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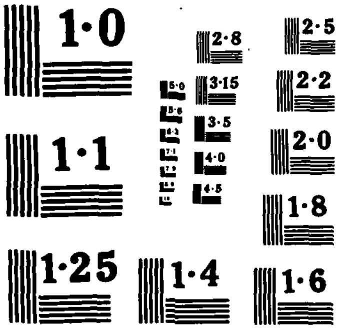

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Dynamics of Airfield Parking Congestion During APOD Operations

THESIS

Daniel L. Cuda
Captain, USAF

AFIT/GST/OS/85M-3

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ABSTRACT

This effort studied airlift parking congestion at a notional aerial port of debarkation (APOD). APOD operations were studied at three tonnage arrival rates and three levels of parking. Data was collected for each combination of parking and arrival rates. The data consisted of tonnage displaced, tonnage delivered, and tonnage throughput. As expected, tonnage displaced was greatest when tonnage arrival rate exceeded an equivalent amount of parking. A strong relationship was found between parking utilization and the percentage of displaced cargo.

AFIT/GST/OS/85M-3

DYNAMICS OF AIRFIELD PARKING CONGESTION DURING APOD OPERATIONS

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
Master of Science in Operations Research

Daniel L. Cuda, B.S.
Captain, USAF

March 1985

Preface

The underlying belief of this effort is that operations research techniques can sharpen personal understanding of combat operations. My belief is that they supplement experience and allow thinking about circumstances that can not be duplicated in peacetime training or exercises. Without having the benefit of long experience with the APOD transhipment systems, this study was a vehicle for learning. As part of that process, I was lucky to lucky to learn military analysis under Major James R. Coakley, my adviser for this study. Maj Coakley's high standards and insistence on producing not only an academic document but an operationally useful report has set an ideal for future efforts. I also want to thank Lt Col Rick Clarke who acted as reader for the project and was my teacher with respect to logistical matters. In addition, I want to thank Maj Ken Feldman for his indirect contribution to my understanding of the larger problems of systems analysis.

I also have to express my gratitude to Miss JoAnne Austin, whos editorial assistance in preparing this study was inestimable and will not be forgotten. Finally, I have to thank the men of the FUG, the Fortran Users Group, for their help throughout this 18 month project. Captains John O'Neill, Joe Alfano, and Colt Mefford were sources of feedback and insights throughout the AFIT experience.

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Abstract

This thesis studied the problems of ramp space congestion at a notional aerial port of debarkation (APOD) for three tonnage arrival rates. Parking was constrained at the APOD to simulate the competition for ramp space by various air missions. This thesis studied the level of aircraft diversions and delays over a range of tonnage arrival rates from 500 to 1,500 tons per day. Parking was constrained to equivalent levels of 500 to 1,500 tons per day. Observations were taken at all combinations of parking and arrival rates. Results indicated parking utilization and aircraft arrival rates were strongly correllated with aircraft diversion rates. [illegible]

I. Problem Formulation

Introduction

In a theater of military operations, there are a limited number of strategically located airfields. On those airfields, there is a limited amount of parking space for aircraft. How to allocate this space for military air operations is one task of a commander. In making his decision, he must allocate this potentially limited resource among several competing aircraft and missions. Potential competitors for this limited resource are fighters, air refueling, aeromedical evacuation, and airlift.

Most of these missions are executed by aircraft based within a theater at a particular airfield. Generally, when these aircraft vacate parking space to execute a mission, they can expect parking available on return. The essence of this parking allocation problem is to count the number of aircraft and assign appropriate space

But the airlift mission is different. Given a requirement to deliver and tranship a given amount of troops and cargo, the number of aircraft on the ground at any time continually fluctuates. The number varies with aircraft arrival rates and the pace of loading and unloading

The technical sophistication of the enemy and the level of combat intensity in the theater is another factor in the operation of the APOD. An enemy with the ability to launch deep air or missile strikes will by necessity force the dispersal of ports of debarkations over the theater. Under such circumstances aircraft parking must be dispersed and aircraft ground times held to a minimum. In such an environment, the theater commander may make a decision to base his airlift resources further to the rear of his designated APODs to avoid the threat.

A technically sophisticated enemy may choose to use chemical weapons against airlift operations. Such attacks would serve to slow offloading and servicing of aircraft by ground crews and force decontamination of supplies shipped into the theater. Although chemical operations may seem to be synonymous with war against the Soviet Union, it must be recalled that Iraq and North Vietnam have shown the capability and the will to use such weapons.

Natural factors in the theater, such as weather and hours of darkness, can impact on operations. Weather and climate can affect the demand for tactical airlift in a theater. A season of heavy rains or a spring thaw can effectively close an under-developed road system and force reliance on aerial delivery. Although operations at a main operating base will probably not be affected by rain and major war in Central America, less than one thousand miles from the continental United States, presents a much smaller logistical problem than a war in the Mid-East, more than ten thousand miles away on a typical deployment. Additionally, en route bases are required to support the strategic flow unless air refueling is available. Both en route basing and tanker support are subject to other circumstances. En route basing is affected by the international politics of the situation, as in the 1973 Airlift to Israel where en route support was denied by many countries. Tanker support is required by fighter deployment and Strategic Air Command operations. Its availability to airlift, which would allow all aircraft to proceed with a maximum cargo, is subject to decisions by the Joint Chiefs of Staff.

Within the theater itself, geography also plays a significant role. The assigned amount of tactical airlift available to the theater commander for his own purposes will be based on the size of the theater and the existence and availability of a transportation system. Sizes may range from South Korea, about three hundred miles from tip to tip, to Western Europe, which measures 2,400 miles from the north of Norway to the south of Spain. The daily tonnage capability of tactical airlift forces will depend on the location of the APOD in the theater and the location of the ultimate destination.

reasons for this choice. First, time within the system is essentially measured in hours. Aircraft require two to three hours for offload, and arrival rates are best stated and comprehended in hours. Second, a one day time scale provides good balance between relative stability in measures of APOD output. If the scale is too short, the volatility of cargo delivered from hour to hour would be enormous and difficult to use as a measure of merit. If the scale is too long, the extremes of behavior are lost in the averages. Finally, 24 hours constitutes a meaningful increment of the expected length of a typical theater campaign.

Scenario

The factors impacting on the operation and capabilities of the system under study are affected by both the theater of operation and the world-wide military situation. In the past, U.S. military planners have prepared for one and one-half wars. That is to say, the U.S. will be able to simultaneously prosecute a major war in Europe or South-West Asia and still retain enough forces to counter a smaller contingency in Central America or the Far East. The amount of strategic airlift available to support any theater of operation will be dependent on contingencies happening elsewhere in the world.

The location of the theater of operation is another critical factor in tonnage arriving per day at the APOD. A this methodology, efficient APOD operation is attained when all tonnage intended to terminate or transit the airfield arrives and/or transits the airfield without unexpected delays. Unplanned or unexpected delays disrupt the deployment chain and threaten meeting the supported commander's requirements.

Using tonnage as an aggregate measure, there are three different measures of effectiveness that reflect the efficacy of APOD operations and the non-binding allocation of ramp space. The first measure is the amount of cargo delivered to the airfield by strategic airlift. More correctly, it is the amount delivered compared to the scheduled flow. The second measure of merit is the amount of air cargo transiting the airfield. The third measure of merit is the amount of cargo displaced because of insufficient parking. Displaced cargo will be defined as cargo scheduled to land at a particular airfield that failed to arrive because of aircraft diversion. Although displaced cargo may have successfully arrived in theater, it becomes an additional and unplanned demand on the transportation system.

The unit of measurement for all these scales is tonnage. For standard density of cargo, tonnage directly relates to military capabilities. The best time scale for the measurement of tonnage is 24 hours. There are two

Air traffic control operations can be coordinated with ALCE operations to minimize the problems of large scale operations.

Measure of Merit

To a theater commander, deploying forces have little combat utility until they arrive at the location where they will execute their mission. The APOD transhipment system is one link in the transportation chain that moves forces to that employment location. The transportation chain may begin at a location in the CONUS with truck movement to an airfield, followed by strategic airlift to the theater APOD, and finish by rail movement to the combat zone. The goal of each link is to contribute to the ultimate delivery of troops and cargo at the time and place designated by the commander.

Deviations from scheduled operations on any link may prevent meeting the time and place designation of the supported commmander. Ideal APOD operations maintain the schedule of deployment and have some capacity to adjust to uncertainties and changing circumstances. To measure the attainment of this operational goal, APOD operations must be gauged by some measure(s) of effectiveness. One way to gauge the achievement of time and place utility is to aggregate the quantity of forces passing through an APOD into a single measure. One such measure is tonnage. In

In addition to physical facilities such as long runways and large parking ramps, ports of debarkation require large amounts of material handling equipment, fuel, and maintenance support. These factors are important determinants in the amount of time an aircraft spends on the ground.

Another important factor in determining the efficiency of airlift ground operations is the Airlift Control Element (ALCE). The ALCE coordinates offloading, ground servicing, and parking for all transiting airlift aircraft. The ALCE is also responsible for planning aircraft parking on the allotted portion of the parking ramp and for marshaling aircraft on the parking ramp, and is equipped with radios that allows communication with aircraft both on the ground and in the air. This communications capability allows the ALCE to exercise some control over the arrivals at the airfield.

Another controlling agency at an airfield that allows increased system efficiency is air traffic control services (ATC). Levels of capability range from a single radio that allows a controller to visually separate aircraft to airfields equipped with radar and all-weather landing facilities. ATC facilities can minimize ground congestion at the airfield by putting airborne aircraft into holding patterns and controlling taxi operations at the airfield.

off the production line, the C-130 force is composed of aircraft anywhere from brand new to thirty years old. Characterizing the capabilities of this force is difficult because of the diverse type of missions and the unique requirements of each theater. However, using 250 miles as an average mission radius, and assuming 1.5 sorties per day per aircraft, the Airlift Master Plan credited the entire force as capable of moving 9,200 tons per day (6:III-16). It must also be pointed out, it is unlikely the entire tactical airlift fleet will ever be completely committed to one theater.

The third major subsystem of the problem is the airfield itself. In a theater of operations, airfields may range in quality from dirt airstrips with little parking and no support facilities, to giant commercial airfields with several runways and sophisticated cargo handling facilities. Airfields designated as APODs will probably have at least one runway capable of handling aircraft such as the C-5, and are also likely to contain large parking areas, warehouses, and quarters for the support personnel. The APOD's location in the theater may change once the war begins. During war, peacetime APODs, such as Rhein Main AB in Germany and OSAN AB in South Korea, will become vulnerable to attack or may shift their operations to fighters. New APODs will then be designated farther to the rear.

APOD throughout the theater. Compared to other modes of transportation within a theater, tactical airlift is the quickest and most secure mode of transportation. Although alternative modes of operation are susceptible to interdiction and require longer shipping times, surface transport will likely move the majority of tonnage in the theater because of airlift's limited capabilities. Tactical airlift can be expected to transport light combat units around the theater, distribute high value cargo, and deliver perishable supplies.

In general, tactical airlift will operate from major airfields designated as main operating bases (MOB) and perform mission as far forward as the battle line. Army divisions and corps with airfields as small as three thousand feet can expect to be resupplied by tactical airlift. Typically, these fields will have only enough parking for two aircraft and limited material handling equipment. The airfields may be within enemy artillery range and subject to enemy air attack. Deep ranging enemy helicopter units are another threat to forward airlift operations.

The primary aircraft for tactical airlift is the C-130 Hercules. First built in the 1950's and well proven in the Vietnam war, it will remain in the airlift inventory until the next century. With the USAF still receiving aircraft

The strategic airlift subsystem consists of a stream of aircraft deploying from the United States and adjacent theaters. That stream is composed of the C-5 Galaxy, the C-141 Starlifter, and aircraft of the Civil Reserve Air Fleet. Presently this fleet has a capability of 28.6 million ton miles per day (6:III-10). A ton-mile is the capability to move one short ton (2000 lbs) one nautical mile. This is to say the complete strategic airlift fleet of CRAF and military airlifters can deliver 2,860 tons per day to a location 10,000 miles from the continental United States. Although in absolute terms this is an impressive figure, it is very small relative to the 25,000 tons required to deploy a typical U.S. Army Division.

It is important to understand the tonnage limitations on the two aircraft. The most obvious is the tradeoff between maximum cargo and range. In general, both the C-5 and the C-141B exchange 1,000 miles in range for every 20,000 pounds of cargo or around 10 tons per thousand miles. An important additional factor is the supply of spare parts for each aircraft and their world-wide distribution. Spare parts set limits on the average utilization of each airframe in hours per day. Finally, the capacity of the fleet is influenced by the ratio of aircrews to aircraft.

The tactical airlift subsystem, the second subsystem of the APOD transhipment system, distributes cargo from the fraction of the total flow directed to tactical airlift than perhaps South-West Asia, where the scale of operations and the transportation infrastructure are much different.

Prevailing weather in the theater also influences operations. Heavy rains can seriously disrupt undeveloped road systems and place increased reliance on tactical airlift. Conversely, cloud cover and rain can disrupt the flow of tactical airlift from the APOD to more forward bases. Finally, and most importantly, enemy capabilities may disrupt APOD operations by chemical weapons, raids, and sabotage. By its very importance, the APOD will become an object of enemy action, and the more important it becomes, the more likely the enemy is to take extraordinary actions to disrupt the operation.

The APOD transhipment system will operate at an airfield located in a combat theater outside the continental United States. The system is composed of three major subsystems. They are the flow of strategic airlift into the theater, the flow of tactical airlift deploying and resupplying forces within the theater, and the airfield itself. Overall, these subsystems combine to transport cargo by air from the CONUS up to and including the combat zone. The airfield acts as the interface between the two airlift systems and between the air and surface modes of transportation.

an ideal APOD include physical facilities, such as warehouses and maintenance hangars, a location away from enemy action yet accessible to the combat zone, and certainly runways and parking ramps sufficient to support airlift operations. Additionally, the airfield requires sufficient air traffic control to manage the flow of aircraft to and from the airfield.

Strategic airlift payloads arriving at the APOD consist of men, equipment, and supplies. Ideally, forces are loaded on the aircraft to allow units to reorganize in minimum time upon arrival. To reorganize and reform, equipment dismantled for air shipment must be reassembled, supplies must be marshaled and inventoried, and troops must be housed and fed. When troops and cargo are ready to continue forward, tactical airlift will deploy light combat units along with high value repair parts, weapons, and munitions. However, of the total amount of troops and cargo arriving at the APOD, only a fraction continues forward by tactical airlift. The remainder either terminates at the APOD to support its organic operations, or continues forward by surface transportation.

The theater itself constitutes the background environment that determines much of the activities at the APOD. Theaters such as Europe, where there are well developed transportation systems, will see a smaller argue for prior professional investigation of all factors that may impact on operational success. Airfield congestion during airlift operations is one such factor.

General System Description

World-wide, there are three major unified commands: Pacific Command (PACOM), European Command (EUCOM), and Central Command (CENTCOM). The unified commander exercises military responsibility for his assigned theater which, by definition, lies outside the continental United States (13:349). Within a theater, there may be further sub-theaters, as is the case of South Korea. Korea constitutes a sub-unified command of the unified command PACOM.

There is currently no major theater where the U.S. has sufficient forces to completly protect its interests. If war breaks out, forces will be deployed from the continental United States to execute combat operations. Although sustained operations will ultimately depend on sealift, airlift is the only transportation mode capable of influencing the initial course of the war. Strategic airlift will deploy combat units from the CONUS to designated aerial ports of debarkation (APOD) within the theater. From the APODs, forces deploy into combat by road, rail, and tactical airlift.

Within a theater, only a few air and sea ports are designated as ports of debarkation. The characteristics of support the planned flow. Insufficient space can result in delays and diversions that may completely disrupt and disorganize the deployment of forces. The "USAF Airlift Master Plan," the guiding document for modernizing airlift forces over the next twenty years, states, "In all scenarios, the requirement to transfer cargo from intertheater aircraft to intratheater aircraft causes airfield saturation at the main operating bases and later delivery [of cargo] to the user." (6:III-5)

Although well established contingency plans can anticipate overcrowding and possibly set in motion construction to alleviate the problem, short notice deployments do not have this luxury. Correct decisions must be swiftly and surely made in the initial plan. In a short notice contingency, the decision-making environment for the initial plan is hurried and confused. Plans are changed almost by the hour as new information arises. High level decisions countermand the assumptions made by lower echelons and planning documents require near constant alterations. Under these circumstances, to misjudge the ability of an airfield to support deployed troops can result in crippling operational errors. Understanding the dynamics of airlift congestion at deployment airfields is a necessity before the operation begins. The short notice contingencies of recent years, such as operations in Grenada and the Falklands, aircraft. Allocating space to such an operation is a difficult task when balancing the competing requirement for parking space. Too much space for the airlift operation will constrict other air missions, while too little space allocated to airlift will result in delays and diversions of cargo intended for the theater.

As for any limited resource within a theater, decisions must be made that will balance the consequences of too little or or too much ramp space for each mission. To make an informed choice, the decision-maker must be aware of the consequences associated with each alternative allocation. That is the general purpose of this study; to gain insights about the consequences of changes in ramp space allocations and thus allow more informed decision-making and planning. If such information is not available then allocations must be made on the basis of intuition or experience. Although these are the basic forms of military decision-making, professional thought and investigation before the fact makes professional judgement that much more sure.

