen to reflect the same relative amount of change in the launch reliability index as in the ton-mile output or as in pipeline output. Figures 5-1a and b are the plots of ton-miles versus cargo arrival rate. Figure 5-1a corresponds to the base pre-departure nonscheduled maintenance rate while Figure 5-1b corresponds to the high pre-departure nonscheduled maintenance rate. In both figures the effect of the higher cargo rate on total output is apparent. At higher cargo arrival rates port levels, and hence load selectivity, are higher so that aircraft capacity utilization is higher. Similarly, at higher mission generation rates, corresponding to higher aircraft utilization rates, total output in ton-miles is higher. Note that this relationship holds whether the pre-departure nonscheduled maintenance rate is high or low.

Figures 5-1a and b also depict plots of launch (departure) reliability versus cargo rate. In either case the correspondence between departure reliability and mission generation rate or cargo arrival rate is not certain. When the transition is made from low unscheduled maintenance rate to high unscheduled maintenance rates the drop in departure reliability is evident and expected. With more aircraft needing unplanned pre-departure maintenance more aircraft will be delayed beyond scheduled departure time.

Figures 5-2a and b illustrate the relationship between

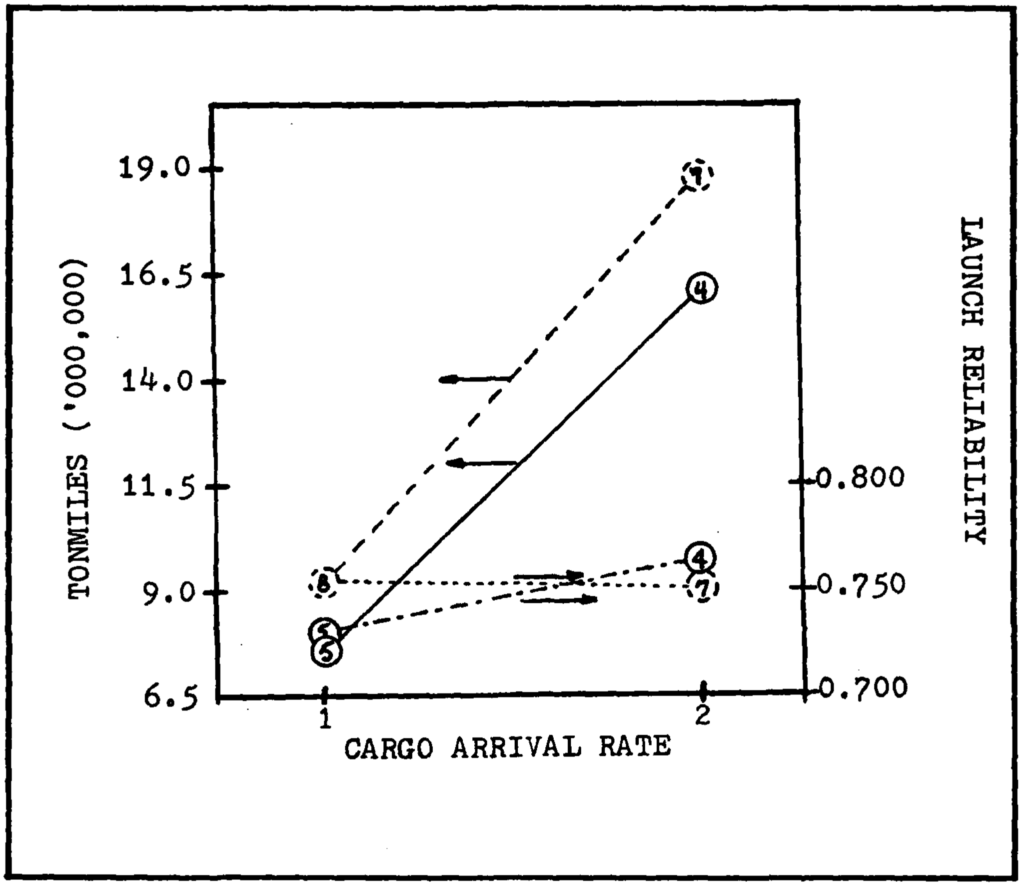

Figure 5-1a Base PDNMR: Ton-Miles and Launch Reliability Versus Cargo Arrival Rate

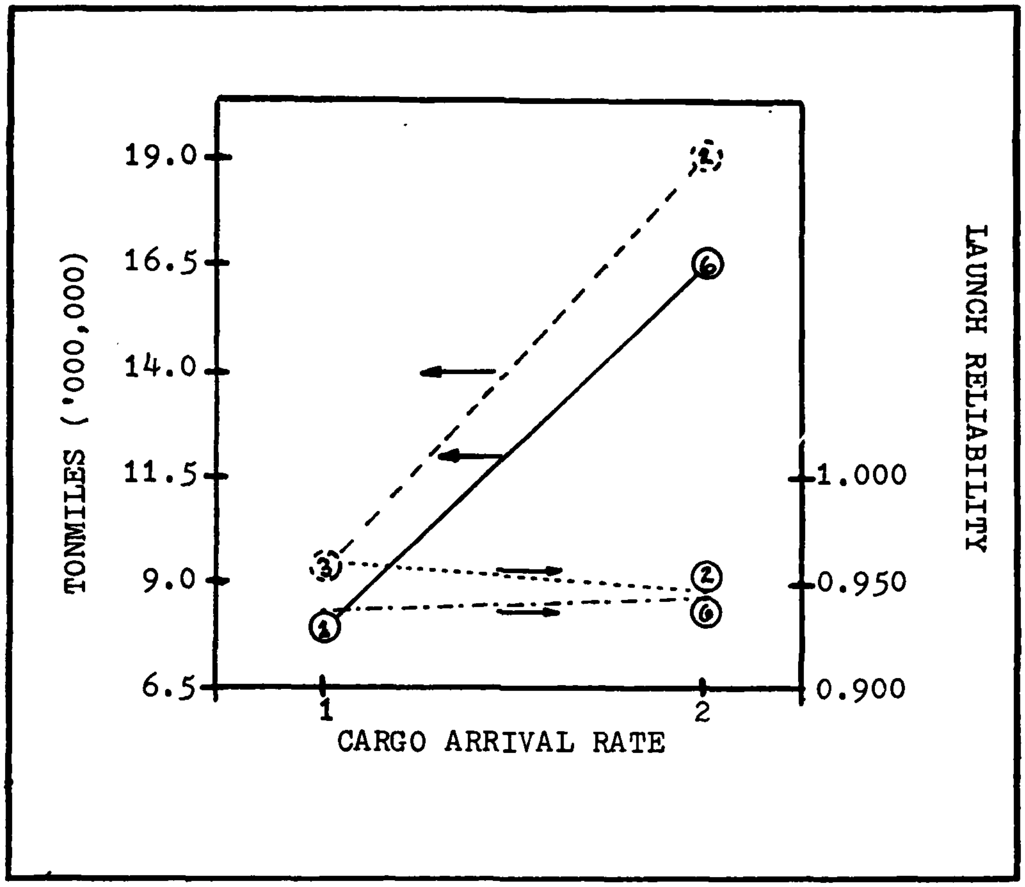

Figure 5-1b High PDNMR: Ton-Miles
and Launch Reliability Versus Cargo Arrival Rate

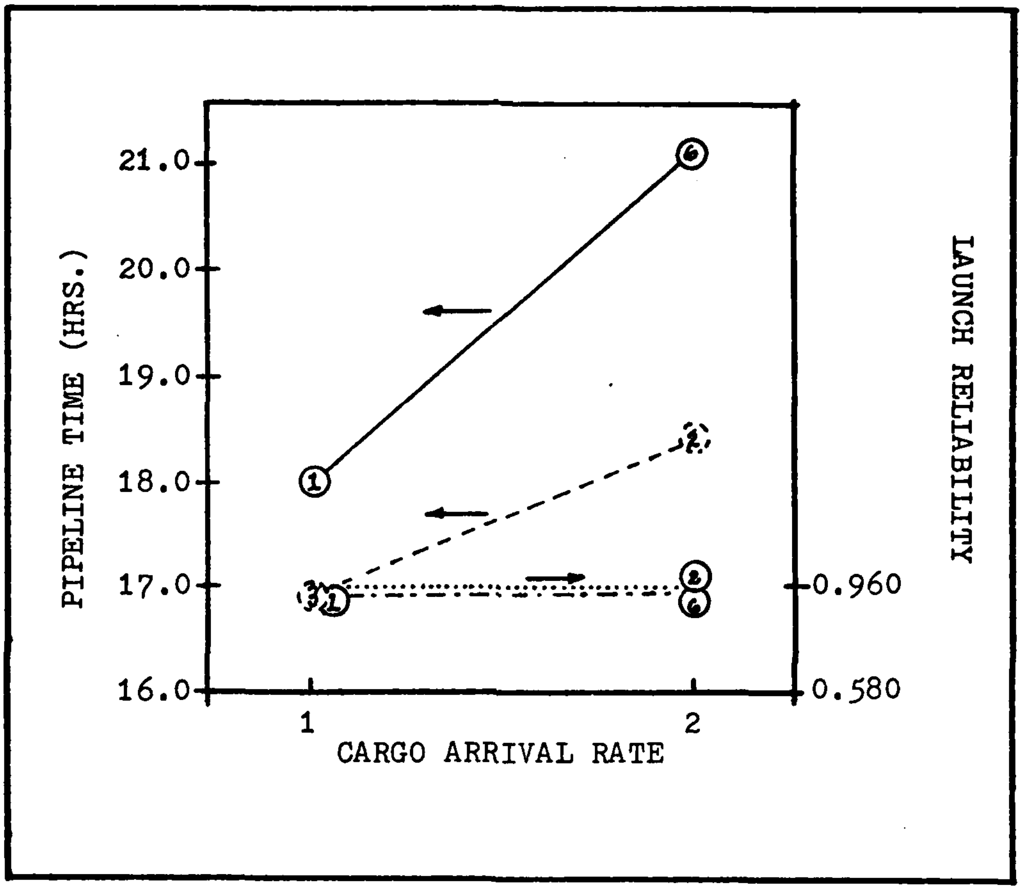

Figure 5-2a Base PDNMR: Pipeline Time and Launch Reliability Versus Cargo Arrival Rate

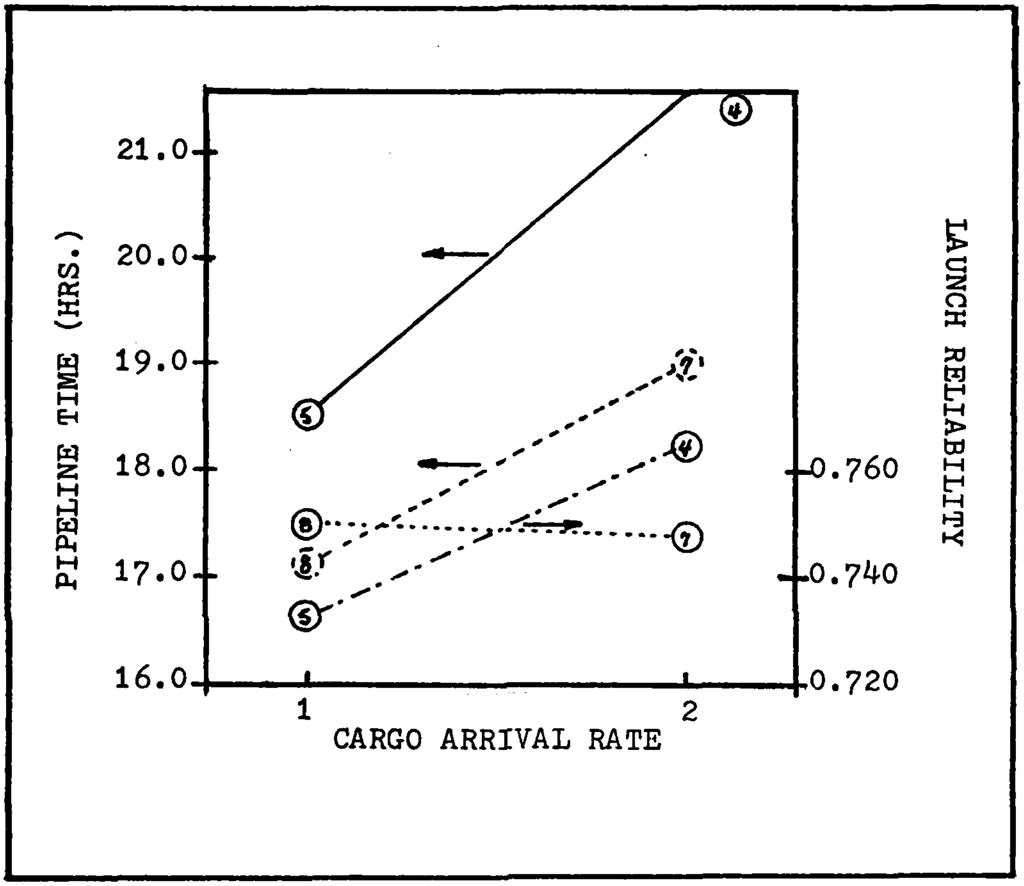

Figure 5-2b High PDNMR: Pipeline Time and Launch Reliability Versus Cargo Arrival Rate

pipeline time, cargo arrival rate and pre-departure unscheduled maintenance rate. It should be noted that the pipeline times are useful only for the purposes of comparing different model environments and policies. The model values do not relate to actual pipeline times which are typically several times higher because they include transshipment times and more complicated interaction. The most obvious relationship noted from Figures 5-2a and b is that pipe line time increases as the cargo arrival rate increases. This should not be surprising, as cargo arrives faster unless mission generation keeps pace the cargo will stagnate. Note that whereas the high cargo arrival rate is three times that of the low cargo arrival rate, the high mission generation rate is not quite twice the lower rate.

In figure 5-2a there appears to be no relationship between the pipeline time and departure reliability. Similarly, in Figure 5-2b it is seen that while high unscheduled maintenance rates lengthen the pipeline time, the departure reliability index improves in one instance and remains level in the other.

It can be concluded from these experiments that under the circumstances described and modeled the departure reliability index is not a measure of system productivity. In fact there appears to be no correlation between departure reliability and system output in general. This can be attributed to the fact that departure reliability measures only one activity, departure, against one standard, scheduled departure time. This is not to suggest that departure reliability is not a worthwhile goal but only that it does not capture any of the output dynamics of the system. For that matter neither dies concentration on pure output measures. In general output measures indicate how much, or how long. There is no indication of cost or general effectiveness of effort.

To compare the different simulation runs from a productivity point of view a number of productivity indices were devised and calsulated for each run, each iteration. The results are displayed in Table 5-2. The indices were calculated as follows:

$$\text{INDEX (A)} = \frac{\text{Total Ton-Miles}}{\text{Total Maintenance Man-Hour}}$$

$$\text{INDEX (B)} = \frac{\text{Total Ton-Miles}}{\text{Total Port Man-Hour}}$$

$$\text{INDEX (C)} = \frac{\text{Total Ton-Miles}}{\text{Total Fuel Consumption}}$$

$$\text{INDEX (D)} = \frac{\text{Total Ton-Miles}}{\text{Total Flying Hours}}$$

$$\text{INDEX (E)} = \frac{\text{Total Ton-Miles}}{\text{(Total Maintenance And Port Man-Hours)}}$$

$$\text{INDEX (F)} = \frac{\text{Total Ton-Miles}}{\text{Total C-5 and C-141 Sorties}}$$

Table 5-2 Productivity Indices

RUN	PONMR	CAP	MGP	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
1A	1	1	1	3.9386	5.5181	.9194	2.8128	2.2982	21.0285	1.2142	.4497	85.4328
1B	1	1	1	3.7129	5.3063	.8945	2.6902	2.1844	20.0193	1.1994	.4243	83.7389
1C	1	1	1	3.5897	5.2534	.8451	2.5926	2.1674	19.2512	1.2557	.4715	78.6110
2A	1	2	2	6.3769	5.0193	1.4824	4.5381	2.8086	33.3066	.4698	.3076	201.0440
2B	1	2	2	6.2743	4.8115	1.4287	4.3151	2.7232	31.8018	.4911	.3316	186.7329
2C	1	2	2	6.5394	4.9991	1.5153	4.5985	2.8332	33.9653	.4727	.3129	201.0370
3A	1	1	2	3.0804	5.2319	.7046	2.1664	1.9389	15.9647	.9683	.3262	96.8484
3B	1	1	2	3.1187	5.3137	.7121	2.1727	1.9653	16.0491	.9549	.3183	99.6718
3C	1	1	2	3.1774	5.3066	.7386	2.2507	1.9874	16.5235	.9572	.3225	99.0778
4A	2	2	1	5.6107	4.7238	1.7602	5.4373	2.5646	40.4127	.5707	.2541	174.6414
4B	2	2	1	5.8286	4.4335	1.8759	5.7015	2.5181	41.6811	.6353	.2876	157.0357
4C	2	2	1	5.8286	4.4335	1.8759	5.7015	2.5181	41.6811	.6353	.2876	157.0357
5A	2	1	1	2.6562	5.1272	.8588	2.6425	1.7497	19.4049	1.2434	.2629	78.8103
5B	2	1	1	2.6235	4.9945	.8202	2.5259	1.7200	18.8442	1.3042	.2759	74.0645
5C	2	1	1	2.6445	5.2516	.9040	2.7761	1.7588	20.2397	1.2468	.2365	80.6071
6A	1	2	1	8.0514	4.5892	1.8447	5.8275	2.9231	42.0541	.6047	.4683	166.8496
6B	1	2	1	8.7356	3.6511	2.0134	5.5521	2.5749	40.7517	1.1873	.7210	119.3000
6C	1	2	1	7.5429	4.6021	1.8529	5.8536	2.8582	40.4691	.5868	.4298	167.6827
7A	2	2	2	4.3722	4.9167	1.4419	4.3130	2.3142	31.7659	.4840	.1701	194.3805
7B	2	2	2	4.5845	4.8444	1.4957	4.3984	2.3816	32.4671	.5036	.1986	187.1517
7C	2	2	2	4.7412	4.9740	1.5639	4.7621	2.4179	34.9815	.5041	.1827	192.8394
8A	2	1	2	2.0322	5.2206	.6512	1.9740	1.4628	14.5770	1.0405	.1766	90.7325
8B	2	1	2	2.0660	5.4177	.6790	2.0620	1.4960	15.1554	.9907	.1680	98.1995
8C	2	1	2	2.1016	5.5283	.6984	2.1246	1.5227	15.6063	1.0012	.1640	98.8858

$$\text{INDEX (G)} = 100.0 \; \frac{\text{Pipeline Time}}{\text{Port Man-Hours}}$$

$$\text{INDEX (H)} = \frac{\text{Total Departure Reliability}}{\text{Total Maintenance Man-Hours}}$$

$$\text{INDEX (I)} = \frac{(\text{Total Ton-Miles} + \text{Total On-Time Departures})}{100.0}$$