Knowledge of the consequences of various allocations of space is particularly important in contingency planning. The quality of the plan and the accuracy of its assumptions will dictate the course of the first days of the war. The timely arrival of troops and equipment into a theater is based on the assumption of sufficient parking space to fog, the absence of air traffic control radars at more forward airfields may restrict the flow of tactical airlift until good weather. An additional minor factor is the seasonal increase or decrease of winds at high altitudes that affect the flow of strategic airlift. Favorable winds require less fuel and accordingly increase cargo tonnage compared to headwinds that have the opposite effect.

The two most important factors in determining the tonnages required to transit APODs are the absence of existing U.S. forces in the region coupled with an undeveloped transportation system. If U.S. military forces are quickly required in an area, the faster the buildup of forces, the greater the liklihood of success. If a theater is lacking a developed transportation network, and limited airlift capability must be allotted to combat forces instead of trucks and road building equipment, then tactical airlift will be forced to substitute until support units can arrive in the theater.

Deployment places the greatest strain on the entire transportation system. As mentioned earlier, a mechanized infantry unit requires 25,000 tons of airlift to deploy. Supporting that unit in the field may require only 2,000 tons per day if the unit is fighting in fixed positions. The point is, combat units may have upper limits on supplies they utilize per day, but it is unlikely a theater commander in a difficult contingency will have an upper limit on the number of forces he would like available.

Problem Statement

Many of the individual elements of the airfield transhipment system are not deterministic variables. Most planning documents use fixed aircraft interarrival times and fixed planning factors in evaluating the requirement of airfield parking. Although these factors over the course of time are good point estimates of system outputs, on any given day the results may have considerable variance. A deterministic approach is a useful planning device for large scale aggregations but gives little insight into operational extremes.

Within the system, there are tolerances and large amounts of personal ingenuity that accommodate operational extremes and maintain the system within parameters. However, there is a point in any operation when the pads, buffers, and the personal ingenuity within the system are overwhelmed. This is especially true when circumstances dictate strict allocation of ramp space. When the margin for error is reduced, there is no slack to accommodate unplanned events. The purpose of this study is to examine the effects of changes in one operational variable, ramp space, and see the response it creates in the system. Over a range of feasible parameters, this study will attempt to quantify the buffering or limiting effects of ramp space on a stochastic airlift system.

Previous Analysis

In general, there has been little investigation of parking space as a limiting factor to airfield operations. Non-military investigation of airfield congestion has centered around the runway as the limiting factor. Apparently, new terminals or improved facilities are more easily acquired than land for new runways.

The congestion problem at civilian airfields centers around the cycle of peak daily activity in the mornings and late afternoon. These arrival and departure times are in demand by passengers and dictate events leading to runway congestion. This behavior differs from the postulated deployment scenario of a constant daily rate of scheduled arrivals.

Three civilian studies have some bearing on the problem under study. Hubbard, in "Terminal Airspace/Airport Congestion Delays," found that the average delays during peak activity at O'Hare Airport in Chicago increased exponentially as arrivals neared the calculated capacity of the airfield. The study, conducted during the mid 1970's, showed that delays quickly increased as demand passed 90 percent of calculated capacity (18). Koopman, in "Air-Terminals Queues Under Time-Dependent Conditions", handled airfield delays as a classical queuing problem with Poisson arrivals and departures from the system. Koopman solved the problem analytically and found that his calculated values for the length of waiting lines was highly sensitive to service rates but insensitive to service discipline (19). Finally, Galliher and Wheeler, in "Nonstationary Queuing Probabilities for Landing Congestion for Aircraft", computed a probability distribution for the length of delay for aircraft arriving into the New York City Terminal Control Area (14).

The only study of congestion in a military operation was the report to Congress by the Comptroller General on MAC airlift operations during the 1973 Mid-East War. The report stated that Lajes Air Base in the Azores was the choke point of the authorized route to Israel. It went on to state that during one 24 hour period, six C-5 and 36 C-141 aircraft transited the base. The total airlift over a period of 30 days delivered 22,497 tons of cargo to Israeli airfields. To put airlift in perspective, it must be pointed out that when the first cargo ship arrived in Israel, it delivered more tonnage itself than airlift had in 30 days of previous operation. Of course it must also be pointed out, that the cargo arrived 20 days after the war was over (4).

Research Objectives

The problem of understanding and predicting the effects of limited ramp space on airlift operations is a continuing one. To aid both the theater commander supported by the APOD and the airlift agencies interested in successful operations, this study will focus on three areas:

1. Determine the general effects of various allocations of ramp space and strategic airlift arrival rates on APOD measures of effectiveness.

2. Determine the compensating levels of aircraft loading times for corresponding changes in ramp space allocations.

3. Gain insight into the general dynamics of APOD congestion and aircraft diversions.

Summary

Allocating the limited ramp space at an aerial port of debarkation in a theater requires understanding the consequences of each possible allocation. This study attempts to quantify the consequences of various levels of ramp space allocation on a continous airlift operation. The objective is to determine the effects on tonnage delivered and transhipped by air over a range of ramp space. The problem is studied as a general system applicable to any operation world-wide.

II. System Conceptualization and Description

Introduction

With respect to airlift deployments, the ideal situation for the commander is the arrival of forces not later than the point in time he first requires their use. Given the restriction on airlift capabilities and reception facilities, this is not likely. Although this goal is infeasible, it sets an ideal for airlift and APOD operations. Any supporting element delaying the arrival of the supported commander's forces to his designated time and place should be increased or modified until it is no longer the limiting factor. For example, if airlift ground times are delaying the arrivals of inbound aircraft, then the resources or tasks that require a given ground time should be increased or prioritized until ground times are no longer the limiting factor.

The process of discovering and removing the limiting factors to airlift operations is one motivation for this study. APODs can be constraints on the insertion of combat power into a theater. Although the possession of aircraft with some individual ability to carry cargo theoretically yields a military capability, this potential is dependent on many less dramatic factors. The inefficient management of these supporting factors can limit the full potential of an airlift fleet. Parking space is one such factor. Its efficient management minimizes aircraft diversions and delays, and thus allows fuller utilization of airlift's potential capabilities.

Conceptualization

There are two general circumstances in a theater of operations where efficient management of ramp space may be critical. The first is in a well established theater when preparation for offensive action or other circumstances may require large scale airlift. The ensuing conflict between the large number of aircraft in the theater and an expanded airlift operation may strain parking resources. The second circumstance, and the primary subject of this study, is during initial deployment into a theater when airlift operations are at a maximum. More importantly, the success of the complete operation swings on the timely arrival of combat resources in accordance with the commander's plan.

Most likely, the number of aircraft will never be enough to meet the commander's ideal plan. In such circumstances, Military Airlift Command will produce a Time Phased Force Deployment Listing (TPFDL) showing the arrival time of the commander's designated forces. For example, although the supported CINC prefers the simultaneous arrival of two infantry batallions, MAC may have only enough airlift to transport one battalion at a time. The commander must then choose which will be transported first. The commander's decision and prioritized ranking of forces will be incorporated into the TPFDL. From this document, MAC will generate a schedule of airlift arrivals into the theater (25).

Simultaneously, tactical airlift units will begin deployment into the combat theater. Upon arriving in the theater, tactical airlift, while remaining under the command of CINCMAC, will fall under the operational command of the theater commander. The commander will designate and prioritize the missions of assigned tactical airlift forces while being responsible for providing support facilities.

Airfields designated as aerial ports of debarkation also fall under the theater commander. The supported CINC is responsible for designating the beddown location of all arriving air units. In general, forces can be expected to quickly increase in number and conceivably create overcrowded parking areas. Part of the necessary planning for deployment requires designation of sufficient parking area to each deploying air unit to allow efficient accomplishment of its mission.

The sufficient allocation of parking space to an airlift operation allows the delivery of troops and cargo in accordance with the commander's plan. Since much of the commander's planning is predicated on the timely accomplishment of the deployment, minimizing deviations from the plan is the general criteria for allocating ramp space. If the ramp space to airlift is limited, and the timing of the deployment flow is unchanged, the commander must accept the risk of delay and diversion caused by the allocation. This study attempts to quantify the consequences of that risk.

Parking Computation

There are several important determinants of an airfield's parking capacity. The most obvious is the aircraft size. The amount of space a parked aircraft consumes is generally computed by forming a rectangle around the aircraft with the dimensions of the aircraft's wing span and the length of the fuselage. For example, the C-130 has a wing span of 133 feet and a length of 99 feet. The area of a rectangle with these dimensions is 13,167 sq feet. However, this statistic only describes an aircraft's static utilization of ramp space. A given area large enough for parking must be accessible to the aircraft. Access is a function of the aircraft's turning radius, its ability to back up, and a function of the obstacles along the taxi route to parking. The relative sizes of each aircraft are shown in Table 2-1. In the right column the relative size of the rectangle formed by each aircraft is shown with respect to a C-130. All values are in feet.

Table 2-1. Comparison of Airlift Aircraft

Aircraft	Wing Span	Length	Area	Ratio
C-5	222	248	55,056	4.18
C-141	160	168	26,880	2.04
C-130	133	99	13,167	1

Each potential APOD must be individually evaluated with respect to each aircraft and the specific circumstances at the airfield. Strengths of each taxiway and the obstacles that prevent aircraft access to parking are evaluated. The output of the evaluation is a figure for Maximum On Ground (MOG) for each type aircraft. The MOG is a measure of the airlift parking potential of an airfield and states by type of aircraft the maximum number of aircraft that may be parked at any given time. For example, an airfield parking survey may report a figure of 2:4:6 as the Maximum On Ground. This value means a maximum of 2 C-5s or 4 C-141s or 6 C-130s may occupy parking at any given time. It is important to emphasize that the MOG relates to the entire airfield. Airlift operations are not likely to receive the entire amount.

When a specific airfield is designated as an APOD, and no planning has been accomplished, the Airlift Control Element arrives early in the deployment to decide on an airlift parking plan for the allocated space. The ALCE is aware of the general size and composition of the airlift flow. Based on this knowledge, the ALCE commander will designate certain areas of the ramp to various types of aircraft. Designation by type is a function of the requirements for offload, the ground traffic flow, and the jet blast associated with each aircraft. The decisions are highly specific with respect to each airfield.

In addition to specific areas set aside for each aircraft, the ALCE will logically designate some area for common parking to allow for overflow and unanticipated diversions. If the planned deployment goes as scheduled, the common parking area is unecessary. But it is a truism of military operations that this will not be so. Buffers that allow adjustment to unanticipated events are the compensations of any military unit to the frictions of war.

System Elements

The transhipment system begins with the arrival of strategic airlift into the theater. The strategic airlift fleet for the purposes of this study will be represented by only the C-5 Galaxy, and the C-141 Starlifter. These two aircraft approximate the size of aircraft in the CRAF.

Respectively, they serve as surrogates for the the B-747s and DC-8s that make up the body of the CRAF fleet. The military airlift fleet consists of 234 C-141B and 70 C-5A aircraft. However, for planning purposes only, 215 C-141s and 64 C-5As are assumed to be available for the intertheater airlift mission. The remainder are held in reserve by the CINCMAC for high priority, non-deployment missions. That amount is based on historical data.

One measure of airlift capability is ton-miles per day. As mentioned earlier, a ton-mile is 2,000 lbs moved one nautical mile. The ability of a fleet of aircraft to generate ton-miles is based on the average daily utilization of each airframe, the ratio of aircrews to airframes, the flying speed of the particular aircraft, and the cargo capacity of the aircraft. The average daily utilization of the aircraft is primarily a function of spare parts and the availability of maintenance personnel. For fiscal year 1983, the capability of the military airlift fleet was 17.8 million ton-miles per day. To place this figure in perspective, if the airlift force of C-5s and C-141Bs were required to deploy forces a distance of 10,000 miles, they could deliver 1,780 tons of payload per day. Recall that one U.S. Army infantry batallion requires approximately 2,500 tons of airlift capacity for deployment.

In a deployment, the strategic airlift fleet would constitute a stream of aircraft inbound to the theater of operation, a certain amount of aircraft within the theater unloading cargo, and a returning stream to the ports of embarkation. Departures to one or several APODs in the theater can occur from all over the CONUS or adjacent theaters. For example, Osan AB South Korea might be designated as an APOD during a contingency. Cargo may arrive from an Army ammunition depot in Pennsylvania, troops may arrive from the 1st Infantry Division at Fort Riley Kansas, and an Air Force maintenance detachment may be arriving from Little Rock, Arkansas.

Ideally, when aircraft are scheduled to arrive at an airbase, the airlift schedule has been deconflicted. Of course, this only means the scheduled arrivals were deconflicted. Arrivals requiring sometimes 20 flying hours to reach a destination are unlikely to arrive on schedule. Depending on en route winds and weather, arrivals can easily vary by one or two hours. For example, over a 24 hour flight time (approximately 10,000 miles at typical airlift speeds), an uncompensated 20 knot wind can create a one hour difference in arrival times. En route delays or delays in departure from the originating base can create deviations of the same magnitude.

Arrivals at the airfield, although part of a larger schedule, are extremely fluid and flexible. Although orchestrated by a larger plan, the arrivals are unpredictable and uncertain to an observer at the airfield. This statement is borne out by interviews with experienced ALCE personnel (14). Although a tentative schedule is passed to the receiving ALCE, the mode of behavior is to be ready for anything. Emphasis is not only on being ready to respond to the scheduled arrivals, but also to amass resources and alternatives to cover any eventuality. MAC places a great deal of faith in the resourcefulness of the ALCE personnel and their ability to adjust to changing circumstances. Although theoretically all MAC ALCEs are tied into the MAC command and control system, often air bases are out of contact for long periods of time. It is not uncommon for aircraft to act as messengers to the ALCEs and for information to be relayed from the bases by returning aircraft.

In general, a simplified model of the airfield and its operations consists of several factors. At a minimum, it consists of a runway, parking ramps, equipment to load and unload aircraft, fuel and refueling equipment, various routine servicing equipment, and a standby maintenance activity. The airlift ramp operation is coordinated by the ALCE, while controlling airborne and taxiing aircraft is an

System Definition

Figure 3-1 shows the APOD transhipment system. Given the requirement for strategic transportation, the system is driven by the arrival of cargo into the theater on board C-141 and C-5 aircraft. Aircraft arrive at some rate designed to meet the requirements of the supported commander. When strategic aircraft arrive at the airfield, they require runway availability and parking before they can be offloaded. If parking is unavailable, aircraft orbit overhead until parking becomes available or low fuel forces them to divert to other bases. Alternately, aircraft may utilize taxiways as temporary parking until parking becomes available. Over some period of time, aircraft occupy parking space to allow cargo offloading, refueling if necessary, and routine maintenance. When aircraft attempt to vacate parking, some probability exists of a maintenance delay keeping the aircraft on the ground beyond normal limits. The length of that delay depends on the availability of spare parts and trained personnel. When these activities are complete, aircraft leave parking, taxi to the runway, and takeoff when the runway is clear.

There are three categories of output cargo from the strategic airlift subsystem. They are terminating cargo, cargo requiring air movement, and cargo requiring surface movement. Depending on the theater of operation, the cargo

III. System Definition and Experimental Design

Introduction

The purpose of this study is to determine the quantitative impact of ramp congestion on airlift operations using a range of arrival rates. Specifically, this study attempts to assess the change in delivered tonnage and throughput for changes in ramp space. Since the general aim is to improve airlift operations during a wartime scenario and the aircraft arrival rates and constrained parking are peculiar to conflict, there is little real world opportunity to observe the system and gain experience in its management. However, an accurate abstraction of the process, designed to capture the essence of the system, can become a training aid supplementing real world experience. Cumulative iterations of defining and redefining the modeled system, when properly validated, gives insight that enables proper system management from the first days of the conflict. However, accurate conceptualization of the APOD transhipment system is vital to obtaining an accurate characterization of its dynamics.

Port Squadons (MAPS) are in place and functioning. Fuel is available and material handling equipment is not a limiting factor. Strategic airlift forces are in the process of deploying men and equipment to the APOD while tactical airlift deploys air-transportable forces to forward operating locations.

accordance with operational planning factors. The ALCE is in place and the tempo of operations at the APOD has achieved its maximum. Ramp space at the APOD is occupied or allocated to deployed air forces. Air traffic control and aerial port squadrons are in place and functioning.

Summary

The APOD transhipment system links the strategic and tactical airlift operations during deployment to a combat theater. The system is composed of three subsystems. They are the strategic airlift arrival system, the tactical airlift subsystem, and the airfield itself. The strategic system deploys forces from the continental U.S. to the APOD, and has the capability to airlift approximately 1750 tons per day to a destination 10,000 miles from the U.S. The tactical subsystem consists of aircraft and crews assigned to the theater commander, and distributes some fraction of strategically airlifted cargo to locations throughout the theater. The airfield subsystem consists of a runway, taxiways, and parking areas. In addition to physical facilities, the airfield subsystem is managed and controlled by combined efforts of air traffic control and the Airlift Control Element.

The scenario chosen for this study consists of the deployment of U.S. forces to a theater threatened with war. At the APOD, air traffic control, ALCEs, and Mobile Aerial deployment bases in the United States. Within the theater of operation, there is one designated APOD. Deploying to the airfield are air and surface forces responding to heightened tensions along the border of a U.S. ally. Although a general contingency plan is available, operational circumstances have dictated unique requirements mandating the execution of short notice contingency planning.

Although circumstances in the rest of the world are calm, the Joint Chiefs have directed CINCMAC to withhold 10 percent of his strategic airlift force in reserve (6:III-10). Sufficient tactical airlift is available in the theater to transport air cargo to forward bases. Air refueling is generally unavailable for airlift and cargo loads are restricted by the critical fuel legs of the deployment routing. En route support has been allowed by U.S. allies and overflight rights have been granted where necessary. The Civil Reserve Air Fleet has not been activated.

The notional single APOD of this study is assumed to consist of a single runway. The parking ramp is connected to the runway by a limited number of taxiways, and although they are strong enough to support any aircraft, because of limited access to the runway they cannot be used for temporary parking. Fuel and material handling equipment are assumed sufficient to maintain airlift ground times in airfield. For this reason, there is only a small variation in the interarrival time of tactical airlift. Scheduled aircraft will arrive separated by their fixed interarrival times. The only other hindrance to their arrival is the requirement to achieve runway landing separation from other aircraft. C-130s will have some calculated holding fuel before they are required to divert from the airfield.

C-130 capacity is set at twelve tons per aircraft. This figure is consistent with the assumption of the "USAF Airlift Master Plan" (AMP:III-16) that tactical aircraft will fly 1.5 sorties per day and carry 12.65 tons per sortie. Although this assumed payload is less than the C-130 maximum cargo of around 30 tons, maximum tonnage is often limited by mission requirements. A typical mission might consist of a positioning leg to the APOD from the beddown location, followed by one or more sorties to forward operating locations in the theater, and then a return to the beddown base.

Scenario

The operational parameters of the airlift transhipment system are scenario dependent. As described earlier, geography, weather, and the military capabilities and intention of the enemy all impact on the systems operation. The scenario chosen for this study consists of a theater of operation approximately 10,000 nautical miles from

Tactical airlift is one transportation resource available to the theater commander. Although theoretically a request for movement can be filled by any transportation mode, certain requests, because of timing and operational considerations, can only be filled by tactical airlift. In the typical APOD under study, the same general procedures outlined above are followed. The arrival of cargo generates a certain amount of movement requirements, and, of that number, some fraction of the total cargo tonnage must be moved by airlift. The request arrives at the agency of the theater commander's staff which validates movement requirements. That agency then tasks tactical airlift to fly the mission.

The arrival of cargo at the airfield generates a requirement for tactical airlift. Of the cargo delivered to the APOD, some fraction of total cargo delivered to the airfield will require transhipment by tactical airlift. The fraction is scenario dependent. Given the requirement to tranship cargo by air, the scheduling agency within the theater generates the appropriate amount of aircraft for arrival at the APOD. The aircraft are assumed to arrive at a uniform interarrival time to minimize the possibility of congestion. The interarrival time is calculated to move the expected amount of required cargo. For this study, C-130s are assumed to be based within a short flying time of the

the two flows account for the unequal movement rates of strategic and tactical aircraft. For example, a cargo arrival rate of 700 tons per day requires 10 C-5 loads. Although the cargo departure rate will on the average equal 700 tons per day, that rate requires around 65 C-130s per day. The varied aircraft rates dictate the amount of unequal parking required for each type of aircraft. In addition, stochastic events associated with each aircraft, such as loading, maintenance and arrivals, dictate additional amounts of parking.

Within a theater, tactical airlift will be scheduled on the basis of requirements. Theater operational and logistical units will assess their requirements for transportation to accomplish their assigned missions. If possible, they will accomplish the movement with organic transportation. However, if requirements exceed their organic capabilities, they will forward requests for transportation augmentation to higher headquarters. Ultimately, requirements that cannot be filled will arrive at the transportation controller on the theater commander's staff. There, all requirements competing for limited transportation resources are consolidated and prioritized. Theater transportation agencies are then tasked to fill the highest priority movement requests.

such as ammunition or food, require time to inventory and organize for transhipment.

When cargo arrives at the airfield, it can be divided into three general categories. In the first category, cargo movement terminates at the airfield to support the APOD or other base operations. The remaining cargo is assummed to transit the airfield. The transiting cargo is distinguished by the transportation mode utilized to remove the cargo from the airfield. Tonnage moved by surface transport constitutes the second cargo category, while cargo moved by air constitutes the third. This third category is the primary interest to this study.

For cargo transiting the airfield, it can logically be assumed that, over a period of time, cargo arriving at the airfield will equal cargo departing. Although for some periods of time cargo arriving or departing will exceed the other rate, on the average they will be equal. This assumption allows the warehouse function to be omitted from explicit consideration in the problem. It can be assumed that when cargo arrives at the airfield and has completed its offload, it becomes available for transhipment.

This simplification directly links the arrival rate of tactical airlift to the strategic airlift. Although the rate of cargo movement at the airfield will on the average be equal, the unequal sizes of the aircraft that constitute

Most other minor tasks can be accomplished concurrently with loading and refueling operations. The remaining major task, aircraft maintenance, is a conditional one. Although minor maintenance is a rountine part of any ground operation, each aircraft has some possibility of requiring repairs that exceed scheduled ground time. In general, the delay rate varies with aircraft age, complexity, and the availability of spare parts. For example, although the C-130 is a relatively old aircraft, its design is simple and rugged and parts are generally available. Alternately, the C-5 is considerably more complicated and the parts are often unavailable. The rate of maintenance delays reflects these factors. The delay rate, along with the associated delay time, reflects both the quantity and degree of an aircraft's maintenance requirements.

Following the completion of ground operation and the aircraft departure, the amount of cargo at the airfield is either increased or decreased. The word cargo is slightly misleading. Cargo, for the purposes of this problem, refers to people, vehicles, and supplies. Although the concept of "warehousing" is applicable to all of those categories, each requires different types of support. Personnel may require messing and shelter, while vehicles or helicopters may require reassembly after being air transported. Supplies, potential for damaging the aircraft. Wheeled vehicles typically move under their own power on or off the aircraft. The final possible airlift payload, personnel, is the quickest to offload. Generally, personnel require no ground handling equipment and are able to exit the aircraft without assistance.

The second major ground task is refueling the aircraft. This can be done either by truck or by refueling pits. Refueling pits are essentially reservoirs and pumps built into the ramp space that allow for a quicker and simpler refueling process. The alternate method requires refueling trucks to cycle between aircraft and fuel storage areas. Generally, no other ground activities may be accomplished while refueling is underway.

Obviously, refueling is not always possible or advisable. A policy of refueling strategic airlift requires large amounts of fuel that may be better allocated to in-theater forces. The magnitude of fuel required by a C-5 is illustrated by comparing its maximum fuel load of 318,000 pounds to a typical capacity of 15,000 pounds for a fighter aircraft. A decision to refuel strategic airlift is likely to be made only after theater forces have ample fuel stocks. Alternative policies might be to use the air refueling or staging bases as an alternative to the use of theater stocks.

marshaling of aircraft into parking, and the disposition of cargo to the controlling agency at the airfield.

When an aircraft enters parking, a series of tasks take place that determines the ground time of the aircraft. The most important task is the loading or unloading of the aircraft. Additionally, the aircraft may require refueling or minor maintenance servicing. Finally, flight crews may be required to file flight plans, report arrival information to a higher headquarters, or seek additional information before continuing their mission.

Normally, the most important and time consuming activity during an aircraft's ground time is cargo loading and offloading. Cargo may consist of pallets, personnel, or wheeled and tracked vehicles. The type of cargo determines the equipment required for offload. Palletized cargo requires the use of specialized material handling equipment. The C-5, C-141, and the C-130 can use the same type of equipment for cargo handling. However, aircraft of the CRAF and the KC-10 require equipment that is in relatively short supply in the Air Force Inventory.

Transporting wheeled or tracked vehicles requires the use of tie down chains and restraints that are manpower intensive to install and remove. Additionally, for very large vehicles, the process of guiding the vehicle on or off an aircraft is an extemely delicate operation due to the functions are assumed to be linked by communications and coordinated. The approach control is capable of maintaining an aircraft in a holding pattern and then vectoring the aircraft to the runway. All three ATC functions, tower, ground control, and approach control, act to avoid traffic conflicts and congestion. All these functions are air portable and available for world-wide deployment.

In coordination with the ATC function, the Airlift Control Element controls operations within assigned ramp space. The ALCE is assumed to be in communications with ATC and with aircraft in the vicinity of the airfield. Assuming an aircraft is waiting for parking, the ALCE is assumed to use these capabilities to minimize delays between the departure of one aircraft and the arrival of another. Aircraft are assumed to hold overhead until parking becomes available. Once parking is available, aircraft must receive landing clearance and maintain time separation from previous takeoffs or landings. Separation between aircraft is assumed to be four minutes from any C-5 takeoff or landing, and two minutes between any other type of aircraft.

In managing the parking spaces, the ALCE has a great deal of latitude in dictating arrival and departures. ALCE commanders have been known to terminate the loading of an aircraft to make room for another arrival (14). The ALCE oversees the loading and unloading of aircraft, the

Air Traffic Control function. Each of these sub-areas will be addressed below.

Physical Facilities

The notional airfield will be assumed to be a single runway airfield with varying amounts of ramp space assigned to the airlift operation. The length and strength of the runway will also be assumed to be great enough to support any aircraft in the strategic airlift flow. Sharing both the runway and parking space at the airfield are various air missions such as fighters, air refueling, and air defense, in addition to airlift. The amount of parking space available is left undetermined, but for the purposes of definition, it is assumed to be sufficient to support any level of airlift operation in the study. Restrictions to airlift parking are due to competing allocations of parking space for other air missions.

There are two controlling agencies that will manage the flow of aircraft into and out of the airfield. The first is the airfield's air traffic control (ATC). As mentioned earlier, the range of services at any airfield vary considerably. For the purposes of this study, it will be assumed that the airfield has a functioning control tower with ground control. Additionally, airspace around the airfield is assumed to be controlled by a radar approach control capable of 24 hour, all weather operation. All ATC

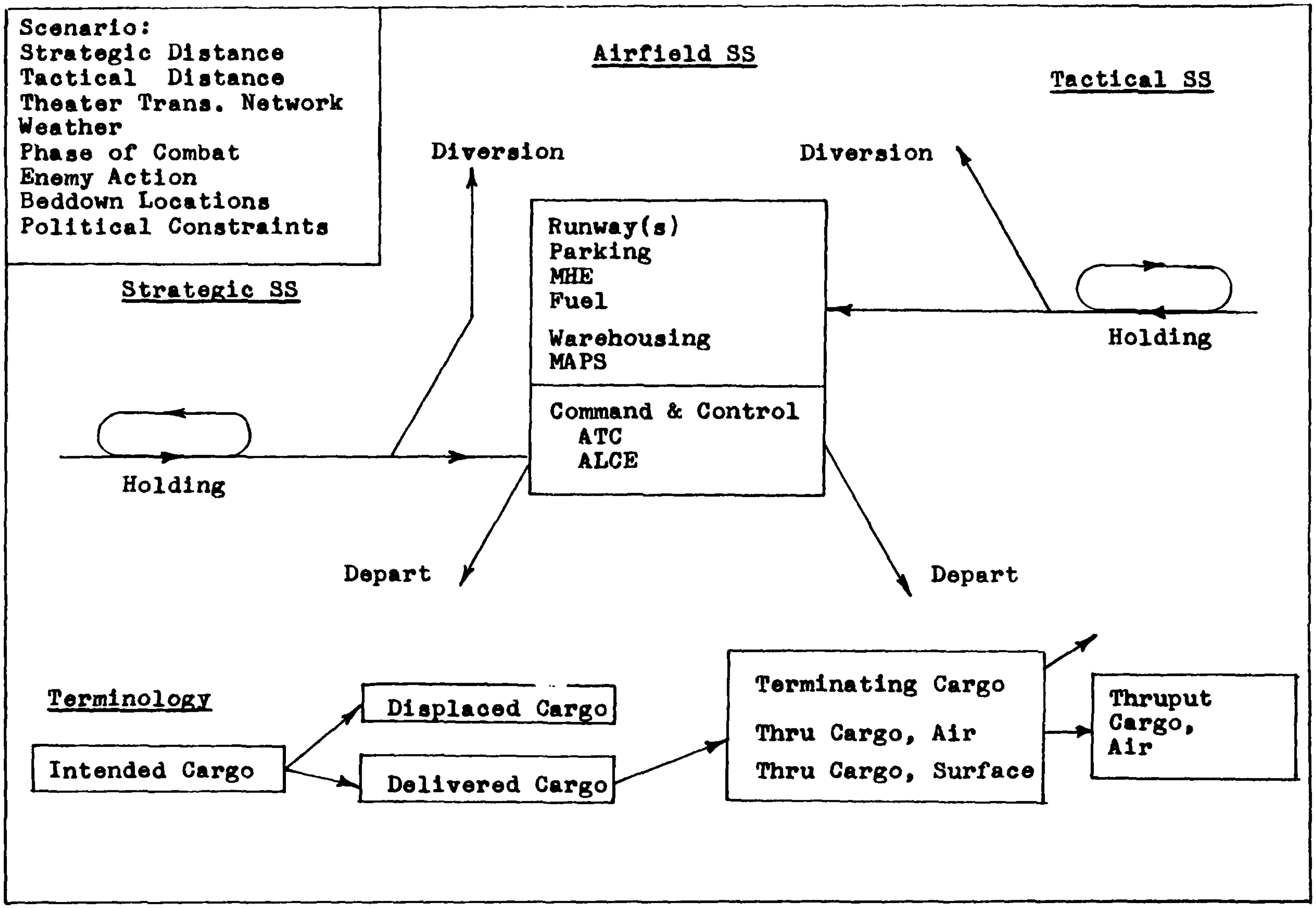


Fig 3-1. The APOD Transhipment System

transhipped by air will amount to various fractions of strategically delivered cargo. Before cargo is transhipped by any mode of transport, cargo must be identified, sorted, and processed.

For the tactical airlift subsystem, mission requirements are driven by the amount of cargo available at the APOD for transhipment to forward operating locations. Upon arrival at the APOD, tactical aircraft undergo the same sequence of events as strategic airlift: wait for clearance to land, wait for parking if necessary, engage in ground operations including loading and offloading of cargo, and finally, departure from the airfield.

Comparing the systems definition to the conceptualized system outlined in the previous chapter, there are several significant simplifications and assumptions:

1. Strategic Flow: The strategic flow will consist of only C-5s and C-141s and excludes aircraft of the Civil Reserve Air Fleet.

2. Cargo is assumed to become available for air transhipment after offloading from strategic aircraft.

3. Total parking is allocated between areas designated for particular aircraft types, such as C-141s, and a common area available to all airlift aircraft. It is assumed that the parking managers take actions that allow aircraft to depart when cargo loading activities are complete. Also,

whenever some fraction of common ramp space is large enough to accommodate the next aircraft requiring parking, parking managers take actions that assure the available fraction is in one aircraft-sized area and not sub-divided. This action must be taken prior to the start of on or offloading. Once that activity begins, the aircraft position is fixed. That is, if a C-130 requires 25 percent of the available common parking ramp, and 25 percent is available, then the common ramp is assumed capable of allowing the C-130 to park.

4. Air traffic control functions are in place and capable of providing separation between all aircraft on a 24 hour basis.

5. Material Handling Equipment and Mobile Aerial Port Squadron resources are assumed sufficient to maintain a standard ground time for each aircraft.

6. Parking does not become available until an aircraft departs the airfield.

7. The airfield is assumed capable of 24 hour, all weather operation.

8. All C-130 destinations are capable of 24 hour, all weather operation.

9. The strategic fleet and the assigned tactical resources are numerically sufficient to maintain the required flow rates.

10. Tactical airlift is based at other than the deployment airfield.

11. The APOD is not subject to conventional enemy action, nor is the APOD subjected to enemy sabotage or terrorism.

Structural Model

The conceptual model can be described by two categories of variables: static and dynamic. A static structural diagram is shown in Figure 3-2. These variables may be further subdivided as either stochastic or deterministic. A static description of the APOD transhipment system at any instant in time can be expressed by four elements:

1. Number and type of aircraft in parking
2. Number and type of aircraft waiting for parking
3. Amount and type of parking available
4. Cargo available for transhipment.