The value of these indices is in comparing apparently equivalent situations. That is, two or more instances where the output is about the same. By considering the input levels or the resources consumed, together with the output level a better idea emerges of how effectively resources including man-hours, are utilized.

For example, runs 2 and 7 in Table 5-1 have comparable ton-mile output. Run 2 represents a situation in which the PDNMR is at the base rate, while both the cargo arrival rate and the mission generation rate are high. Run 7 represents a similar situation except that the PDNMR is also high, consequently the direct maintenance man-hour requirements to support the Channel mission would be higher. This becomes more evident when the values of index A, ton-miles per maintenance man-hour, for runs 2 and 7 are compared. Index A for 7 is only seventy percent of what index A is for 2. The situation in run 7 could be expected to breakdown over a period of time unless the pre-departure maintenance rate could be improved.

Comparisons between other situations can also be made.

There is nothing magical about an index. The usefulness of an index is in putting complex situations into a simpler framework for easier comparison. Productivity indices may also be used for comparing the performance of a single unit over a period of time. Integrated into a program of statistical analysis the productivity index can serve as a control device for initiating management action or closer scrutiny. Well constructed indices can also measure inertia of a system, how well or how poorly the system adjusts to changes in conditions. As such, a series of indices could be developed to predict system capacity under given conditions.

An appropriate set of productivity rates measures for the MAC system depends on both the critical processes and MAC Commander's assessment. For example, one of the critical processes of the MAC airlift system is the generation of aircraft to support mission requirements. Therefore, maintaining sortie productivity ratios for particular channels could point up patterns for decreasing actual aircraft requirements while maintaining training levels and ton-mile output levels.

Summary

Chapter V has presented the results of the simulation experiments conducted as described in Chapter IV. The conclusion from the experiments is that departure reliability does not track system output. Consequently, departure reliability as a system measure of productivity is inadequate. A number of productivity ratio indices were described and computed for each of the runs and tabulated in Table 5-2. The indices can be used for comparing instances with similar output or for comparing the same conditions with varying outputs. As a ratio of system output to system input the indices are also useful for flagging management action and attention and in guiding management planning.

VI Conclusions and Recommendations

This study has examined the MAC peacetime airlift system. In particular, the objective has been to develop a measure of productivity or rather an approach to measuring system productivity. In the process considerable pains were taken to define the MAC system, its environment and its system productivity. A simulation model was developed to study how operations, maintenance and transportation interact to generate output from the system. A number of experiments were conducted with the model to examine what happens to system input and output under certain circumstances. From this effort a number of conclusions can be drawn and a number of recommendations can be made. This Chapter presents both.

Conclusions

1. Departure reliability is not suitable as a productivity measure because it is not sensitive to system output. As an effectiveness measure it is limited to the assessment of an activity not an output. Furthermore, unduly emphasizing departure reliability actually works against system productivity by neglecting output.

2. The use of indices to measure output level to input level ratios can serve as a tool to compare one unit with another in terms of productivity. Additionally, a unit can gauge its own productivity over a period of time by the use of productivity ratios. The exact formulation of the ratio depends on the situation at hand. However, a particular resource or

manpower shortage would suggest designing a ratio measure to track output as a function of critical resources.

3. The real impact of productivity management comes from focusing on productivity and the approaches to its enhancement.

Recommendations

The areas of productivity measurement and of productivity management appear to offer potential for exploitation by the MAC system in general and bear further investigation. By focusing airlift management attention on system output and the means to increase this output rather than on the system constraints, productivity management in MAC could open new avenues for capability enhancement. Contingency planning could be improved if planning factors were derived from established productivity measures. In line with this, airlift training exercises planned and executed with an eye to system productivity would benefit contingency planners and airlift managers alike by pointing up the real costs and limitations.

Finally, the findings of this study could be enhanced by the inclusion of the return leg from Europe as well as multiple destinations, in the MAC system model. Furthermore, by employing a blocking experimental design many more factors in the model could be investigated and controlled. With more iterations of each case the results could be analyzed using analysis of variance, statistical significance testing and linear regression techniques.

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Appendix A

FORTRAN Code Listing of DATANAL Program

and Sample Output

APPENDIX A: DATANAL FORTRAN LISTING

```
      PROGRAM DATANAL(INPUT,OUTPUT,TAPE6=OUTPUT,TAPE5=INPUT)
      REAL DAY(250),HOUR(250),FLYT(250),PAX(250),CARGO(250),
     1BTIM(250),BDEV(250),FDEV(250),PDEV(250),CDEV(250),
     2JHOUR(250),B(11),F(11),P(11),C(11)
      INTEGER KB(10),KF(10),KP(10),KC(10),HH
      DIMENSION ACODE(4)
      DATA ACODE/8HBTWTIME:,8HFLYTIME:,8HPASSNGR:,8HCARGOPD:/
 88   READ(5,999) RUNAME,RANAME
      IF(EOF(5LINPUT).NE.0.0) GO TO 99
      I = 0
      SFLYT = 0.0
      SPAX = 0.0
      SCARGO = 0.0
      SBTIM = 0.0
      SBDEV = 0.0
      SFDEV = 0.0
      SPDEV = 0.0
      SCDEV = 0.0
 1    I = I + 1
      READ*,DAY(I),HOUR(I),FLYT(I),PAX(I),CARGO(I)
      IF(DAY(I).LT.0.0) GO TO 2
      H = HOUR(I)/100.0
      IH = H
      HHH = IH
      HM = (H - HHH)*60.0
      HOUR(I) = H + HM
      JHOUR(I) = DAY(I)*24.0 + HOUR(I)
      SFLYT = SFLYT + FLYT(I)
      SPAX = SPAX + PAX(I)
      SCARGO = SCARGO + CARGO(I)
      GO TO 1
 2    I = I - 1
      A = FLOAT(I)
      FBAR = SFLYT/A
      PBAR = SPAX/A
      CBAR = SCARGO/A
      CALL SORT(I,JHOUR)
      CALL SORT(I,FLYT)
      CALL SORT(I,PAX)
      CALL SORT(I,CARGO)
      CALL SORT(I,DAY)
      BTIM(1) = JHOUR(1) - DAY(1)*2 .0
      SBTIM = BTIM(1)
      DO 3 J = 2, I
      BTIM(J) = JHOUR(J) - JHOUR(J-1)
 3    SBTIM = SBTIM + BTIM(J)
      CALL SORT(I,BTIM)
      BBAR = SBTIM/A
      DO 4 K = 1, I
      BDEV(K) = (BTIM(K)-BBAR)** 2.0
```

```
      FDEV(K) = (FLYT(K) -FBAR)**2.0
      PDEV(K) = (PAX(K) - PBAR)**2.
      CDEV(K) = (CARGO(K) - CBAR )**2.0
      SBDEV = SBDEV + BDEV(K)
      SFDEV = SFDEV + FDEV(K)
      SPDEV = SPDEV + PDEV(K)
4     SCDEV = SCDEV + CDEV(K)
      BVAR = SBDEV/(A-1)
      FVAR = SFDEV/(A-1)
      PVAR = SPDEV/(A-1)
      CVAR = SCDEV/(A-1)
      B10 = (BTIM(I) - BTIM(1))/10.
      F10 = (FLYT(I) - FLYT(1))/10.
      P10 = (PAX(I) - PAX(1))/10.0
      C10 = (CARGO(I) - CARGO(1))/10.0
      WRITE(6,1000) I,RUNAME,RANAME
      WRITE(6,1001) ACODE(1),BBAR,BVAR,BTIM(1),BTIM(I),B10
      WRITE(6,1001) ACODE(2),FBAR,FVAR,FLYT(1),FLYT(I),F10
      WRITE(6,1001) ACODE(3),PBAR,PVAR,PAX(1),PAX(I),P10
      WRITE(6,1001) ACODE(4),CBAR,CVAR,CARGO(1),CARGO(I),C10
      B(1) = BTIM(1)
      F(1) = FLYT(1)
      P(1) = PAX(1)
      C(1) = CARGO(1)
      DO 5 L = 2, 11
      B(L) = B(L-1) + B10
      F(L) = F(L-1) + F10
      P(L) = P(L-1) + P10
5     C(L) = C(L-1) + C10
      DO 7 M = 1, 10
      KB(M) = 0
      KF(M) = 0
      KP(M) = 0
7     KC(M) = 0
      DO 8 N = 1, 10
      DO 8 NM = 1, I
      IF(BTIM(NM).GE.B(N).AND.BTIM(NM).LT.B(N+1))KB(N) = KB(N) + 1
      IF(FLYT(NM).GE.F(N).AND.FLYT(NM).LT.F(N+1))KF(N) = KF(N) + 1
      IF(PAX(NM).GE.P(N).AND.PAX(NM).LT.P(N+1))KP(N) = KP(N) + 1
      IF(CARGO(NM).GE.C(N).AND.CARGO(NM).LT.C(N+1))KC(N) = KC(N) + 1
8     CONTINUE
      WRITE(6,1002) (K,K=1,10)
      WRITE(6,1003)ACODE(1),(KB(N),N=1,10)
      WRITE(6,1003)ACODE(2),(KF(N),N=1,10)
      WRITE(6,1003)ACODE(3),(KP(N),N=1,10)
      WRITE(6,1003)ACODE(4),(KC(N),N=1,10)
      GO TO 88
C     ***********FORMAT   STATEMENTS *********
999   FORMAT(2A10)
1000  FORMAT(1H1,12X, I3," TRANSACTIONS OBSERVED/",2A10,//,7X,
```