The dynamic elements of the system drive the static elements to different values. These are the arrival rates of strategic airlift, the arrival rates of scheduled tactical airlift, and the rate at which cargo becomes available for transhipment by tactical airlift. Other variables describing system behavior in time are the length of ground time for all types of aircraft, and the length of delay if the aircraft requires maintenance. The relationship

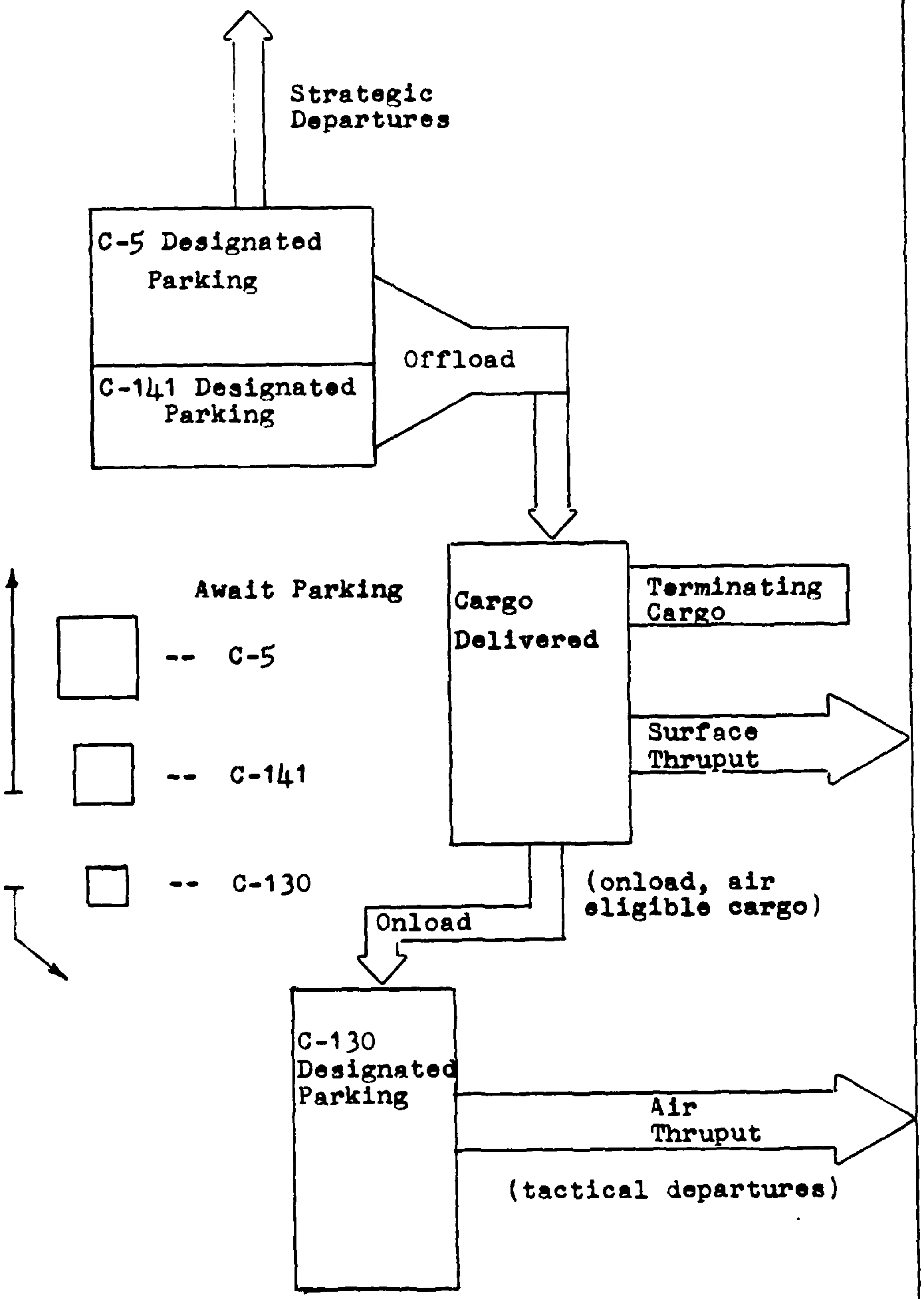


Fig 3-2. Static Structural Diagram

between the static and dynamic variables are shown in the causal loop diagram depicted in Figure 3-3.

Referring to the causal loop diagram, there are four sources of randomness within the model. They are: 1) the arrival rates associated with the strategic and tactical flows, 2) the length of the loading operation for each aircraft, 3) the probability of a takeoff delay, and 4) the length of a delay given it occurs. The presence of these stochastic variables makes the achievement of any one amount of cargo delivered or cargo throughput impossible to predict. Instead, when accurately appraising the system, a planner must speak in terms of a confidence interval, or of a daily minimum value the system can be expected to achieve.

The presence of these variables and the associated variation in system output makes the system best modeled by a Monte Carlo simulation process that can provide a confidence interval of system values. The alternative approach to dealing with the stochasticity of the system is to determine an expected value for various measures of merit. Although this technique is quicker and simpler than simulation, it fails to provide the range of values the system may generate on any given day. Expressing outputs as confidence intervals allows system managers to identify normal and abnormal operation of the system and make appropriate decisions. This concept is especially important

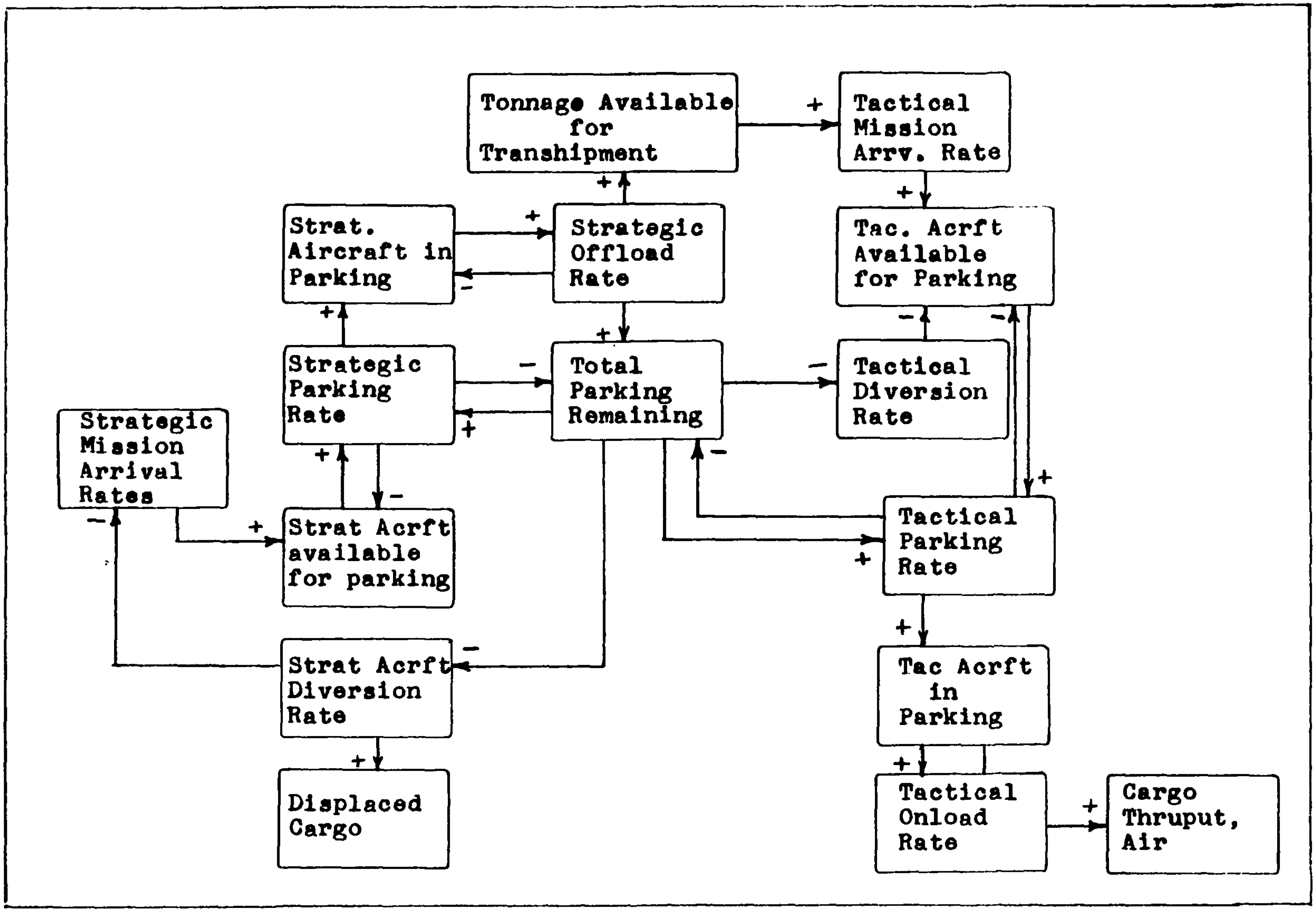


Fig 3-3. Causal Loop Diagram

when a system output must be greater than a certain value on a given day to assure operational success. To assume an expected value for a critical output on a given day is an invitation for failure.

Computer Model Development

A SLAM network simulation model was constructed to duplicate the conceptual model described above. The SLAM network is shown in the Appendix. Within the simulation model, C-5 and C-141 aircraft are modeled as entities moving through a conditional and probabilistic network. The arrival of aircraft to the airfield is modeled as a stream of aircraft inbound to the airfield at uniform interarrival times. Deviations from the scheduled interarrival times are inserted into the flow after their creation. As mentioned earlier, the flow is composed of the two military airlifters. The general proportions of the two aircraft types within the flow are determined by the composition of the airlift fleet. However, the order of arrival into the airlift system is random. The randomness is represented by a Bernoulli probability distribution. Overall, the nature of the arrival stream is composed of two stochastic variables that govern the type of aircraft arriving and the deviation of that aircraft from a scheduled interarrival time.

At the airfield, there are four possible types of parking: one for each type of aircraft, and a fourth designated as common parking. These four parking types are modeled as SLAM resources. When entities representing C-141s and C-5s enter the airfield system, they will wait until one of two events occur: either a resource for the appropriate amount and type of aircraft parking becomes available, or an appropriate amount of the common parking resource becomes available and queuing discipline has designated the particular waiting aircraft as the next aircraft to enter parking. If parking is unavailable, entities are diverted from the system after waiting appropriate amounts of time. Cargo diverted from the system is assumed to be lost to the theater.

Within the model, common parking is assigned by the use of a FORTRAN insert to the SLAM network. When common parking is available and no appropriate parking resources are available for the particular type of aircraft, the common parking is assigned based on various decision rules. The base case queue discipline for common parking is to allow first access of common parking to new system arrivals. Provided common parking space is available, new arrivals utilize appropriate amounts of the common resource. For the simulation, the common parking resource required by each aircraft is proportional to the area occupied by the aircraft as outlined in Chapter two. If common parking is not available, aircraft priority for common parking is based on first-come-first-serve. If appropriate parking for the type of aircraft waiting becomes available, for example a C-141, the aircraft departs the waiting line and seizes one unit of parking resource.

Once the aircraft arrive at the airfield, each type of aircraft have five attributes that describe their interaction with the system. Each aircraft will: 1) have some cargo capacity measured in tons, 2) require some amount of ground time to complete its on/offload, 3) occupy some percentage of the total parking available, 4) have a takeoff delay rate, and 5) given a takeoff delay occurs, have some delay length associated with each aircraft. The length of the delay will depend on the severity of the maintenance problem and the availability of appropriate parts and personnel.

When a waiting entity is allocated parking, the three functions of offloading, refueling, and maintenance servicing are modeled by the passage of time. The variability of each of these activities is modeled in the aggregate by a single stochastic variable. The variable represents the commitment of some level of resources to attain a given ground time. When ground operations are complete, cargo is assumed to become available for transhipment.

The runway in the SLAM model is represented as a single server activity requiring variable amounts of time for each type of aircraft. In the model, entities pass through the runway activity after parking becomes available. It is also possible that aircraft would land and await parking on the ground. The statistics generated by this network arrangement are valid for either case. Entities also pass through the runway activity before departing the system. Priorities for the use of the runway go to arrivals. Arrivals and departures are ranked according to first-come-first-serve. Separation between aircraft is modeled by assigning time values for the use of the runway.

Data Collection

Once the simulation model was developed, appropriate times had to be assigned to activities and arrival rates. Specific data falls into the categories of experimentally dependent, such as daily tonnage arrival rates, and those values that will remain constant throughout the simulation. Those values left constant should be applicable to any experimental scenario under study and reflect standard behavior and operating procedures. Table 3-1 shows a list of scenario independent variables, and lists the parameters and

Table 3-1. Experimentally Independent Variables

Variable	Parameter	Source
1. C-5A Cargo Capacity	70(tons)	(7)
2. C-141B Cargo Cap.	20	(7)
3. C-130E Cargo Cap.	12	(6)
4. Offload Time (C-5)	uniform(150-195min)	(8,1,21)
5. Offload Time (C-141)	uniform(90-135min)	(8,1,21)
6. Offload Time (C-130)	uniform(80-120min)	(8,1,21)
7. Maint. Delay Prob.		(1,21)
a. C-130	5%	
b. C-141	10%	
c. C-5	15%	
8. Delay Length	triang(0,35,240)	(1,21)
9. Holding Time		(8)
a. C-5	45(min)	
b. C-141	45	
c. C-130	60	

class for each. Experimentally dependent values are covered in the Experimental Design subsection.

Strategic airlift arrival rates are based on the daily amount of tonnage required to be delivered to the APOD and the mix of strategic aircraft deploying the forces. The military airlift fleet has a capability of 17.8 million ton-miles, and 40 percent of that capability is provided by C-5 aircraft. Given the assumption that 40 percent of tonnage arriving at the airfield is delivered by the C-5, the average number of C-5 arrivals to the APOD will be proportional to the percentage of cargo they deliver. The number of arrivals is computed by dividing the amount of tonnage by the payload capacity of the C-5 to provide the number of C-5 arrivals per 24 hours. The remaining tonnage will be provided by the C-141. The same procedure is applied to the C-141 to yield the required number of daily arrivals. The arrivals of each aircraft type are then summed to yield the total number of strategic arrivals per day. That number is then divided into the number of minutes per day to yield the average interarrival time of all strategic airlifters.

Within this study, the strategic airlift stream is scheduled to give a uniform interarrival time. Scheduled interarrival times vary for each rate of tonnage arriving at the APOD. The actual arrival time will vary around the eduled arrival time. Variations occur for many reasons: route winds deviating from predicted speed and direction, ays at en route refueling locations, delays in departure es from the port of embarkation, and early departures m the port of embarkation. The average deviation was ermined by soliciting typical deviations from experienced lift personnel (1 & 21). Airlift deviations from scheduled ival times are modeled by a truncated normal distribution h a mean centered on the average interarrival time of h aircraft and a standard deviation of one hour.

A key point of this formulation is the independence of terarrival times. Instead of the interarrival times lated to the previous arrival, interarrival times are nerated, for this formulation, as a byproduct of the viation from scheduled arrival times. Scheduled arrival mes are, of course, related by the nature of the scheduled rlift flow. This stream of strategic arrivals simulates a deployment flow coordinated and deconflicted by some ntral scheduling function. Although the scheduled arrival mes are known to the controlling agencies at the APOD, the pe aircraft for each arrival is unknown until its arrival the airfield.

For a given arrival at the APOD, the probability of one pe of aircraft arriving is determined by its percentage of tal arrivals. That is, if 5 C-5 and 15 C-141 sorties are

In making a point estimate of the airfields throughput cargo delivered, each replication of the model is assumed o be independent. This assumption is key to constructing oint estimates of the true behavior of the system. If a eries of system observations are not independent, then they re described as auto-correlated and that set of system bservations will not constitute a random sample. To avoid his outcome, the simulation technique of independent eplications is used. This technique gives each replication f the model a different random number stream for each eplication. The outcomes can then be assumed to be statistically independent and identically distributed. This factor, coupled with the minimization of initialization bias, allows the construction of confidence intervals and the use of hypothesis testing on the system data (B&C:421).

Summary

This chapter describes the conceptualization of the APOD transhipment system and the simplifications required for modeling. Among the assumptions are the omission of weather from the problem, 24 hour operations for C-130, basing of tactical airlift away from the APOD, and the assumption of sufficient levels of material handling equipment and aerial port facilities. Chapter IV describes the process of selecting simulation as the methodology for modeling and a description of the computer model. The itial values of cargo to speed the achievement of a steady ate.

Reductions of output variance were achieved ructurally in the model by the use of synchronized common ndom number streams. The purpose of using common random mber streams, also known as correlated sampling, is to hieve positive correlation between output values on each n of the model. Although the value on each replication is dependent of all other replications, the use of correlated mpling creates a positive correlation between replications d thus achieves variance reduction in the estimator of the an difference over various runs of the model.

As a supplement to correlated sampling, synchronization f the common random number streams was built into the odel. Synchronization means that the random number used in e model run is used for the same purpose in the second. andom number streams are dedicated to each source of tochasticity in the system. That is, deviations from cheduled arrivals for strategic airlift use a different andom number stream than that used for determining the round time of the C-5. In the simulation, the first trategic arrival will always receive the first value from ts dedicated random number stream. Over each replication f the model, the seed to that stream is varied to insert tochasticity into the system.

fact, a lower level of aircraft ground time is set at 50 percent of the MAC planning factor. Combinations of tactical and strategic airlift are evaluated against the base case level of parking and tonnage arrival rates. This experiment complements the first research objective by examining alternatives to increased parking space by determining equivalent system performance.

Sample Size and Reliability

In running the experiments, goals were set to statistically discriminate a 10 percent change in the mean value of throughput or cargo delivered. Significance levels are set at an alpha of .05 and the power of the test at a beta of .01. Preliminary runs of the model were made to gain an estimate of variation around the measures of effectiveness. As in any steady state system, variance around the mean values decreased as run length increased. Judgements were made on the tradeoffs between run lengths and the number of replications required to achieve desired statistical accuracy. Additionally, antithetic variance reduction technique was applied to further reduce output variance. A final decision was made for 20 replications per run using antithetic variance reduction technique. It was determined that the simulation model achieved steady state after approximately 12 days. Initialization bias was minimized by the use of queue pre-loading and providing

3. Multiplying the number of arrivals per day by the standard ground time for each aircraft. This figure is the total parking-hours required by each aircraft per day.

4. Dividing total parking hours by 24 hours to yield the required parking per day per aircraft. Fractions are rounded to the next highest integer.

The ultimate goal of this particular experiment is to gain insight into the response of the system over various regions of feasible parameters. Constructing a general surface of data points gives clues to system behavior. Specifically, this experiment can give data on the relationships between the percentage of cargo delivered and the percentage utilization of allocated parking space.

The second major experiment concerns the tradeoff rates of aircraft ground times to the percent of cargo delivered and throughput. In essence, this experiment is designed to illustrate the ability of the system to compensate for constrained parking by reducing the ground time of aircraft.

In the baseline model, aircraft ground times are set in accordance with MAC planning factors. These factors are based on levels of availability of material handling equipment, aerial port squadrons, and refueling capabilities. Ground times can be substantially reduced by concentrating increased resources and/or greater priority for resources to portions of the system. To reflect this

Table 3-2. Aircraft Parking Levels and MOG

Level	Parking/Aircraft Type			MOG
	C-5	C-141	C-130	
1500	2	5	4	(5:10:22)
1000	1	3	3	(3:6:13)
500	1	2	2	(3:5:10)

Note: For all cases, throughput fraction is equal to 33 percent

There will logically be some point in the system where inadequate parking will force the diversion of aircraft from the system without unloading their cargo. The objective of the first research question is to gain information on the response of the measures of effectiveness over some operational regime of the system. If sufficient information can be gained, some inferences can be made about system behavior over a wide range of parking and tonnage arrival rates.

To secure this data, three levels of tonnage arrival and three levels of parking were selected. Levels of tonnage were selected based on feasible delivery rates of the military airlift capability of 17.8 million ton-miles per day (MTM/D). Levels of parking were deterministically calculated for each level of tonnage to allow 100 percent delivery and throughput of all intended cargo. Levels of tonnage and the calculated parking levels are shown in Table 3-2. Allocations for each parking level were calculated by the following steps:

1. Apportioning tonnages between the two strategic aircraft. For this study, C-5s will comprise 40 percent and C-141s 60 percent of the strategic flow.

2. Calculating the required number of arrivals per day by dividing aircraft payload into aircraft category tonnage.

The final step in Naylor's validation procedure is confirmation of input-output transformations. Validation was simplest when available parking did not delay cargo arrival. In that case, output was examined for reasonableness and statistically tested against the expected output. As parking constrained the arrival of cargo, a decreased amount of cargo actually arrived at the airfield as expected. The causal loop diagram was used to guide input-output experimentation and confirm the postulated input-response relationships.

Experimental Design

There are three main research objectives for this study. They are:

1. For a given level of parking and a rate of cargo arriving at the airfield, what is the change in throughput and cargo delivered as available parking is changed?

2. For a given level of parking and a rate of cargo arriving at an airfield, what is the change in the percentage of throughput and cargo delivered as ground times for aircraft are decreased?

3. What are the dynamics of airfield congestion that lead to aircraft diversions?

Conceptually, a given rate of tonnage intended for an airfield and a given level of allocated parking will allow some percentage of intended cargo to arrive at the airfield.

use of direct solicitation of parameters from experienced airlift personnel, each with well over 2,000 flying hours. There were four distributions used in the model: the normal distribution of deviations from scheduled arrival time, uniform distributions representing loading/offloading times for all three aircraft types, a triangular distribution representing the length of delay after a maintenance problem, and Bernoulli trials representing both the proportion of takeoff delays and the type of strategic arrival to the airfield.

The uniform and the triangular distributions are approximations when there is little data on the behavior of the system. Using the qualitative knowledge of the expert personnel, ranges and parameters were estimated by a series of questions and feedback designed to reach agreement over ranges of likely values. With respect to the triangular distribution, the three parameters used are the high value, low value, and the mode. The mode represents the most likely value to occur from the distribution, while the remaining two parameters bound the system. For the normal distribution of arrival deviations, the defining parameter was arrived at by estimating fractile points in the distribution. Expert personnel were asked to estimate what interval of time would they expect to contain 66 percent of all strategic arrivals.

assumptions of the exponential distribution is the memoryless property that states that time, until the next arrival, is completely uninfluenced by when the last arrival occured (16:410). This is an inappropriate assumption when the arrivals to the airfield are managed and controlled by airlift operation centers. The operation centers schedule arrivals and, for the purposes of this problem, the interarrival times were assumed to be scheduled at uniform intervals to minimize congestion. A better assumption is to base the arrival pattern on deviations from a scheduled time and make each arrival independent. Over a period of time, deviations will tend towards a normal distribution based on the Central Limit Theorem. Parameter estimations for this distribution are discussed under Verification and Validation.

A second major assumption requiring justification in the validation process is the assumption of 24 hour operation at forward airfields, thus driving 24 hour operation at the APOD. This assumption is justified based on the selected scenario. A scenario that stipulates a pre-conflict deployment through the APOD can reasonably assume forward bases to be at least partially illuminated to allow the arrival of reinforcements and supplies.

In general, assumptions about deviations and the nature of probability distributions in the model are based on the to explain the model, the widespread knowledge of the fundamentals of network dynamics from PERT diagrams aids face validity. The designation within the model of specific aircraft, parking resources, and runways speeds the process of gaining user confidence.

Calibration is another element of face validity. Calibration is the iterative process of comparing the model's output and features to the real system. During the course of producing SLAM simulation, the model underwent the addition and refinement of several attributes. Over the iterative calibration process, decisions were made to add a runway function and to use a dual track parking configuration with dedicated and common parking. No model ever completely duplicates its real world counterpart, and the end of calibration occurs only when the modeler judges that sufficient accuracy and veracity has been obtained.

The second step in Naylor's validation procedure concerns model assumptions. Assumptions fall into two categories: structural and data (2:385). A particularly important data assumption of the model was the use of the normal distribution for deviations from scheduled arrival times for strategic airlift. Strategic airlift in this model corresponds to arrivals within a queuing system. A very common assumption of queuing systems is an exponential distribution for interarrival times. One of the basic minutes, and a high value of four hours. Aircraft delayed beyond this period are assumed to be moved away from the active parking area. The assumption is that if parking congestion is at an extreme level, then some extreme action will be taken to fly the aircraft away from the field or to move it onto unpaved areas.

Verification and Validation

The verification process consisted of testing the model over its range of flow rates and at various levels of parking. Output was examined for reasonableness. Statistical tests were used to confirm that model throughput was statistically identical to the deterministic calculations. The computer model was compared with the conceptual model already described. Of special interest was the believability of parking utilization, cargo availability, and aircraft delays.

The validation portion of the problem involved Naylor's three step approach of face validity, validation of the model's assumption, and comparison of the model's input-output transformations with that of the real world.

Banks and Carson (2:435) state that the first goal of a simulation modeler is to construct a model that appears reasonable on its face to model users. The use of SLAM, with it capability to model network queuing problems, aids in face validity. When SLAM network symbology is utilized

28-2. However, there is little information on the variation of ground times for each aircraft. Ground times vary significantly according to the type of cargo being on or offloaded and the availability of material handling equipment. Planning factors generally set an upper limit for ground times during peacetime operation. This fact is reflected in modeling ground times by a uniform distribution with an upper value of the planning factor.

Everytime an aircraft lands and shuts down engines there is a possibility of maintenance delays beyond the planned ground time. The probability of an extended delay is dependent upon such factors as parts availability and the presence of specialized maintenance personnel. For the purposes of this study, the rate of maintenance delays are shown below. The values reflect historical data and interviews with experienced airlift personnel (SULA).

Given that a maintenance delay occurs, the length of time the aircraft remains on the ground will depend on the urgency of the situation and, again, parts and personnel. For the purposes of this model, the average ground time for each aircraft will be assumed to be around the time of the planning factor. Variations around the average will depend primarily on maintenance factors. To reflect the uncertainties, delay length was modeled by a triangular distribution with a low value of zero minutes, a mode of 35 dense cargo, such as armored vehicles, will cause the average tonnage per sortie to be higher than the typical cargo of an infantry division.

For the purpose of this model, average cargo per sortie is calculated by using values obtained from the Airlift Loading Model of the Joint Chiefs of Staff. The results of the model are published in Air Force Regulation 76-2, Airlift Planning Factors (7). The model has determined the typical weight by type of aircraft for five types of army divisions. The five types are armor, mechanized, infantry, airborne and airmobile. For each type of division, the model gives average cargo loads over peacetime and wartime for nine potential air-routes. For this study, average cargo loads for the C-5 and the C-141 were determined as follows: first, an average deployment cargo load for each type division was obtained by averaging the values over each air-route. Then the value associated with each type division was given a weighting according to its proportion of the total number of divisions in the continental U.S. The average number then became the cargo load of the models C-5 and C-141.

Given arrivals of aircraft into the airfield system and the availability of parking, aircraft will require some amount of ground time to offload and refuel. Planning factors are available for all aircraft from MAC Regulation required per day to deliver 1000 tons, then on the average, the chance of any given arrival being a C-5 will be 25 percent. For the respective strategic aircraft to deliver tonnage in proportion to their ton-mile contributions to the total military airlift fleet, C-5 aircraft constitute 16 percent of all arrivals. Arrivals are handled as independent Bernoulli trials.

Tactical airlift missions are scheduled by the availability of air transportable cargo at the APOD. C-130 arrivals are calculated by the same methodology as strategic arrivals. Interarrival times are calculated to transport the expected amount of throughput cargo. Arrivals are scheduled for a uniform interarrival time to minimize airfield congestion. Deviations from scheduled interarrival times are normally distributed around the scheduled time with a standard deviation equal to 20 percent of the interarrival times. Given shorter interarrival times for increasing tonnages, theater airlift managers can be expected to impose increasing standards on meeting scheduled arrival times.

The amount each aircraft will carry per sortie is dependent on the fuel required to reach the destination and the type of cargo. The presence of low density cargo, such as helicopters, will cause the aircraft to run out of cargo space before its maximum tonnage is reached. Very heavy and process of verification and validation is described along with the process of data collection and parameter estimation. Experiments will be conducted over three levels of available parking and arrival rates to gain data on: 1) the change in cargo delivered with a change in parking levels, 2) the change in parking utilization for a reduction in ground time, and 3) general insights into system dynamics.

IV. Experimentation

Introduction

The experimental domain can be divided into three separate regions. For all regions, the fraction of air transhipped cargo from strategically delivered tonnage will be 33 percent. The first region is determined by the diagonal line formed by the three experimental combinations where available parking equals the tonnage arrival rate (Fig 4-1). This region will be referred to as the base case. The second region is to the left of the diagonal where the tonnage arrival rate exceeds the parking available. The third case lies to the right side of the base case diagonal. In that region, parking available is greater than the tonnage arrival rate. Parking and arrival rates were set at equivalent levels of 500, 1000, and 1500 tons per day (tpd). These levels will be referenced by the use of a prefix to designate the parking or arrival level followed by numerical expression. For example, the 1500 ton per day arrival rate will be referred to as A15. The 500 ton parking level will be referred to as P5. The data point where parking is calculated to allow 1000 tons per day and the arrival rate is 1500 tons per day would be referred to as the P10-A15

EXPERIMENTAL DESIGN

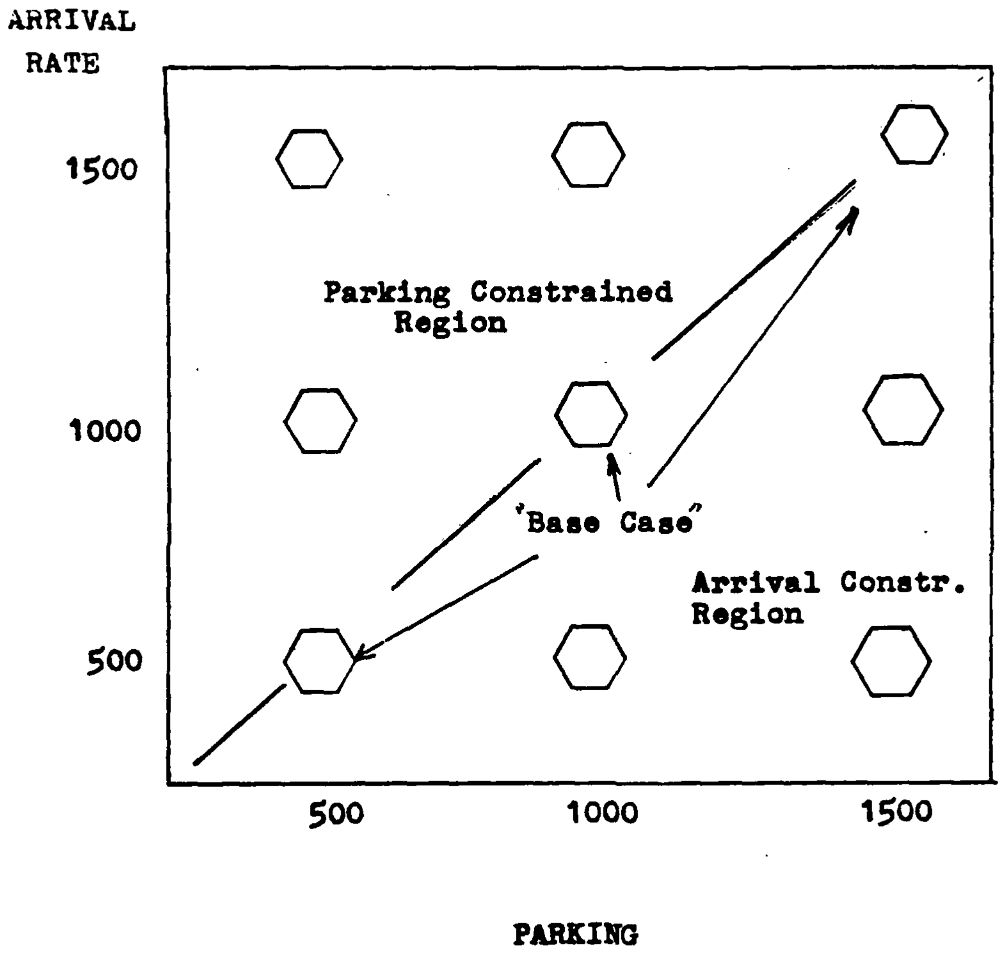


Fig 4-1

case. Additionally, for all cases, references to high, medium, and low levels respectively refer to 500, 1000, and 1500 ton levels.

Actual amounts of parking for the three parking levels of P5, P10, and P15, correspond to values shown in the table below. Parking levels referenced to tonnage refer to the deterministically calculated amounts of parking for strategic airlift.

General Results

Experimental results are reported in terms of the major system outputs: cargo delivered, cargo displaced, and air cargo throughput. The sum of cargo delivered and cargo displaced constitutes the total cargo intended for the APOD.

Table 4-1 presents the response of the APOD transhipment system over the nine combinations of arrival and parking levels. For all arrival rates, the results show the logical effect of increases in parking available. In general, over each arrival rate, the mean value of cargo delivered increased as parking increased. Conversely, over the same range, displaced cargo decreased. Over each parking level for the A15 and A10 arrival rates, increases in cargo delivered tested significant at the .01 level. However, increases for cargo delivered at the A5 arrival rate of 500 tpd could not be statistically distinguished.

Table 4-1. System Outputs Measured in Short Tons

Arrival Rate	Parking Level 500	1000	1500
1500			
Cargo Delivered	778.0	970.5	1438.5
Cargo Thruput,air	255.0	319.8	468.0
Cargo Displaced	795.0	610.0	145.5
1000			
Cargo Delivered	677.0	788.5	981.5
Cargo Thruput,air	219.0	259.2	325.2
Cargo Displaced	331.5	224.5	43.0
500			
Cargo Delivered	449.0	476.5	514.0
Cargo Thruput,air	148.2	155.4	172.8
Cargo Displaced	61.0	36.0	0.0

The response of the system becomes more clear when the percentage of expected cargo is presented for each case. The values are presented in Figure 4-2. For each data point, a parking level and an arrival rate combine to yield some percentage of expected cargo. Data was analyzed by performing a two-way ANOVA followed by a one-way ANOVA and Duncan's multiple range test. Differences were statistically significant at the .01 level.

As parking increases, increases in cargo delivered are most significant when arrival rates exceed the parking level. However, this response is not uniform across arrival rates. Comparing the A15 and A10 arrival rates, the respective step from the P5 and P10 levels to the base case levels of P10 and P15 yielded unequal increases in cargo delivered.