APPENDIX A: DATANAL FORTRAN LISTING

```
     1"    QUANTITY    AVERAGE     VARIANCE    MIN-VALUE   MAX-VALUE   RTEN
     2TH")
1001  FORMAT(1H0,9X,A8,3X,F7.1,2X,F12.1,3X,F8.1,4X,F8.1,3X,F6.1)
1002  FORMAT(1H0,29X,"FREQUENCY DATA",//,20X,10(3X,I2))
1003  FORMAT(1H0,9X,A8,2X,10(2X,I3))
99    CONTINUE
      STOP "END OF PROGRAM"
      END
```

57 TRANSACTIONS OBSERVED/C-5 (US-EUR) MAX RNG

QUANTITY	AVERAGE	VARIANCE	MIN-VALUE	MAX-VALUE	RTENTH
BTWTIME:	13.3	113.9	.4	37.5	3.7
FLYTIME:	7.6	.2	6.3	8.7	.2
PASSNGR:	26.1	603.6	0.0	74.0	7.4
CARGOPD:	55860.2	187181992.9	19165.0	99795.0	8063.1

FREQUENCY DATA

	1	2	3	4	5	6	7	8	9	10
BTWTIME:	15	7	9	5	5	4	4	2	3	2
FLYTIME:	1	0	2	10	8	21	8	5	1	1
PASSNGR:	20	6	4	3	7	3	3	3	2	5
CARGOPD:	1	2	4	18	14	12	0	4	1	0

51 TRANSACTIONS OBSERVED/C-5 (EUR-US) MAX RNG

QUANTITY	AVERAGE	VARIANCE	MIN-VALUE	MAX-VALUE	RTENTH
BTWTIME:	12.6	155.4	.3	56.0	5.6
FLYTIME:	9.6	.6	8.3	12.2	.4
PASSNGR:	29.6	751.4	0.0	74.0	7.4
CARGOPD:	51221.5	391934316.9	0.0	99867.0	9986.7

FREQUENCY DATA

	1	2	3	4	5	6	7	8	9	10
BTWTIME:	22	13	9	4	5	4	1	0	0	1
FLYTIME:	6	6	15	15	12	2	0	3	0	0
PASSNGR:	20	6	5	3	5	1	4	1	3	11
CARGOPD:	4	3	0	4	9	22	16	0	0	2

200 TRANSACTIONS OBSERVED/141 (US-EUR) MAX RNG

QUANTITY	AVERAGE	VARIANCE	MIN-VALUE	MAX-VALUE	RTENTH
BTWTIME:	3.8	12.8	.0	15.6	1.6
FLYTIME:	7.3	1.5	4.7	10.3	.6
PASSNGR:	7.7	285.7	0.0	85.0	8.5
CARGOPD:	31199.7	126562322.9	0.0	54282.0	5428.2

FREQUENCY DATA

	1	2	3	4	5	6	7	8	9	10
BTWTIME:	76	40	21	17	17	12	8	[illegible]	[illegible]	4
FLYTIME:	21	13	2	13	52	67	11	2	7	11
PASSNGR:	150	24	4	5	4	2	3	2	3	0
CARGOPD:	5	6	16	11	17	43	46	34	13	8

192 TRANSACTIONS OBSERVED/141 (EUR-US) MAX RNG

QUANTITY	AVERAGE	VARIANCE	MIN-VALUE	MAX-VALUE	RTENTH
BTWTIME:	4.0	17.2	.0	21.6	2.2
FLYTIME:	9.3	2.2	5.8	11.9	.5
PASSNGR:	9.3	149.8	0.0	82.0	8.2
CARGOPD:	25583.8	74734449.2	0.0	37701.0	3770.1

FREQUENCY DATA

	1	2	3	4	5	6	7	8	9	10
BTWTIME:	86	43	21	13	9	5	5	0	2	1
FLYTIME:	16	12	0	3	24	33	35	39	21	8
PASSNGR:	110	51	16	5	4	2	1	1	1	0
CARGOPD:	9	4	8	4	8	13	18	58	65	6

Appendix B

Q-GERT Code Listing of Airlift Model Network

APPENDIX B: Q-GERT CODE LISTING

```
GEN,RICHARD,THESIS PROGRAM,2,1 ,19 ,15,2,999,72 .0,1,F,0,7*
SEE,1,3459221,2,9  00371,3,23 912 8E6,4,96 82 1 57*
SEE,5,5576352864,6,73  15 499,7,38 265832,8,55 38 2436*
SEE,9,2855735497 7,10,55449378 93*
SOU,10,0,1*                          DISJOINT NETWORK
ACT,10,11,CO,24.0*
REG,11,1,1*
VAS,11,1,UF,12*
ACT,11,10,CO,0.0*
SOU,50,0,1*                          PORT NETWORK
ACT,50,50,NO,1*
PAR,1,1.0,0. 00,1.5,0.25*            CARG  ARRIVAL PARAMETERS
ACT,50,54*
QUE,54/TRKOFFLD*
VAS,54,1,NO,2*
PAR,2,3.12,0.1,5.4,1.12*             CARGO WEIGHT PARAMETERS
ACT,54,56,UF,13,,10*
REG,55,1,1,F*
ACT,56,60,CO,1.0,(8)0.66*
REG,60,1,1*
VAS,60,2,CO,141,1,UF,14*
ACT,60,61,CO,0.0*
STA,61/LDASM141,9,9,,B,(9)F*
ACT,61,62,UF,15*
QUE,62/LOADC141,(10)120*
VAS,62,1,UF, *
ACT,55,70,CO,1.0,(8)0.34*
REG,70,1,1*
VAS,70,2,CO, ,1,UF,14*
ACT,70,71*
STA,71/LDASM5,9,9,,B,(9)F*
ACT,71,72,UF,15*
QUE,72/LOADC5,(10)220*
VAS,72,1,UF, *
SOU,100,0,1*                         C-141 GENERATION NETWORK
ACT,100,105,CO,10. *
REG,105,1,1,D,M*
VAS,105,1,CO,141,2,IN,1,4,NO,3*C-1 1 MISSION PARAMETER ASSIGNMENT
PAR,3,7.3,4.7,10.3,1.2*              C-141 FLYING TIME PARAMETERS
ACT,105,105,NO,4*                    C-141 MISSION GENERATOR
PAR,4,3.8,0.0,15.6,3.6*              C-141 INTERDEPARTURE PARAMETERS
ACT,105,106,CO,8.0*
ACT,105,125,CO,12.0*
QUE,106/FUELC141*
ACT,106,110,UF,3,(7)10*
REG,110,1,1*
VAS,110,3,UF,16*
ACT,110,115,CO,0.0*
QUE,115/ACFTLDQ,(10)120*
SEL,120,ASM,,B/1,,62,115*
```