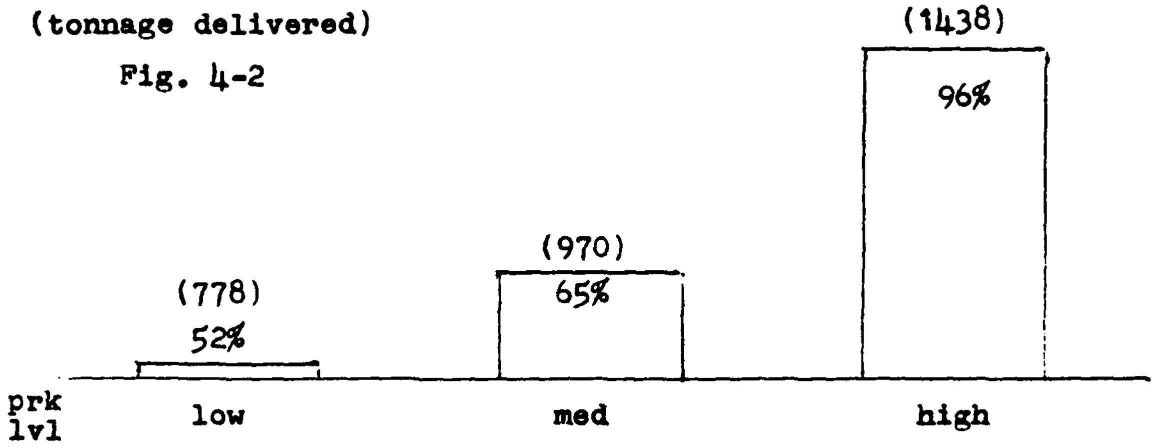
Parking Constrained Regions

Over the parking constrained region, cargo throughput, the second measure of merit, appeared to vary in a similar manner to cargo delivered. However, closer investigation shows cargo throughput closely equals 33 percent of cargo delivered. This fact indicates that this particular subsystem of the model was unaffected by parking congestion

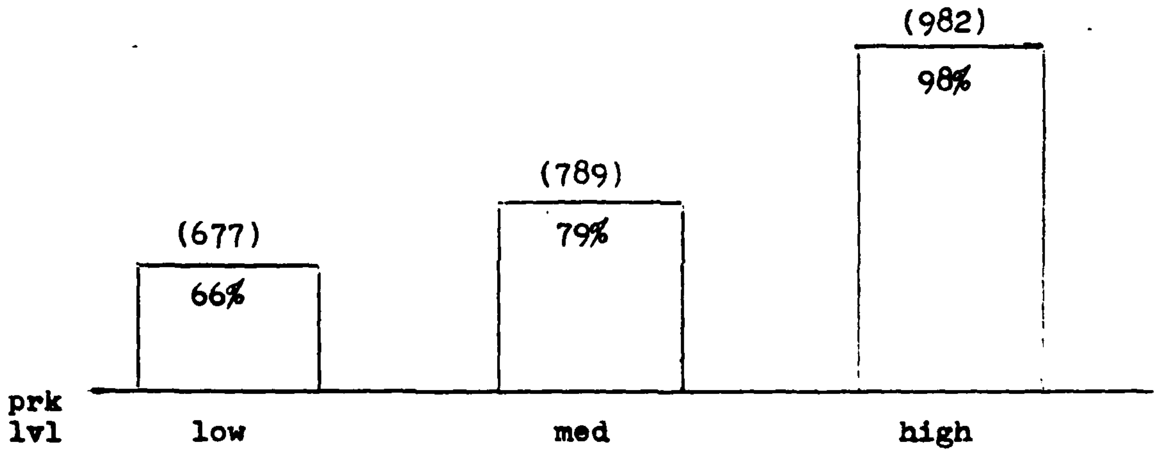
Displaced cargo exhibited its largest values over the parking constrained region. Displaced cargo reached a maximum at the P5-A15 levels. However, over the entire

(tonnage delivered)

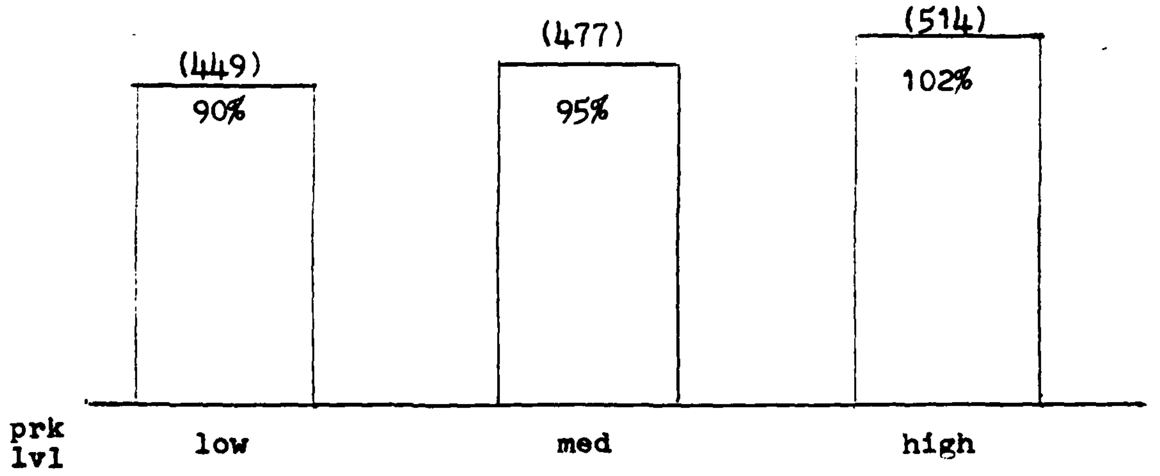
Fig. 4-2



Percentage Intended Cargo, 1500 tpd arrival rate



Percentage Intended Cargo, 1000 tpd arrival rate



Percentage Intended Cargo, 500 tpd arrival rate region, statistical tests were unable to discriminate between values over the region. But, since cargo displaced plus cargo delivered equals the potential cargo to an unconstrained system, displaced cargo measures the degree of congestion at the APOD. Since a decrease in displaced cargo increases cargo delivered, cargo displaced is a supplemental measure to cargo delivered.

Base Cases Region

Along the base case diagonal where parking and arrival levels were equal, the transhipment system shows its probabilistic nature. In all cases, actual amounts of cargo delivered were below the expected level. The difference between the observed mean and the expected value were significant at an alpha of less than .01. A surprising result for the low arrival rate is the small increase in cargo delivered as parking increases from the base case. Testing for that pair of means was unable to detect a statistically significant difference. This result differs from values over the A10 arrival rate. In that case, the differences in cargo delivered as parking increased from the base case, tested significant at the .01 level. No data was obtained for levels of parking greater than 1500 tons. Over all base cases, cargo throughput again failed to deviate from its designated 33 percent of cargo delivered.

Arrival Constrained Cases

For the third class of data where parking available exceeded the tonnage arrival rate, delivered cargo approached its expected levels. For cargo delivered at an A5 arrival rate, values slowly increased as the apparently constraining effects of the base level diminished. However, this apparent trend of values cannot be statistically distinguished. For the A10 arrival rate, parking at the high level was significantly different from the base case at the .01 level. Cargo displaced decreased by a factor of five from a mean value of 224 tons per day to 43 tons per day. As with all other regions of the APOD transhipment system, cargo throughput was maintained at the 33 percent level of cargo delivered.

Disproportionate System Response

The general response of the system agrees with the conceptualized model of the causal loop diagram (Fig 3-2). Holding the strategic arrival rate constant while increasing the amount of parking results in a greater amount of cargo delivered. A suprising result is the tonnage delivered for the P5-A15 data point. For a level of parking calculated to allow 500 tons per day, an average of 778 tons were delivered. T-tests at the .05 level showed the mean value of 778 tons per day statistically different than the expected level. Compared to the response in the adjacent cell, the P10-A15 point, this response remains disproportionate. The P10-A15 data point approximately yields its expected output of 1,000 tons. However, for the same arrival rate the 778 ton output is well above its expected value of 500 tons.

An explanation for this result may lie in the technique utilized for calculating parking required. Space assigned to each level of parking is shown in Table 4-2. Using a ratio of 2:1 for the relative size of each aircraft (see Chap 2), a single measure of total allotted parking is shown in Table 4-3.

After determining the percentage of the base case parking level assigned to each lower level, the percentage of base case cargo delivered for each level of parking is also calculated. The resulting points are also shown in Table 4-3. The figures show the apparent ability of a parking level that, calculated to allow one third the cargo of the highest level, actually allows over 50 percent as much cargo. Obviously, the 50 percent cargo diversion rate associated with this value is unacceptable, but it does illustrate the inherent ability of a system to operate at a much higher capacity than expected. Apparently, the deterministic technique for assigning parking levels allocates some unrecognized amount of potential capability.

Table 4-2. Parking Assigned by Aircraft Type

Arrival Rate	C-5	C-141	C-130
500	1	2	2
1000	1	3	3
1500	2	5	4

Table 4-3. Strategic Parking Expressed in C-141 Equivalents

Arrival Rate	500	1000	1500
Strat Parking	4	5	9
Parking (% tot)	44	55	100
Carg. Deliv. (%)	54	67	100

Marginal Value of Parking

As parking increases from the low to the high levels, parking is incremented by one C-141 from low to high. For the step from medium to high parking, C-141 parking increases by two parking places (from three to five) and C-5 parking steps up from one to two. The increases over each of these steps show the marginal value of parking for each type of aircraft. Data on the number of diversions by aircraft type is shown in Tables 4-4, 4-5 and 4-6. The data was tested by a one-way ANOVA and Duncan's test. Vertical lines on the table indicate a statistically insignificant difference between values. Differences between mean values are significant at the .05 level.

Regression of Data

In attempting to find causal factors for all data points, percentage of displaced cargo was plotted against percent utilization of strategic parking. Strategic and tactical utilization of parking is shown in Figure 4-3. Strategic parking utilization was calculated by giving equal weight to C-5 and C-141 parking utilization and finding an average value. The plot shows an increasing fraction of tonnage intended for the airfield being diverted as utilization approaches 100 percent. This plot is shown in Figure 4-4.

Table 4-4. Average Diversions by Aircraft, 1500 tpd

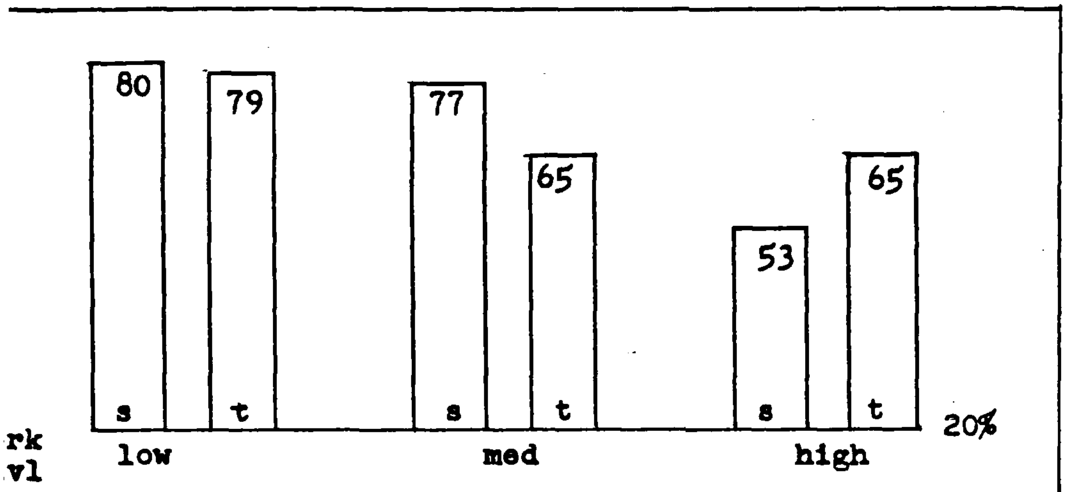
	Diverted Aircraft	
Parking Level	C-5	C-141
500 (1:2)	4.6 ⋮	23.8
1000 (1:3)	4.7 ⋮	14.1
1500 (2:5)	1.6	1.9

Table 4-5. Average Diversions by Aircraft, 1000 tpd

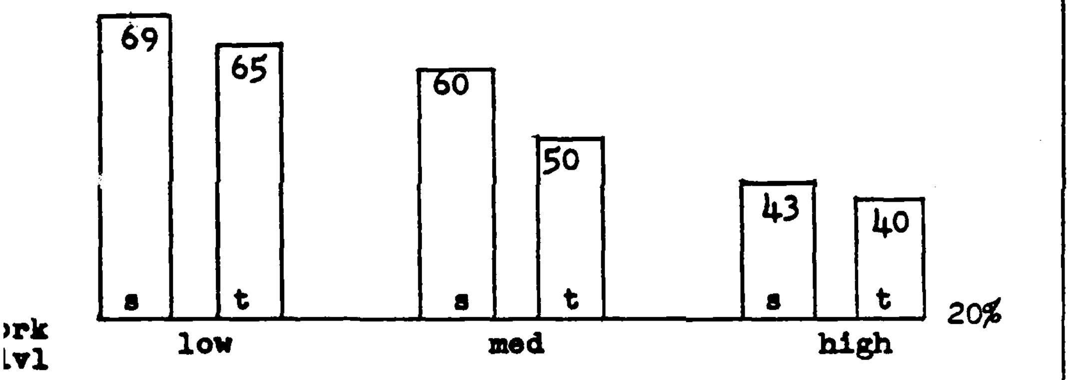
	Diverted Aircraft	
Parking Level	C-5	C-141
500 (1:2)	2.0 ⋮	9.6
1000 (1:3)	2.3 ⋮	3.4
1500 (2:5)	0.6	0.1

Table 4-6. Average Diversions by Aircraft, 500 tpd

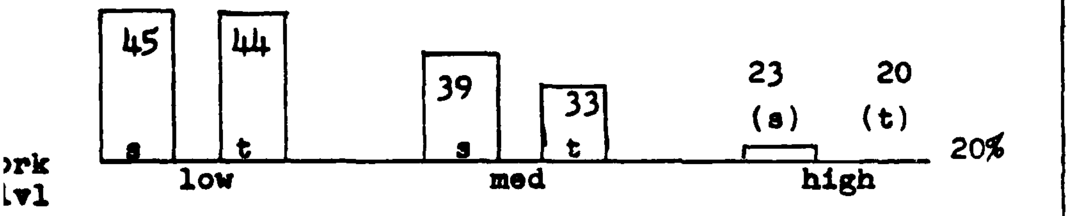
	Diverted Aircraft	
Parking Level	C-5	C-141
500 (1:2)	0.45 ⋮	1.10
1000 (1:3)	0.50 ⋮	0.10 ⋮
1500 (2:5)	0.00	0.00 ⋮



Park. Util., Strategic and Tactical Airlift, 1500 tpd



Park. Util., Strategic and Tactical Airlift, 1000 tpd



Park. Util., Strategic and Tactical Airlift, 500 tpd

Fig 4-3. Strategic and Tactical Parking Util.

AD-A155 778 DYNAMICS OF AIRFIELD PARKING CONGESTION DURING APOD 2/2
(AERIAL PORT OF DEBARKATION)(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. D L CUDA
UNCLASSIFIED MAR 85 AFIT/GST/OS/85M-3 F/G 1/5 NL

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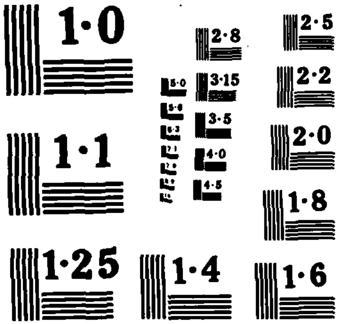


NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

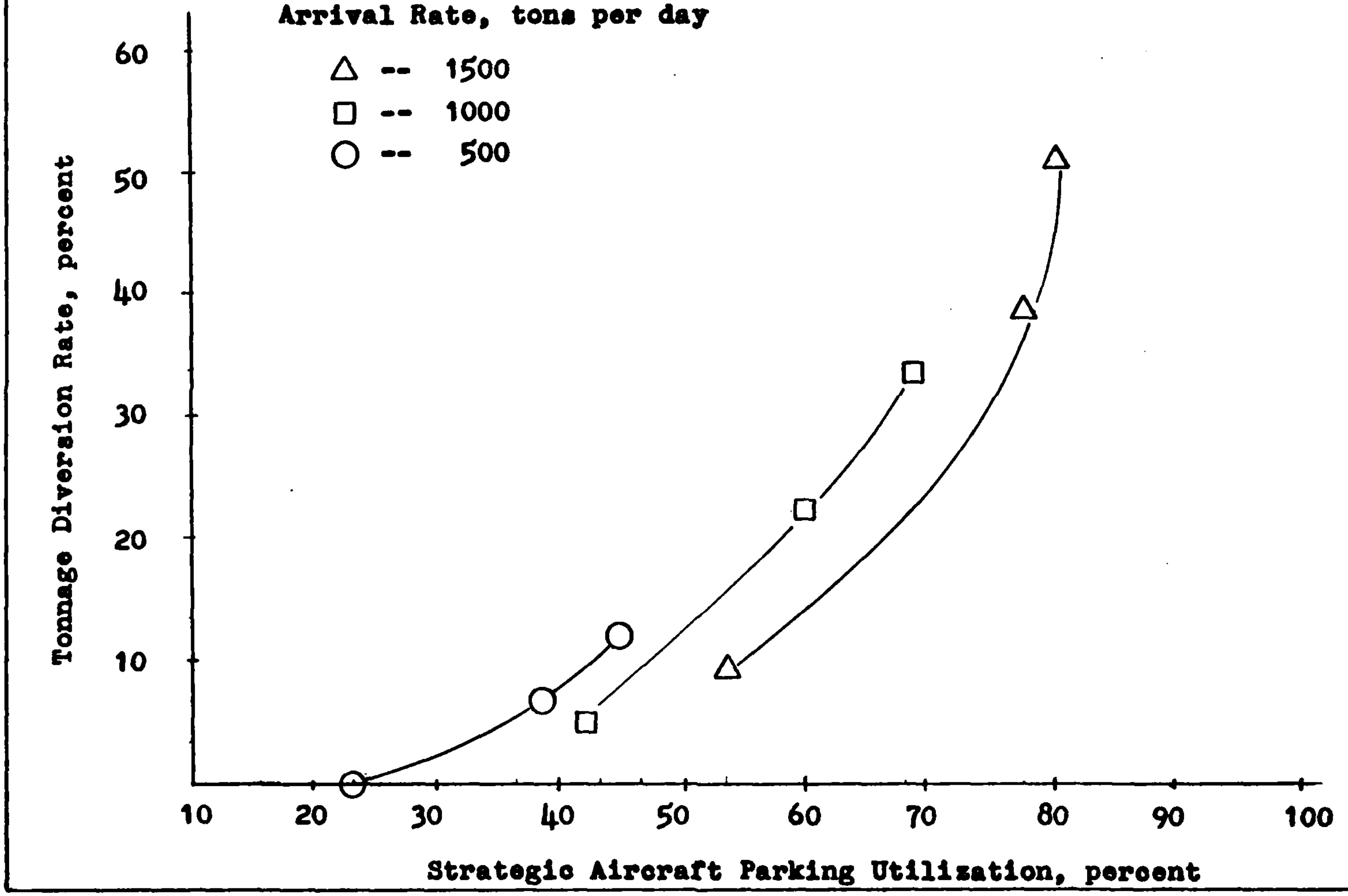


Fig 4-4. Tonnage Diversion Rate vs Parking Utilization

Statistical testing by two-way ANOVA over parking and arrival rates, followed by one-way ANOVA and Duncan's test over the arrival rates, showed statistically significant differences at the .05 level. Regression against the data plotted in Figure 4-4 confirmed the existence of a quadratic term in the data and yielded a regression fit (R^2) of 99 percent. The regression equation was calculated to be:

$$T = 1.48(U/100)^2 - .53(U/100) - .0001(A)$$

T = tonnage diversion rate in percent
U = strategic parking utilization in percent
A = tonnage arrival rate in tons

The significance of this finding is its impact on managing or planning APOD parking. The plots give guidance to planners and parking managers on setting levels of parking utilization that have lower probabilities of diversions. However, referring back to deterministically calculated parking levels, initially expected levels appear to have little relationship to experimentally derived results. Deterministic calculations for the three base cases are shown below in comparison to experimentally derived values:

Parking Level	Calc. Util.	Actual Util.
1500	.71	.53
1000	.85	.60
500	.55	.45

The variance in values is probably best explained by the number of diversions actually reducing the utilization of parking to the observed results. However, a constant correction factor of approximately 0.75 seems to yield the actual observed utilization and allows the use of experimental data to predict diversion rates.