APPENDIX B: Q-GERT CODE LISTING

```
ACT,120,121,UF,5,(7)10*
QUE,121/ACFT0141,(10)130*
REG,125,1,1*
VAS,125,5,UF,1*
ACT,125,128,CO,0.0*
QUE,128/CREW0141,(10)130*
VAS,128,4,UF,6*
MAT,130,2,128/131,121/131*
REG,131,2,2,(7)3/4*
ACT,131,132,UF,7*
REG,132,1,1,P*
ACT,132,140,(8)0.8*                 C-141 PREDEPT O.R. RATE
ACT,132,1,(8)0.2*                   C-141 PREDEPT NONSCHED MAINT RATE
SOU,200,0,1*                        C-5 GENERATION NETWORK
ACT,200,205,CO,20.0*
REG,205,1,1,0,M*
VAS,205,1,CO,5,2,IN,1,4,NO,5*       C-5 MISSION PARAMETER ASSIGNMENT
PAR,5,7.6,6.3,8.7,0.45*             C-5 FLYING TIME PARAMETER SET
ACT,205,205,NO,6*                   C-5 MISSION GENERATOR
PAR,6,13.3,0.4,37.5,10.7*           C-5 INTERDEPARTURE PARAMETERS
ACT,205,206,CO,7.0*
ACT,205,225,CO,12.0*
QUE,206/FUEL05*
ACT,206,210,UF,3,(7)10*
REG,210,1,1*
VAS,210,3,UF,16*
ACT,210,215*
QUE,215/ACFTLD05,(10)220*
SEL,220,ASM,,B/1,,72,215*
ACT,220,221,UF,5,(7)10*
QUE,221/ACFT05,(10)230*
REG,225,1,1*
VAS,225,5,UF,1*
ACT,225,228*
QUE,228/CREW05,(10)230*
VAS,228,4,UF,6*
MAT,230,2,228/231,221/231*
REG,231,2,2,(7)3/4*
ACT,231,232,UF,7*
REG,232,1,1,P*
ACT,232,240,(8)0.8*                 C-5 PREDEPT O.R. RATE
ACT,232,1,(8)0.2*                   C-5 PREDEPT NONSCHED MAINT RATE
REG,1,1,1,P*                        MAINTENANCE NETWORK
ACT,1,2,(8)0.2*                     ENGINE MAINTENANCE
STA,2/ENGMX,1,1,D,B*
VAS,2,3,CO,1*
ACT,1,3,(8)0.2*                     HYDRAULIC MAINTENANCE
STA,3/HYDRMX,1,1,D,B*
VAS,3,3,CO,2*
ACT,1,4,(8)0.1*                     ELECTRIC/AVIONICS MAINTENANCE
```

APPENDIX B: Q-GERT CODE LISTING

```
STA,4/ELECTRMX,1,1,D,B*
VAS,4,3,CO,3*
ACT,1,5,(8)0.5*                        "OTHER" MAINTENANCE REQUIREMENTS
STA,5/OTHERMX,1,1,D,B*
VAS,5,3,CO,4*
ACT,2,6,CO,0.0*
ACT,3,6,CO,0.0*
ACT,4,6,CO,0.0*
ACT,5,6,CO,0.0*
QUE,6/MINORMX*
ACT,6,7,UF,2,(7)10*
STA,7/SYSTMMX,1,1,F,I*
ACT,7,132,(9)A1.EQ.141*
STA,140/SYSTM141,1,1,D,I*
ACT,140,141,CO,0.0*
REG,141,1,1*
VAS,141,3,UF,8*                        C-141 DELAY STATUS DETERMINATION
ACT,141,142,UF,9*
REG,142,1,1,F*
ACT,142,143,CO,0.0,(9)A3.EQ.1*
STA,143/ONTM141,1,1,D,I*
ACT,142,144,CO,0.0,(9)A3.GT.1*
STA,144/LATE141,1,1,D,I*
ACT,143,145*
ACT,144,145*
STA,145/POST141,1,1,D,I*
VAS,145,3,UF,1*
ACT,145,80,AT,4*                       C-141 FLIGHT TO WESTEUR
QUE,80/OFFLOD*                         WESTEUR PORT NETWORK
ACT,80,81,UF,10,(7)10*
REG,81,1,1,F*
ACT,81,85,UF,11,(9)A1.EQ.141* C-141 MISSION REPORT
SIN,85/SINK141,1,1,D,B*          C-141 MISSION TRANSACTION SINK
ACT,7,232,(9)A1.EQ.5*
STA,240/SYSTIME5,1,1,D,I*
ACT,240,241*
REG,241,1,1*
VAS,241,3,UF,8*                        C-5 DELAY STATUS DETERMINATION
ACT,241,242,UF,9*
REG,242,1,1,F*
ACT,242,243,(9)A3.EQ.1*
STA,243/ONTIMEC5,1,1,D,I*
ACT,242,244,(9)A3.GT.1*
STA,244/LATEC5,1,1,D,I*
ACT,243,245*
ACT,244,245*
STA,245/POST5,1,1,D,I*
ACT,245,80,AT,4*                       C-5 FLIGHT TO WESTEUR
VAS,245,3,UF,1*
ACT,81,95,UF,11,(9)A1.EQ.5*     C-5 MISSION REPORT
```

APPENDIX B: Q-GERT CODE LISTING

```
SIN,90/SINKS,1,1,D,9*            C-5 MISSION TRANSACTION SINK
PAR,10,,0.5,3.00*               C5 ENGINE MAINT PARAMETERS
PAR,11,,0.5,2.00*               C5 HYDRAULIC MX PARAMETERS
PAR,12,,0.5,2.50*               C5 ELECTO*AVIONICS MX PARAMETERS
PAR,13,,0.5,2.50*               C5 "OTHER" MAINTENANCE PARAMETERS
PAR,14,,0.5,1.75*               C141 ENGINE MAINT PARAMETERS
PAR,15,,0.5,2.00*               C141 HYDRAULIC MX PARAMETERS
PAR,16,,0.5,1.50*               C141 ELECTO*AVIONICS MX PARAMETERS
PAR,17,,0.5,2.00*               C141 "OTHER" MAINTENANCE PARAMETERS
FIN*
```

Appendix C

FORTRAN Code Listing of User Program Inserts

APPENDIX C: PROGRAM INSERTS FORTRAN LISTING

```
*********************************************************************
*********************************************************************
**********FUNCTION UF(IFN) MAIN PROGRAM INSERT************************
**********CONTROL TO VARIOUS AREAS IS BY COMP-************************
**********UTED GO TO STATEMENT WITH ARGUMENT  ************************
**********IFN.                               *************************
*********************************************************************
*********************************************************************
      FUNCTION UF(IFN)
*********************************************************************
*********************************************************************
**********     FUNCTION UF(IFN)  VARIABLE LIST    *******************
*********************************************************************
*********************************************************************
*                                                                   *
*         ARRTIM  : DESTINATION ARRIVAL TIME                        *
*         ATT     : ATTRIBUTE VECTOR (CF P. 70)                     *
*         CAT141  : CARGO ARRIVAL TIME FOR C-141                    *
*         CAT5    : CARGO ARRIVAL TIME FOR C-5                      *
*         CRG141  : WEIGHT FOR C-141 LOAD TRX                       *
*         CRG5    : WEIGHT FOR C-5 LOAD TRX                         *
*         CRUDAY  : CREWDAY (IN HOURS) OF TRX                       *
*         CSH141  : CREW SHOWTIME FOR C-141 TRX                     *
*         CSH5    : CREW SHOWTIME FOR C-5 TRX                       *
*         EASPORT : PORT LEVEL IN TONS OF EASTUS PORT               *
*         ESTNDL  : TONS DELIVERED BY TRUCK TO EASTUS               *
*         FTIM    : FLYING TIME OF TRX                              *
*         IDAY    : SIMULATION DAY COUNTER                          *
*         IDUM    : Q-GERT VARIABLE (CF. P. 71)                     *
*         IECOUNT : NUMBER OF TRUCK ARRIVALS AT EASTUS              *
*         IEP     : NUMBER OF EMPTY "PALLETS"                       *
*         IFN     : FUNCTION CALL ARGUMENT                          *
*         IMXTYP  : MAINTENANCE TYPE CODE                           *
*         IP      : MISSION ARRIVAL PRINT OPTION                    *
*         ITYP    : AIRCRAFT TYPE: 5 = C-5, 141 = C-141             *
*         IWACNT  : AIRCRAFT ARRIVAL COUNT AT WESTEUR               *
*         K       : C-141 LOAD ACCUMULATION COUNTER                 *
*         L       : C-5 LOAD ACCUMULATION COUNTER                   *
*         MSNNO   : MISSION NUMBER OF TRANSACTION                   *
*         NDE     : Q-GERT VARIABLE  --NOT USED--                   *
*         NFTBU   : Q-GERT VARIABLE  --NOT USED--                   *
*         NK      : DO LOOP COUNTER                                 *
*         NL      : DO LOOP COUNTER                                 *
*         NREL    : Q-GERT VARIABLE  (CF. P. 70)                    *
*         NRELP   : Q-GERT VARIABLE  --NOT USED--                   *
*         NREL2   : Q-GERT VARIABLE  --NOT USED--                   *
*         NRUN    : Q-GERT VARIABLE  (CF. P. 70)                    *
*         NRUNS   : Q-GERT VARIABLE  CF. P. 70)                     *
*         NTC     : Q-GERT VARIABLE  --NOT USED--                   *
*         PARAM   : Q-GERT DISTRIBUTION PARAMETER SET               *
```

```
*          PIPE    : AVERAGE PIPELINE TIME FOR RUN              *
*          PIPTIME: PIPELINE TIME FOR ONE MISSION              *
*          TBEG    : Q-GERT VARIABLE --NOT USED--               *
*          TC5     : TOTAL CARGO AIRLIFTED BY C-5               *
*          TC141   : TOTAL CARGO AIRLIFT BY C-141               *
*          TFLY    : TOTAL RUN FLYING TIME                      *
*          TFUEL   : TOTAL RUN FUEL CONSUMPTION (GALLONS)       *
*          TMXHR   : TOTAL RUN MAINTENANCE HOURS                *
*          TNOW    : Q-GERT VARIABLE (CF. P. 71)                *
*          TONMILE: TOTAL RUN TONMILES                          *
*          TPMHR   : TOTAL RUN PORT MANHOURS                    *
*          TRW141  : TRANSFER WEIGHT OF C-141 LOAD TRX          *
*          TRW5    : TRANSFER WEIGHT OF C-5 LOAD TRX            *
*          TWA141  : TOTAL RUN C-141 ARRIVALS IN WESTEUR        *
*          TWA5    : TOTAL RUN C-5 ARRIVALS IN WESTEUR          *
*          TW141   : LOAD WEIGHT ACCUMULATION VAR-C-141         *
*          TW5     : LOAD WEIGHT ACCUMULATION VAR-C-5           *
*          UF      : FUNCTION NAME                              *
*          UTE141  : AVERAGE RUN C-141 CAPACITY UTIL.           *
*          UTE5    : AVERAGE RUN C-5 CAPACITY UTILIZATION       *
*          WESDEL  : TONS OF CARGO AIRLIFTED TO WESTEUR         *
*          WGTUTE  : WEIGHT UTILIZATION                         *
*                                                               *
*****************************************************************
**********TRX = TRANSACTION                           ***********
**********EASTUS = EASTERN U.S. PORT                  ***********
**********WESTEUR = WESTERN EUROPEAN PORT             ***********
*****************************************************************
*****************************************************************
      COMMON/QVAR/NDE,NFTBU(500),NREL(500),NRELP(500),NREL2(500),NRUN,
     1NRUNS,NTC(500),PARAM(100,4),TBEG,TNOW
      COMMON/USER/EASPORT,IECOUNT,IWACNT,ESTNDL,WESDEL,K,L,TW141,TW5,
     1TRW141,TRW5,TON,PIPE,TWA5,TWA141,TMXHR,TPMHR,TFUEL,TFLY,UTE5,
     2UTE141,IP,TC5,TC141
      REAL UN
      DIMENSION ATT(8)
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16),IFN
*****************************************************************
*****************************************************************
**********UF 1 RETURNS VALUE OF TNOW FOR UF          ***********
*****************************************************************
*****************************************************************
1     UF = TNOW
      RETURN
*****************************************************************
*****************************************************************
**********UF 2 DETERMINES MAINTENANCE SERVICE        ***********
**********TIMES. CF. TEXT P. 72                      ***********
*****************************************************************
*****************************************************************
```

```
 2      IMXTYP = GATRB(3)
        IF(GATRB(1).EQ.5) GO TO 30
        GO TO (22,23,24,25),IMXTYP
    22  UF = UN(14)
        TMXHR = TMXHR + UF*3.0
        RETURN
    23  UF = UN(15)
        TMXHR = TMXHR + UF*2.0
        RETURN
    24  UF = UN(16)
        TMXHR = TMXHR + UF*1.0
        RETURN
    25  UF = UN(17)
        TMXHR = TMXHR + UF*2.0
        RETURN
    30  GO TO (32,33,34,35),IMXTYP
    32  UF = UN(10)
        TMXHR = TMXHR + UF*3.0
        RETURN
    33  UF = UN(11)
        TMXHR = TMXHR + UF*2.0
        RETURN
    34  UF = UN(12)
        TMXHR = TMXHR + UF*1.0
        RETURN
    35  UF = UN(13)
        TMXHR = TMXHR + UF*2.0
        RETURN
**************************************************************
**************************************************************
**********UF 3 DETERMINES FUELING SERVICE          **********
**********TIME AND TOTAL FUEL NEEDS, P. 72         **********
**************************************************************
**************************************************************
 3      FTIM = GATRB(4)
        IF(GATRB(1).EQ.5) GO TO 40
        UF = (FTIM*1.1 + 1.25)*0.0675
        TFUEL = TFUEL + UF*30000
        TMXHR = TMXHR + UF + 3.0
        RETURN
    40  UF = (FTIM*1.1 + 1.25)*0.1125
        TFUEL = TFUEL + UF*30000
        TMXHR = TMXHR + UF + 0.0
        RETURN
**************************************************************
**************************************************************
**********UF 4 USED TO PASS WEIGHT OF CARGO        **********
**********BEING ONLOADED TO AIRCRAFT TRX FOR       **********
**********INCLUSION IN TRX ATTRIBUTES. P. 72       **********
**************************************************************
```