Sensitivity Analysis

Sensitivity analysis was conducted on the three base case sets of parking and arrivals. Available parking was incremented in two steps, each by the equivalent of one C-5 aircraft. The area was designated as common parking to all aircraft. The queuing discipline directed each aircraft first to the parking area designated for its particular model. If parking in that area was unavailable and if parking was unavailable in the common area, the aircraft then entered a queue composed of all aircraft awaiting parking. For those aircraft, the queuing discipline was first-come-first-serve. If designated parking became available, an appropriate aircraft departed the common parking queue and entered designated parking. For example, assume both a C-130 and a C-5 are awaiting parking, and the C-5 had arrived in the queue first. If enough common parking became available to accomodate a C-5, then the C-5 would depart the queue and enter common parking. However, if during that time both aircraft were waiting and a designated C-130 parking spot became available, the C-130 would enter its designated parking leaving the C-5 in the queue. The C-5 stayed in the queue until appropriate parking became available, or the aircraft was forced to divert for lack of fuel. Results of these runs are shown in Table 4-7.

A two-way ANOVA was performed on the data followed by a one-way ANOVA and Duncan's test. For the first increment of the high and medium base cases, the increase in cargo delivered tested significant at the .05 level. However, the second increment of those cases, and all increments on the 500 ton case, had no statistical difference. Looking again at the number and composition of diverted aircraft, the marginal value of additional ramp space is apparent. This data is shown in Table 4-8.

A question arises over the sensitivity of parking utilization to decreases in ground time. Decreasing ground time by the commitment of material handling equipment and refueling resources is a possible strategy for decreasing congestion. A factorial analysis was accomplished using the 1000 ton base case. Ground times were cut by 50 percent on each category of aircraft to test the impact of reduced ground time on parking congestion. To determine the response of the system, three additional computer runs were made to obtain all combinations of high and low ground

Table 4-7. System Outputs for Two Increments of Common Parking

Arrival Level	Base Case	Step 1	Step 2
1500			
Cargo Delivered	1438.5	1587.5	1590.5
Cargo Thruput	468.0	495.0	501.0
Cargo Displaced	145.5	32.6	14.7
1000			
Cargo Delivered	788.5	971.0	1009.5
Cargo Thruput	260.0	313.2	324.0
Cargo Displaced	224.5	635.0	7.0
500			
Cargo Delivered	449.0	510.5	517.5
Cargo Thruput	148.2	164.4	165.0
Cargo Displaced	61.0	11.1	0.0

Table 4-8. Average Diversions by Aircraft for Common Parking

Parking/Arrival	Base Case	Step 1	Step 2
1500			
C-5	1.4	0.4	0.0
C-141	2.0	1.3	0.1
1000			
C-5	1.7	0.6	0.1
C-141	3.7	0.0	0.0
500			
C-5	0.4	0.1	0.0
C-141	1.0	0.0	0.0

times. Results were obtained and a two-way ANOVA performed. At first glance, the results were surprising. A change in ground time for tactical airlift had insignificant impact on cargo delivered or throughput. In contrast, reduction in C-141 and C-5 ground time had dramatic impact in increasing cargo delivered. The results are shown in Table 4-9 and Figure 4-5. After testing with one-way ANOVA and Duncan's Multiple Range Test, changes in strategic airlift ground times were shown significant at the .01 level.

The results suggest a feasible alternative to increased parking for airlift operations or a means of reducing congestion. A linear regression was accomplished to estimate the tradeoff beteen ground time and parking utilization. The regression yielded a correlation of .85 with the data and supplied the following equation for calculating the tradeoff:

Utilization = .3 (Avg Gnd Time)/(Std Gnd Time) + .28

Utilization refers to the combined fraction of assigned parking occupied by strategic airlift. Average ground time refers to the new average ground time achieved by a new policy or additional resources. Standard ground time refers to the current planning factors for ground time maintained by MAC (MACR 28-2).

The value of these results are to give the commander some feel for the relative tradeoffs between aircraft ground

Table 4-9. System Outputs for 50% Reduction in Aircraft Ground Time, 1000 tons per day

Strategic Ground Time	Tactical Ground Time High	Tactical Ground Time Low
High		
Cargo Delivered	788.5	789.0
Cargo Thruput	224.5	227.5
Cargo Displaced	260.0	244.0
Low		
Cargo Delivered	918.5	920.5
Cargo Thruput	307.2	313.8
Cargo Displaced	103.0	90.5

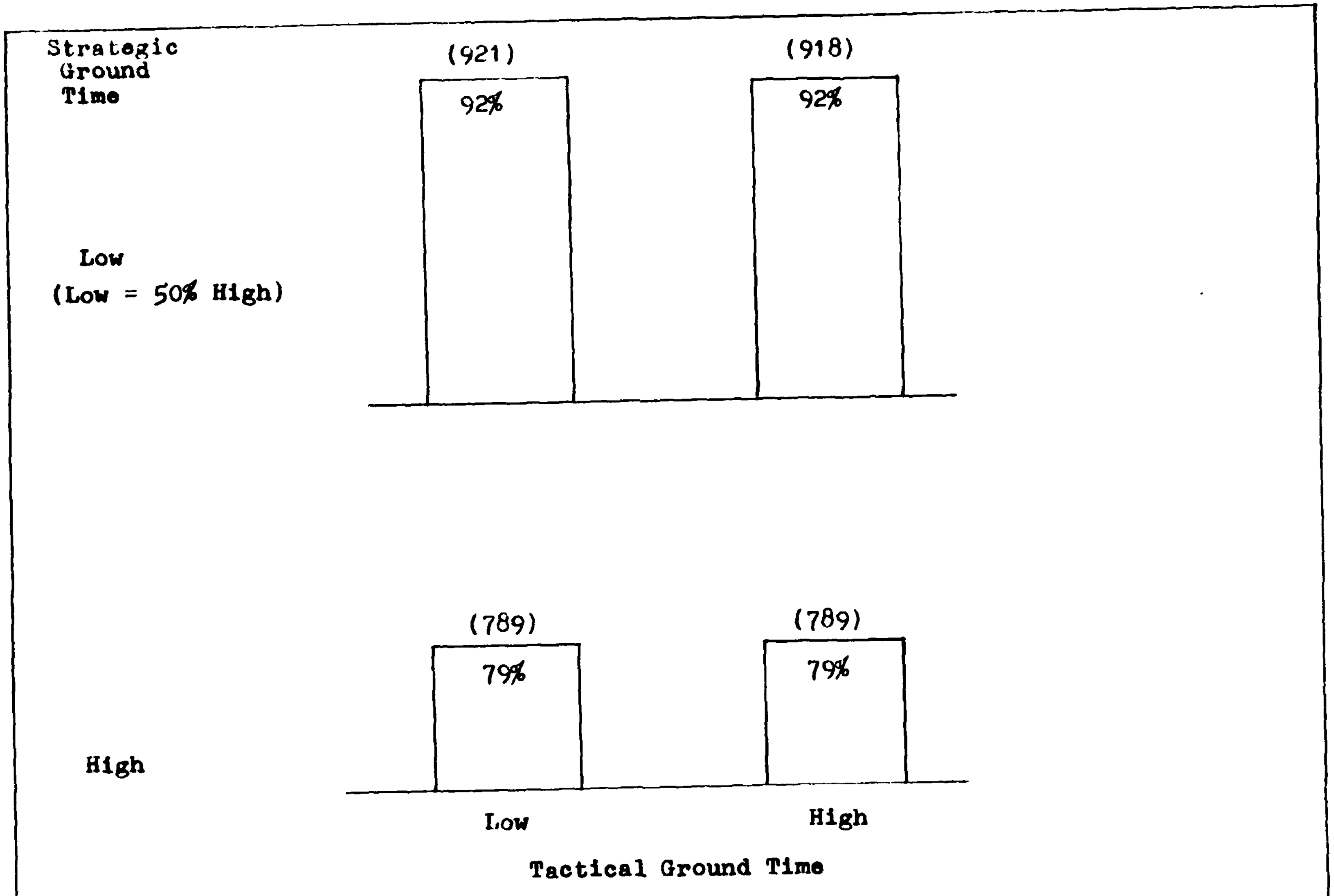


Fig 4-5 Comparison of System Outputs with Variation in Gnd. Time

time and parking congestion. For example, assume aircraft ground time is a function of material handling equipment, speed of refueling, and/or the capability of a mobile aerial port squadron. The value of these findings is to show that increasing the level of these resources, assuming they are the limiting factors to ground time, will decrease ground time, and in turn decrease the possibility of aircraft diversions.

In addition to no detectable change in tonnage throughput over any point of the data, C-130 operations were generally unaffected over all combinations of arrival rates and parking levels. However, some diversions of C-130s began to occur for the 1500 ton arrival rate as parking reached the 1000 ton level and reached a maximum at the 500 ton parking level. Additionally, some diversions occurred for the 1000 ton arrival rate when parking was set at the 500 ton level. Some measure of the apparent flexibility of the tactical airlift subsystem was shown when ground times were reduced by 50 percent (Fig 4-5). With no detectable changes in parking congestion, the tactical airlift subsystem maintained the 33 percent throughput fraction even though cargo delivered increased by nearly 20 percent.

The lack of change in cargo throughput with respect to tactical ground times continues the unaffected response shown by tactical airlift all through the experiment.

However, the lack of response in the factorial experiment can be easily explained in the context of the previous results. Throughout the experiment, tactical airlift was able to respond to any level of available cargo delivered by strategic airlift. Tactical airlift was unconstrained by any required level of effort. In the factorial experiment, a change in the response should only have been expected if tactical airlift was limited at the normal level of ground times. Apparently, tactical airlift effort was directly keyed and dependent on cargo delivered by strategic airlift, rather than on available tactical parking. When the tactical system's limiting factor was the amount of cargo available for movement, a reduction in tactical ground time had no effect on increasing cargo availablity, and thus no change in cargo throughput.

There was one other additional fact concerning C-130 operations that raises a question about the larger system. C-130 utilization of assigned parking was much higher than strategic airlift. Average C-130 utilization factors over all nine cases are shown in Table 4-10. Note the 79 percent utilization for the low/low combination. Compared to the number of diversions recorded for strategic airlift at similar utilization factors, diversions for tactical airlift were insignificant. The likely explanation is the decreasing deviation from scheduled arrival times as arrival

Table 4-10. C-130 Parking Utilization

Arrival Rate	Parking Level		
	500	1000	1500
1500			
Cargo Throughput	255.00	319.80	468.00
(% of Cargo Deliv.)	33.00	32.60	33.60
Avg Diverts	1.20	0.65	0.00
Parking Util (%)	0.79	0.65	0.65
1000			
Cargo Throughput	219.00	260.00	325.00
(% of Cargo Deliv.)	32.00	33.00	33.00
Avg Diverts	0.05	0.00	0.00
Parking Util (%)	0.65	0.50	0.40
500			
Cargo Throughput	148.20	155.40	172.80
(% of Cargo Deliv.)	33.00	32.80	32.50
Avg Diverts	0.00	0.00	0.00
Parking Util (%)	0.44	0.33	0.26

rates increased (Chap three). An additional factor might be the smaller probability of takeoff delays for C-130s over other aircraft.

To test one of these possibilities, sensitivity analysis was conducted for deviations of scheduled arrival times for strategic airlift. The expected results were to show decreased diversion rates as deviation from scheduled arrival time decreased. The results are shown in Figure 4-6. Unfortunately, the decrease in deviation was not statistically significant over the chosen increments. However, the values do show a slow decrease with decreasing deviation that indicate at least a small amount of cause-effect relationship.

Summary

Results showed up to 50 percent diversion of cargo when arrival rates exceeded parking available. Cargo delivered for the three base cases deviated significantly from expected rates. Deterministic calculations appear to overstate the capacity of parking to absorb a typical airlift arrival pattern. A significant relationship was found between parking utilization for strategic airlift and percentage of cargo diverted. As utilization decreased, diversions also decreased significantly. Additionally, a tradeoff was found between the average ground time and parking utilization.

Title: Throughput

Source of Variation	Sum of Squares	DF	Mean SQ	Fo
Parking	204917	2	102458	300
Arv Rate	538945	2	269472	788
Interact	94221	4	23555	69
Error	27688	81	341	
Total	865771	89		

CELL MEANS

	Low	Med	High
High	255.0	319.8	468.0
sd	20.6	21.5	25.1
Med	219.0	259.2	325.2
sd	14.8	16.2	13.5
Low	148.2	155.4	172.8
sd	10.6	8.7	26.5

Duncan's Multiple Range Test over Parking Intervals

Arv Rate	GAP [Level a - Level b] (H-L)	(H-M)	(M-L)
High	213.0	148.2	64.8
High	106.2	66.0	40.2
High	24.6	17.4	7.2
LSD.05	17.3	16.4	16.4
LSD.01	22.6	21.7	21.7

Test Standard Error: 5.8466

Title: Cargo Delivered

Source of Variation	Sum of Squares	DF	Mean SQ	Fo
Parking	1842996	2	921498	316
Arv Rate	5129352	2	2564676	880
Interact	960768	4	240192	82
Error	235932	81	2912	
Total	8169048	89		

CELL MEANS

	Low	Med	High
High	778.0	970.5	1438.5
sd	68.3	53.3	76.2
Med	677.0	788.5	981.5
sd	55.1	58.5	63.7
Low	449.0	476.5	514.0
sd	26.0	20.6	35.9

Duncan's Multiple Range Test over Parking Intervals

Arv Rate	GAP [Level a - Level b]		
	(H-L)	(H-M)	(M-L)
High	660.5	468.0	192.5
High	304.5	193.0	111.5
High	65.0	37.5	27.5
LSD.05	50.5	48.0	48.0
LSD.01	66.0	63.5	63.5

Test Standard Error: 17.067

Title: Cargo Delivered, percentage of total

Source of Variation	Sum of Squares	DF	Mean SQ	Fo
Parking	1.3207	2	0.6603	229.3
Arv Rate	0.9550	2	0.4751	165.5
Interact	0.2647	4	0.0661	22.9
Error	0.2338	81	0.0028	
Total	2.7744	89		

CELL MEANS

	Low	Med	High
High	.5187	.6470	.9590
sd	.0455	.0355	.0508
Med	.6770	.7850	.9815
sd	.0550	.0586	.0637
Low	.8980	.9530	1.0280
sd	.0520	.0411	.0717

Duncan's Multiple Range Test over Parking Intervals

	GAP [Level a - Level b]		
Arv Rate	(H-L)	(H-M)	(M-L)
High	.4403	.3120	.1283
High	.3045	.1930	.1115
High	.1300	.0750	.0550
LSD.05	.0503	.0477	.0477
LSD.01	.0658	.0632	.0632

Test Standard Error: .0170

Using the mean squared error estimate of the ANOVA testing, the minimum gap between values is calculated and compared to the actual values. Although values at extreme ranges may prove significant during portions of the test, all intervening values must all test as significant in order to report a statistical difference.

Brief Testing Description

ANOVA is the partitioning of total variation within experimental observations between error and treatment. The computation and allocation of variation allows testing of the hypothisis that at least one treatment mean is statistically different from the set of all treatment means. The test is accomplished by constructing Chi-square distributions for the pooled treatment means and for the variations due to error. The degrees of freedom computed in the ANOVA table supports the construction of the Chi-square distribution. The variation of each distibution is compared by the calculation of the Fo statistic. Fo is used in the F-Test, which is a procedure to compare the equality of variance for two distributions. In the ANOVA table, if the computed Fo statistic is greater than the appropriate value of the F-distribution for similar degrees of freedom, then there is statistical evidence that at least one mean of the pooled values is statistically significant.