APPENDIX C: PROGRAM INSERTS FORTRAN LISTING

```
*****************************************************************
4      IF(GATRB(2).EQ.5) GO TO 46
       CRG141 = GATRB(1)
       CAT141 = TMARK(IDUM)
       UF = 0.0
       RETURN
   46  CRG5 = GATRB(1)
       CAT5 = TMARK(IDUM)
       UF = 0.0
       RETURN
*****************************************************************
*****************************************************************
**********UF 5 USED TO SET AIRCRAFT TPX ATTRI-*******************
**********BUTE #6 EQUAL TO CARGO WEIGHT. P.72 ********************
*****************************************************************
*****************************************************************
5      IF(GATRB(1).EQ.5) GO TO 55
       CALL PATRB(CRG141,6)
       CALL PATRB(CAT141,7)
       EASPORT = EASPORT - CRG141
       UF = CRG141 * 0.06
       TPMHR = TPMHR + UF*2.0
       RETURN
   55  CALL PATRB(CRG5,6)
       CALL PATRB(CAT5,7)
       EASPORT = EASPORT - CRG5
       UF = CRG5 * 0.06
       TPMHR = TPMHR + UF*2.0
       RETURN
*****************************************************************
*****************************************************************
**********UF 6 USED TO PASS CREW SHOWTIME TO    ********
**********AIRCRAFT TRANSACTION FOR INCLUSION    ********
**********IN ATTRIBUTE SET. P. 72.              ********
*****************************************************************
*****************************************************************
6      IF(GATRB(1).EQ.5) GO TO 56
       CSH141 = GATRB(5)
       UF = 0.0
       RETURN
   56  CSH5 = GATRB(5)
       UF = 0.0
       RETURN
*****************************************************************
*****************************************************************
**********UF 7 USED TO SET AIRCRAFT ATTRIBUTE  ********
********** 8 EQUAL TO AIRCREW SHOWTIME. P.72 ***********
*****************************************************************
*****************************************************************
7      IF(GATRB(1).EQ.5) GO TO 51
```

```
      CALL PATRB(CSH141,5)
      UF = 1.0
      RETURN
   51 CALL PATRB(CSH5,5)
      UF = 2.0
      RETURN
*****************************************************************
*****************************************************************
**********UF 8 USED TO DETERMINE ON-TIME OR         **********
**********LATE STATUS OF AIRCRAFT TAX DEPAR-         **********
**********TURE.  P.72                               **********
*****************************************************************
*****************************************************************
8     UF = 1.0
      IF(TNOW.GT.(TMARK(IDUM) + 15.0)) UF = 2.0
      RETURN
*****************************************************************
*****************************************************************
**********UF 9 USED TO SCHEDULE AIRCRAFT DE-          **********
**********PARTURES BASED ON DELAY STATUS. P.72**********
*****************************************************************
*****************************************************************
9     IF(GATRB(3).GT.1) GO TO 71
      UF = TMARK(IDUM) + 15.5 - TNOW
      RETURN
   71 UF = 0.0
      RETURN
*****************************************************************
*****************************************************************
**********UF 10 USED TO COMPUTE AIRCRAFT OFF- **********
**********LOAD SERVICE TIME AND TO UPDATE TON **********
**********DELIVERY TOTALS. P.73                **********
*****************************************************************
*****************************************************************
10    UF = GATRB(6) * 0.05
   74 IWACNT = IWACNT + 1
      WESDEL = WESDEL + GATRB(6)
      TPMHR = TPMHR + UF*2.0
      RETURN
*****************************************************************
*****************************************************************
**********UF 11 USED AS MISSION REPORT CENTER **********
**********FOR AIRCRAFT ARRIVING AT WESTEUR     **********
**********AND UPDATES OVERALL PARAMETERS.P.73 **********
*****************************************************************
*****************************************************************
11    MSNNO = GATRB(2)
      ITYP = GATRB(1)
      ARRTIM = GATRB(3) + GATRB(4)
      CRUDAY = TNOW - GATRB(5)
```

```
      PIPTIME = TNOW - GATRB(7)
      IF(GATRB(1).EQ.5) GO TO 75
      TONMILE = GATRB(6)*(GATRB(4)* 24.78 - 176.79)
      WGTUTE = GATRB(6)/32.2
      UTE141 = UTE141 + WGTUTE
      TWA141 = TWA141 + 1.0
      TC141 = TC141 + GATRB(6)
      GO TO 76
   75 TONMILE = GATRB(6)*(GATRB(4)* 45.98 - 185.66)
      TC5 = TC5 + GATRB(6)
      WGTUTE = GATRB(6)/50.0
      UTE5 = UTE5 + WGTUTE
      TWA5 = TWA5 + 1.0
   76 TON = TON + TONMILE
      PIPE = PIPE + PIPTIME
      TFLY = TFLY + GATRB(4)
      IF(IP.GT.1) GO TO 77
      WRITE(6,1000)ITYP,MSNNO,TNOW,GATRB(3),ARRTIM,GATRB(4),GATRB(6),
     1WGTUTE,TONMILE,PIPTIME,OFUDAY
 1000 FORMAT(1H ,1X,I3,1X,I4,3(1X,F6.1),2(1X,F4.1),1X,F4.2,1X,F8.1,1X,
     12(F5.1,1X))
   77 CONTINUE
      UF = 0.0
      RETURN
*****************************************************************
*****************************************************************
**********UF 12 USED TO GENERATE PORT REPORTS ********************
**********AND TO REINITIALIZE PORT PARAMETERS ********************
**********ON A DAILY BASIS. P.73                       ***********
*****************************************************************
*****************************************************************
 12   IDAY = TNOW/24.0
      IECOUNT = 0
      ESTNDL = 0.0
      WESDEL = 0.0
      IWACNT = 0
      UF = 0.0
      RETURN
*****************************************************************
*****************************************************************
**********UF 13 COMPUTES TRUCK OFFLOAD SERVICE********************
**********TIMES AND UPDATES PORT LEVEL DATA.          ***********
**********P. 73                                        ***********
*****************************************************************
*****************************************************************
 13   IECOUNT = IECOUNT + 1
      ESTNDL = ESTNDL + GATRB(1)
      UF = GATRB(1) * 0.16
      TPMHR = TPMHR + UF*1.0
      RETURN
```

```
*****************************************************************
*****************************************************************
**********UF 14 USED TO ACCUMULATE DISCRETE            **********
**********TRUCK LOADS INTO PLANE LOADS: FIVE          **********
**********FOR C-141S AND NINE FOR C-5S. P. 73         **********
*****************************************************************
*****************************************************************
14      IF(GATRB(2).EQ.5) GO TO 83
        K = K + 1
        IF(K.LT.6) GO TO 82
        K = 1
        TW141 = 0.0
     82 TW141 = TW141 + GATRB(1)
        EASPORT = EASPORT + GATRB(1)
        IF(K.EQ.5)TRW141 = TW141
        UF = GATRB(1)
        TPMHR = TPMHR + 1.0
        RETURN
     83 L = L + 1
        IF(L.LT.10) GO TO 84
        L = 1
        TW5 = 0.0
     84 TW5 = TW5 + GATRB(1)
        EASPORT = EASPORT + GATRB(1)
        IF(L.EQ.9) TRW5 = TW5
        UF = GATRB(1)
        TPMHR = TPMHR + 1.0
        RETURN
*****************************************************************
*****************************************************************
**********UF 15 USED TO ASSIGN LOAD WEIGHT TO          **********
**********LOAD TRANSACTIONS THAT WILL BE LOAD-         **********
**********ED ONTO AIRCRAFT. P.73                       **********
*****************************************************************
*****************************************************************
15      IF(GATRB(2).EQ.5) GO TO 85
        CALL PATRB(TRW141,1)
        UF = 0.5
        TPMHR = TPMHR + 0.5
        RETURN
     85 CALL PATRB(TRW5,1)
        UF = 0.5
        TPMHR = TPMHR + 0.5
        RETURN
*****************************************************************
*****************************************************************
**********UF 16 USED TO GENERATE "DUMMY LOADS"         **********
**********BASED ON PORT LEVEL AND LOAD SELECTI-        **********
**********VITY. P.73                                   **********
*****************************************************************
```

```
*****************************************************************
15    ATT(1) = 0.0
      ATT(4) = 0.0
      ATT(5) = 0.0
      ATT(6) = 0.0
      ATT(7) = 0.0
      IF(GATRB(1).EQ.5) GO TO 96
   93 IF(NREL(62).GE.1) GO TO 95
      IF(NREL(61).EQ.0) GO TO 95
      IEP = NREL(61)
      DO 94 NK = 1, IEP
      ATT(2) = 141.0
      ATT(3) = 2.0
      K = K + 1
   94 CALL PTIN(61,0.0,TNOW,ATT)
      TRW141 = TW141
   95 UF = 0.0
      RETURN
   96 IF(NREL(72).GE.1) GO TO 98
      IF(NREL(71).EQ.0) GO TO 98
      IEP = NREL(71)
      DO 97 NL = 1, IEP
      ATT(2) = 5.0
      ATT(3) = 2.0
      L = L + 1
   97 CALL PTIN(71,0.0,TNOW,ATT)
      TRW5 = TW5
   98 UF = 0.0
      RETURN
      END
*****************************************************************
*****************************************************************
**********SUBROUTINE UI : USED TO INITIALIZE           **********
**********VARIABLES INTERNAL TO FUNCTION UF AT**********
**********THE BEGINNING OF EACH RUN.                   **********
*****************************************************************
*****************************************************************
      SUBROUTINE UI
      COMMON/QVAR/NDE,NFTBU(500),NREL(500),NRELP(500),NREL2(500),NRUN,
     1NRUNS,NTC(500),PARAM(100,4),TBEG,TNOW
      COMMON/USER/EASPORT,IECOUNT,IMACNT,ESTNCL,WESDEL,K,L,TW141,TW5,
     1TRW141,TRW5,TON,PIPE,TWA5,TWA141,TMXHR,TP4HR,IFUEL,TFLY,UTE5,
     2UTE141,IP,TC5,TC141
*****************************************************************
*****************************************************************
**********        MISSION REPORT PRINT OPTION          **********
**********                                             **********
**********              IP = 1 : PRINT                 **********
**********              IP > 1 : NO PRINT              **********
**********                                             **********
```

APPENDIX C: PROGRAM INSERTS FORTRAN LISTING

```
******************************************* **********************
******************************************* **********************
      IP = 1
      TC5 = 0.0
      TC141 = 0.0
      EASPORT = 0.0
      K = 0
      L = 0
      WESDEL = 0.0
      IWACNT = 0
      IECOUNT = 0
      ESTNDL = 0.0
      TW141 = 0.0
      TW5 = 0.0
      TRW141 = 0.0
      TRW5 = 0.0
      TON = 0.0
      PIPE = 0.0
      TEA = 0.0
      TWA5 = 0.0
      TWA141 = 0.0
      TMXHR = 0.0
      TPMHR = 0.0
      TFUEL = 0.0
      TFLY = 0.0
      UTE5 = 0.0
      UTE141 = 0.0
      IF(NRUN.EQ.1) REWIND 7
      WRITE(6,1000)
1000  FORMAT(1H1, " A/C  MSN.  REPT    DEPT    ARR.  FLY         CAP     TON
     1   PIPE  CREW" ,/,2X,"TYP  NO.  TIME    TIME    TIME TIME TONS UTE
     2   MILES   LINE  DAY:" ,/,2X,13("=====")) 
      RETURN
      END
******************************************* **********************
******************************************* **********************
**********SUBROUTINE UO: USED TO COMPUTE AVER-**********
**********AGE RUN PARAMETERS FOR LAUNCH RELIA-**********
**********BILITY, CAPACITY UTILIZATION, AND   **********
**********PIPELINE TIMES, AS WELL AS TO PRINT **********
**********OUT VALUES OF RUN PARAMETERS OF IN- **********
**********TEREST: TOTAL TONMILES,AVERAGE PIPE-**********
**********LINE TIME, OVERALL LAUNCH RELIA-    **********
**********BILITY, TOTAL MAINTENANCE MANHOURS, **********
**********TOTAL PORT MANHOURS, TOTAL FUEL, TO-**********
**********TAL FLYING TIME, AVERAGE CAPACITY   **********
**********UTILIZATION VALUES, TOTAL AIRCRAFT  **********
**********ARRIVALS, AND TOTAL TONS CARRIED    **********
**********BY EACH AIRCRAFT TYPE.              **********
******************************************* **********************
```

APPENDIX C: PROGRAM INSERTS FORTRAN LISTING

```
************************************************************************
      SUBROUTINE UO
      COMMON/QVAR/NDE,NFTBU(500),NREL(500),NRELP(500),NREL2(500),NRUN,
     1NRUNS,NTC(500),PARAM(100,4),TBEG,TNOW
      COMMON/USER/EASPORT,IECOUNT,IWACNT,ESTNDL,WESDEL,K,L,TW141,TW5,
     1TRW141,TRW5,TON,PIPE,TWA5,TWA141,TMXHR,TPMHR,TFUEL,TFLY,UTE5,
     2UTE141,IP,TC5,TC141
************************************************************************
************************************************************************
**********PDNMR : PREDEPARTURE NONSCHEDULED          **********
**********MAINTENANCE RATE                           **********
**********                    ******                 **********
**********   CAR : CARGO ARRIVAL RATE                **********
**********                    ******                 **********
**********   MGR : MISSION GENERATION RATE           **********
************************************************************************
************************************************************************
      REAL PDNMR,CAR,MGR
      PDNMR = 1.
      CAR = 2.
      MGR = 5.
      A = FLOAT(NTC(143))
      B = FLOAT(NTC(145))
      C = FLOAT(NTC(243))
      D = FLOAT(NTC(245))
      REL5 = C/D
      REL141 = A/B
      RELO = (A + C)/(B + D)
      PIPE = PIPE/(TWA5 + TWA141 )
      UTEO = (UTE5 + UTE141)/(TWA5 + TWA141)
      UTE141 = UTE141/TWA141
      UTE5 = UTE5/TWA5
      WRITE(6,3000) PDNMR,CAR,MGR,TON,PIPE,REL5,REL141,RELO,UTE5,UTE141,
     1TMXHR,TPMHR,TFUEL,TFLY,TWA5,TWA141,TC5,TC141
 3000 FORMAT(1H1,3X,"RUN RECAP:",/,1X,"PDNMR = ",F2.0,5X,"CAR = ",F2.0,
     15X,"MGR = ",F2.0,/,1X,"TONMILES = ",10X,E11.5,/,1X,"PIPELINE TIME
     2= ", 9X,F6.2,/,1X,"C-5 DEPT. REL. = ",10X,F5.3,/,1X,"C-141 DEPT. R
     3EL. = ", 8X,F5.3,/,1X,"OVERALL DEPT. REL. = ", 5X,F5.3,/,1X,
     4"C-5 CAPACITY UTE = ", 8X,F5.3,/,1X,"C-141 CAPACITY UTE = ", 6X,F5
     5.3,/,1X,"TOTAL MAIN MANHOURS = ", 1X,F7.1,/,1X,"TOTAL PORT MANHOUR
     6S = ", 1X,F7.1,/,1X,"TOTAL FUEL(GALLONS) = ", 5X,E11.5,/,1X,"TOTAL
     7 FLYING TIME = ", 3X,F7.1,/,1X,"TOTAL C-5 ARRIVALS = ", 4X,F4.0,/,
     81X,"TOTAL C-141 ARRIVALS = ", 2X,F4.0,/,1X,"TOTAL TONS BY C-5 = ",
     9 1X,F7.1,/,1X,"TOTAL TONS BY C-141 = ", 1X,F7.1)
      IF(NRUN.EQ.NRUNS) REWIND 7
      RETURN
      END
```

Appendix D

Sample Q-GERT Analysis Program Output

GERT SIMULATION PROJECT THESIS PROGR BY RICHARD
DATE 2/ 14/ 1980

FINAL RESULTS FOR FIRST SIMULATION

TOTAL ELAPSED TIME = 720.0000

NODE STATISTICS

NODE	LABEL	AVE.	STD.DEV.	NO OF OBS.	STAT TYPE
85	SINK141	4.2554	3.3713	161.	B
90	SINK5	15.3256	10.4017	44.	B
245	POST5	15.7310	.8250	46.	I
244	LATEC5	17.2710	1.6839	6.	I
243	ONTIME5	15.5000	0.0010	40.	I
240	SYSTIME5	14.5280	1.2522	46.	I
145	POST141	15.5264	.142	165.	I
144	LATE141	15.0211	.3533	9.	I
143	ONTM141	15.5000	.0010	156.	I
140	SYSTM141	13.8483	.7243	165.	I
7	SYSTMMX	15.3229	1.1597	65.	I
5	OTHERMX	22.7754	30.1855	29.	B
4	ELECTRMX	80.9163	50.1141	8.	B
3	HYDRMX	50.6973	65.4730	13.	B
2	ENGMX	60.3407	59.1989	11.	B
71	LOASM5	15.0728	8.4027	45.	B
61	LOASM141	4.2678	2.8863	165.	B

NUMBER IN Q-NODE / ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
54	TAKOFFLD	0.0000	0.	[illegible]	0	0.0000
62	LOADQ141	.3246	0.	2.	0	1.3212
72	LOADQ5	.1236	0.	1.	0	2.0281
106	FUELQ141	0.0000	0.	[illegible]	0	0.0000
115	ACFTLDQ	.0744	0.	3.	0	.3229
121	ACFTQ141	.5540	0.	[illegible]	1	2.4027
128	CREWQ141	0.0000	0.	0.	0	0.0000
206	FUELQ5	0.0000	0.	[illegible]	0	0.0000
215	ACFTLDQ5	.0236	0.	2.	0	.3696
221	ACFTQ5	.1602	0.	3.	0	2.0680
228	CREWQ5	0.0000	0.	0.	0	0.0000
6	MINORMX	0.0000	0.	[illegible]	0	0.0000
80	OFFLDQ	0.0000	0.	0.	0	0.0000

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
850		10	.4815	10.0000	2.0000
849		10	.1465	10.0000	3.0000
848		10	.0687	10.0000	3.0000
847		10	.1135	10.0000	2.0000
846		10	.1738	10.0000	3.0000
850		10	.1470	10.0000	3.0000
849		10	.0659	10.0000	2.0000

GERT SIMULATION PROJECT THESIS PROGR BY RICHARD
DATE 2/ 14/ 1980

RESULTS FOR RUN 1

ELAPSED TIME FOR RUN = 720.0000

NODE STATISTICS

NODE	LABEL	AVE.	NO OF OBS.	TYPE OF STATISTICS
85	SINK141	4.2554	161.	B
90	SINK5	15.3266	44.	B
245	POST5	15.7310	46.	I
244	LATE5	17.2710	6.	I
243	ONTIME5	15.5000	40.	I
240	SYSTIME5	14.5280	46.	I
145	POST141	15.5284	165.	I
144	LATE141	16.0211	9.	I
143	ONTM141	15.5000	156.	I
140	SYSTM141	13.8483	105.	I
7	SYSTMMX	15.3229	65.	I
5	OTHERMX	22.7754	29.	B
4	ELECTRMX	80.9063	8.	B
3	HYDRMX	50.8973	13.	B
2	ENGMX	60.8407	11.	B
71	LOASM5	15.0728	45.	B
61	LOASM141	4.2878	105.	B

NUMBER IN Q-NODE / ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
54	TRKOFFLD	0.0000	0.	[illegible].	0	0.0000
62	LOAD0141	.3046	0.	2.	0	1.3212
72	LOAD05	.1296	0.	1.	0	2.0281
106	FUEL0141	0.0000	0.	[illegible].	0	0.0000
115	ACFTLDQ	.0744	0.	3.	0	.3229
121	ACFT0141	.5540	0.	4.	1	2.4027
128	CREW0141	0.0000	0.	.	0	0.0000
206	FUELQ5	0.0000	0.	0.	0	0.0000
215	ACFTLDQ5	.0236	0.	3.	0	.3696
221	ACFTQ5	.1502	0.	3.	0	2.5080
228	CREWQ5	0.0000	0.	0.	0	0.0000
6	MINORMX	0.0000	0.	[illegible].	0	0.0000
80	OFFLDQ	0.0000	0.	0.	0	0.0000

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
850		10	.4815	10.0000	2.0000
849		10	.1465	10.0000	3.0000
848		10	.0557	10.0000	3.0000
847		10	.1135	10.0000	2.0000
846		10	.1738	10.0000	3.0000
850		10	.1470	10.0000	3.0000
849		10	.0569	10.0000	2.0000

VITA

Philip A. Richard was born on 11 December 1948 in Nashua, N.H. He graduated from Sacred Heart Preparatory School in Pascoag, R.I. in 1966. He attended Providence College, Providence, R.I. from which he received a Bachelor of Science Degree in Chemistry. He received a commission in the United States Air Force upon completing Officer Training School in January 1972. He completed navigator training and received his wings in May 1973. After completing C-130 upgrade training at Little Rock AFB, Ar he was assigned to the 772nd TAS, 463rd TAW, Dyess AFB, Tx. During his five years at Dyess AFB he served as a C-130 navigator, instructor navigator, and flight examiner as well as Wing command post duty controller. He entered the School of Engineering, Air Force Institute of Technology, in August 1978. He is married to the former Denise I. Archambault of Nashua, N.H. He and his wife have two sons, Christopher and Kevin.

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