Following the one-way ANOVA testing, Duncan's Multiple Range Test was applied to determine the minimum statistically significant difference between means. The means are rank ordered and the differences calculated.

Appendix I. Statistical Testing

assumption of a constant throughput fraction for delivered cargo is an extreme simplification.

Recommended Embellishments in Future Studies

Before going forward with this study's conceptual model of APOD operations, the beliefs of this study require validation and verification. Use of historical data from the frequent world-wide exercises of the Military Airlift Command require analysis to validate the studys assumption of arrival rates and deviations from schedule.

Recommended enhancements to the model are the addition of two to three additional APODs to quantify the parking dynamics of a more complex system. A numerically more complex model can study the effect of displaced cargo and model the unexpected arrivals into an APOD system. Secondly, the "warehouse" assumption of this model requires additional study. The addition of a function in the model that explicitly sorts, prepares, and dispatches troops and cargo as they become available for air movement, could have large payoffs. Finally, the effects of weather could be easily included into the model.

controlling elements must be proportional to the variability of the system. For example, to allow an ALCE to manage its parking, when the arrival interval of aircraft is measured in hours, real time information is required on the location of inbound aircraft. To allow an arrival to surprise the ALCE is to risk a set of circumstances, such as a lack of parking, that the ALCE can not overcome in the time before an aircraft must divert. In essence, it is a statement of the requirement for information by the controlling agencies of highly stochastic systems.

Study Limitation and Caveats

In a strict sense, this study is applicable only to contingencies where deployment is through a single airfield. This study's assumptions of displaced cargo being lost to the theater is inapplicable to a network of theater APODs. The thrust of this study was to gain simplistic insights into the dynamics of parking congestion in and of itself. Any insights to improved theater management of parking are worthwhile by-products that must be tempered by the spare details of the modeled system when compared to reality.

A second caveat to the use of this study was the unconstrained use of tactical airlift. The methodology of computing available parking and the assumption of a beddown location near the APOD can minimize perceptions of the difficulties involved in theater airlift. Additionally, the more cargo than a stochastic system. The likely reason is the high utilization rate of parking. In the deterministic system, a given parking space can be allocated to a given arrival. That arrival appears in the system when parking is vacated, occupies parking for a specific period, and then departs. This invariant behavior allows flawless scheduling for all arrivals and achieves maximum output.

In contrast, if the stochastic system attempts to operate by the same procedure, aircraft will be forced to divert whem cumulative events have delayed the availability of parking beyond the aircraft's holding time. To avoid any diversions or delays, the stochastic system must schedule parking availability for the beginning of the expected arrival interval. As the interval increases (recalling the 3.5 hour interval of strategic airlift), parking utilization will decrease. Alternately, for a given arrival rate and arrival interval, the required parking must increase to maintain a given utilization with no delays.

For a contingency planner, knowledge on the dynamics of a stochastic system is necessary to allow confidence in attaining a given system output. Making calculations based on the expected values, such as interarrival times, is appropriate when techniques and resources are available to the system managers that give control over the random elements of the system. However, the span of control for the airlift and the smaller variation from scheduled arrival time. Lower delay rates minimize the unexpected requirement for parking. As the delay rate decreases, the system moves one step closer to the zero diversion rate of a deterministic system.

With respect to arrival variability, sensitivity analysis reported in Chapter four showed it is not the complete explanation of aircraft diversions. However, some thought on the dynamics of the system gives evidence for arrival deviations as a causal factor. As an example, compare the expected arrival intervals for the two aircraft. For strategic aircraft, the standard deviation from scheduled arrival time remained constant at one hour for the base case data. Given a normal distribution centered on the scheduled arrival time and using a similar methodology to the construction of a probability confidence interval, the length of time over which the airfield could expect a given strategic arrival with 95 percent confidence was approximately 3.25 hours. For a given C-130 arrival, the interval varied, but it equaled 0.5 hours at its longest.

If the system's dynamics can be seen on a scale ranging from deterministic arrivals through increasing amounts of scheduled deviations, some measure of a cause and effect relationship can be shown. For a given parking level and arrival rate, a deterministic system can be expected to give point of the model can be described by the equation:

Utilization = .3 (Avg Gnd Time)/(Std Gnd Time) + .28

Standard ground time refers to planning factors published by Military Airlift Command.

There is a strong relationship between strategic airlift parking utilization and percentage of cargo diverted. The plot shown as Figure 4-4 shows increasing percentage of diversions as parking utilization increases. A linear regression of data points on the line yields the three equations reported in Chapter four.

There is evidence from this study of a relationship between deviations from scheduled arrivals and the threshold parking utilization where aircraft diversions begin. Evidence for this hypothesis comes from the widely varying diversion rates of both systems for equal utilization levels. For example, C-130 diversions did not begin to appear until parking utilization reached 65 percent for the case of parking at a low level and a high arrival rate. For this level of utilization, the arrival diversion rate was less than 2 percent. The small diversion rate failed to be reflected in throughput averages because the model's tactical airlift scheduling feature rescheduled the diverted mission.

The best explanation for the higher utilization levels rests on the lower maintenance delay rate for tactical

For the pattern and rates of arrival, data was obtained for the marginal value of parking over the three arrival rates. For the addition of one parking space, the percentage of diversions decreased most significantly at the highest arrival rates. Additionally, it was found deterministic calculations understate the delivery capacities of parking for some cases.

Tactical airlift operations were unaffected over all combinations of arrival and parking. Cargo throughput remained a constant fraction of cargo delivered throughout the experimental region. However, the explanation probably lies in the methodology of allocating parking to tactical airlift rather than to systemic capabilities. That methodololgy based tactical parking on the assumption of 100 percent delivery of intended cargo by strategic airlift. As was seen over eight out of nine data points, a significant amount of tonnage was actually diverted from APOD arrival. Given this fact, the actual requirement for throughput was less than expected for seven out of eight cases.

Another finding was that parking congestion appears highly sensitive to changes in ground time. Factorial experiments on one combination of parking and arrivals showed large changes in cargo delivered and parking utilization. For strategic airlift, the relationship between ground time and parking utilization for one

V. Observations and Conclusions

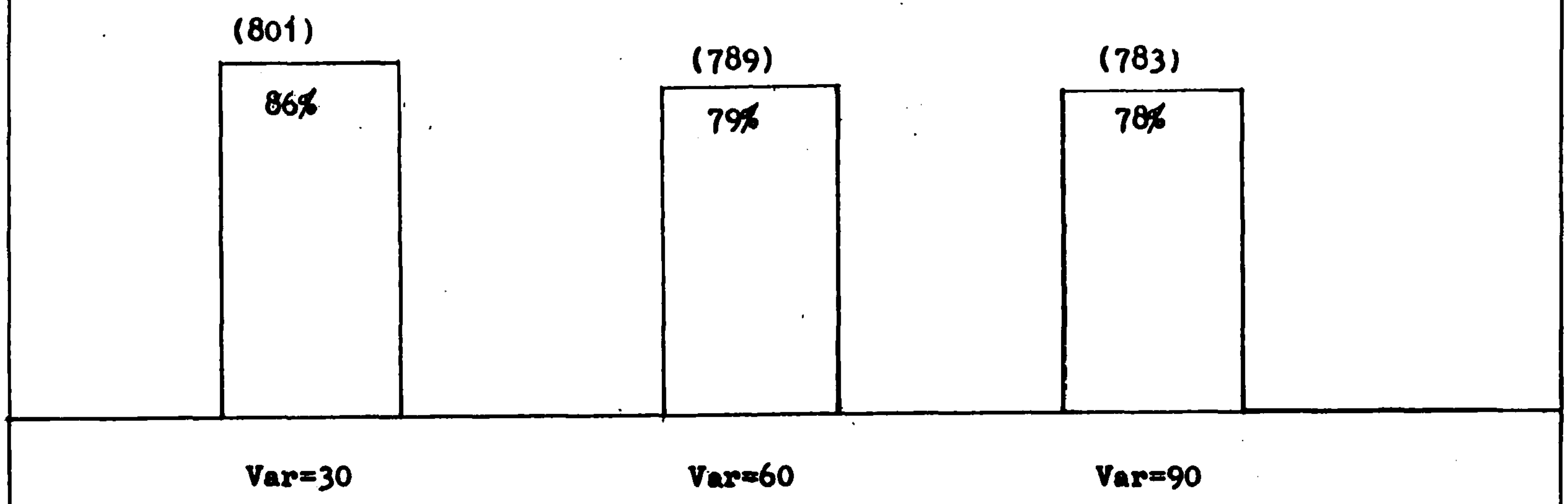
Experimental Summary

This study examined congestion in airlift operations at a single APOD during deployment and transhipment of forces. Daily tonnage rates were set at 500, 1000, and 1500 tons per day. Although tonnage rates were set at feasible levels for strategic airlift, the amount of strategic and tactical aircraft were unconstrained. Transhipment rates by air were maintained at a constant 33 percent throughout the problem. Parking levels were calculated deterministically using standard ground times for loading and offloading. Parking was assigned to each aircraft type on the basis of expected number of arrivals and the respective ground time.

Observations

Study of all nine combinations of parking and arrival rates showed the percentage of cargo diversion increases as arrival rate exceeds available parking. Also, the study showed significant amounts of diverted cargo for parking levels believed sufficient to accommodate the arrivals.

Strategic airlift operations suffered the most from constrained parking levels. Of cargo intended for the APOD, percentage of cargo diversions climbed as high as 50 percent.



Sensitivity Analysis for Variance in Strategic Arrival Times
Fig 4-6

Title: Common Parking Sensitivity Analysis

Source of Variation	Sum of Squares	DF	Mean SQ	Fo
Parking	356440	2	178220	35.3
Arv Rate	162277880	2	8138940	1612.1
Interact	67624	4	16906	3.4
Error	408952	81	5049	
Total	17110896	89		

CELL MEANS

	Low	Med	High
High	1438.5	1567.0	1576.0
sd	76.2	121.3	102.4
Med	788.5	971.0	1009.5
sd	58.5	57.6	58.8
Low	449.0	504.5	517.5
sd	26.0	46.3	38.2

Duncan's Multiple Range Test over Parking Intervals

	GAP [Level a - Level b]		
Arv Rate	(H-L)	(H-M)	(M-L)
High	138.0	9.5	128.5
Med	221.0	38.5	182.5
Low	68.5	13.0	55.5
LSD.05	66.5	63.1	63.1
LSD.01	87.0	83.6	83.6

Test Standard Error: 22.470

```
      Title:    C-141 Diversions at 1500 tons per day

Source of        Sum of
Variation        Squares        DF          Mean Sq     Fo

Diversion        2387.5          2           1119.7    446.0

Error              72.2         27              2.7

Tot              2459.7          29


                 Duncan's Multiple Range Test

                 LVL         Mean       Std Dev

                1500        23.65        4.39

                1000        14.05        3.25

                 500         1.85        0.39

     Significance Level:       .05
     Standard  Error   :       .01

     Significant Deviations

                   500        1000       1500
                   ---        ---        ----
```

Title: C-5 Diversions at 1500 tons per day

Source of Variation	Sum of Squares	DF	Mean Sq	Fo
Diversion	64.12	2	32.05	12.88
Error	67.23	27	2.49	
Tot	131.34	29		

Duncan's Multiple Range Test

LVL	Mean	Std Dev
1500	4.60	3.43
1000	4.70	2.23
500	1.55	1.80

Significance Level: .05
Standard Error : .50

Significant Deviations

```
500     1000     1500
---     ----     ----
```

Title: C-141 Diversions at 1000 tons per day

Source of Variation	Sum of Squares	DF	Mean Sq	Fo
Diversion	470.52	2	235.26	139.1
Error	45.65	27	1.69	
Tot	516.17	29		

Duncan's Multiple Range Test

LVL	Mean	Std Dev
1500	0.5	.025
1000	3.4	1.558
500	9.6	3.488

Significance Level: .05
Standard Error : .95

Significant Deviations

500	1000	1500
----	----	----

Title: C-5 diversions at 1000 tons per day

Source of Variation	Sum of Squares	DF	Mean Sq	Fo
Diversion	15.8	2	7.91	6.47
Error	33.0	27	1.22	
Tot	48.9	29		

Duncan's Multiple Range Test

LVL	Mean	Std Dev
1500	.60	.38
1000	2.25	1.74
500	2.00	1.55

Significance Level: .05
Standard Error : .27

Significant Deviations

500	1000	1500
---	----	----

Title: C-141 Diversions at 500 Tons Per Day

Source of Variation	Sum of Squares	DF	Mean Sq	Fo
Diversion	7.05	2	3.51	48.5
Error	1.95	27	0.07	
Tot	8.97	29		

Duncan's Multiple Range Test

LVL	Mean	Std Dev
1500	0.0	0.00
1000	0.1	0.03
500	1.05	0.19

Significance Level: .05

Significant Deviations

500	1000	1500
---	----	----

Title: C-5 Diversions at 500 ton per day

Source of Variation	Sum of Squares	DF	Mean Sq	Fo
Diversion	1.51	2	.0758	6.35
Error	3.23	27	.1190	
Tot	4.74	29		

Duncan's Multiple Range Test

LVL	Mean	Std Dev
1500	0.0	0.0
1000	0.50	0.22
500	0.45	0.14

Significance Level: .05
Standard Error : .11

Significant Deviations

```
500    1000    1500
---    ----    ----
```

Appendix II. SLAM Code and Variable Listing

Variable Listing

xx(1) --- Tonnage Delivered by Stategic Flow
xx(2) --- Tonnage throughput
xx(3) --- Total Displaced Cargo
xx(5) --- Air Cargo Available for Tactical Movement
xx(9) --- assigned cargo
xx(10) --- unassigned cargo
xx(11) --- throughput fraction
xx(15) --- total number of delayed aircraft
xx(16) --- accumulated delay time for all aircraft
xx(20) --- current time plus departure delay length
xx(30) --- C-130 Number in System
xx(31) --- C-130 Number in Parking
xx(32) --- C-130 Number in Common Parking
xx(35) --- C-130's scheduled to arrive at any time
xx(37) --- C-130 Total Delayed
xx(38) --- C-130 Diverts
xx(40) --- C-141 Number in System
xx(41) --- C-141 Number in Parking
xx(42) --- C-141 Number in Common Parking
xx(47) --- C-141 Total Delayed
xx(48) --- C-141 Diverts
xx(50) --- C-5 Number in System
xx(51) --- C-5 Number in Parking
xx(52) --- C-5 Number in Common Parking
xx(57) --- C-5 Total Delayed
xx(58) --- C-5 Diverts
xx(80) --- Intermediate Variable
xx(81) --- Intermediate Gate Variable
xx(90) --- Fraction of Strategic cargo requiring air movement

ATTRIBUTES

1 --- Cargo Capacity in Tons
2 --- Aircraft Type (1=C5/WB; 2=C141/NB; 3=C130)
3 --- Creation Time
4 --- Amount of Type Parking/Aircraft
5 --- Amount of Common Parking Utilized
6 --- Common Parking Flag
7 --- Runway time required
8 --- Airborne/ON ground flag
9 --- Maintenance delay time

RANDOM NUMBER STREAMS

1 - C-5 unloading time
2 - C-141 unloading time
3 - C-130 uploading time
4 - Strategic Airlift Mix
5 - Unused
6 - length of mx delay
7 - Strategic interarrival time
8 - Sortie time for C-130's
9 - Maintenance Delay (y or n)
10 - C-5 arrival probability

FILES

1 - C5 Gate
2 - C141 Gate
3 - C130 Gate
4 - C5 Await Wide Body Parking Resource
5 - C141 Await Narrow Body Parking Resource
6 - C130 Await Tactical Airlift Parking Resource
7 - All Aircraft Type Await Common Parking Resource
8 - Scheduled Tactical Airlift Arrivals

SIGNIFICANT ACTIVITES

General Key

1. "30" type activities relate to C130
2. "40" type activities relate to C141
3. "50" type activities relate to C5
4. "60" type activities relate to maint. delays
5. "70" type activities relate to common parking

Unlisted activities generally perform only entity counts and perform no significant function.

1 - Contains strategic airlift inbound to APOD
31 - Assigns C130 arrival time
35 - C130 uploading activity
37 - C130 aircraft with one sortie per day
38 - C130 aircraft with two sorties per day
45 - C141 offloading activity
55 - C5 offloading activity
61 - Contains aircraft delayed by maintenance problems
70 - Returns C5 to main program
71 - Returns C141 to main program
72 - Returns C130 to main program

```
gen,XXXXX, APOD Trans Sys, 01/15/85,1,,n,,,,72;
limits,10,10,600;
timst,xx(50),C5   in System;
timst,xx(40),C141 in System;
timst,xx(30),C130 in System;
timst,xx(51),Total   C5 Prkd;
timst,xx(41),Total C141 Prkd;
timst,xx(31),Total C130 Prkd;
timst,xx(52),C5   in Allpark;
timst,xx(42),C141 in Allpark;
timst,xx(32),C130 in Allpark;
timst,xx(35),Sched C130s;
timst,xx(5),Air Cargo Avail;
priority/1,lvf(3);
priority/2,lvf(3);
priority/3,lvf(3);
priority/9,lvf(8);
intlc,xx(5)=130;
intlc,xx(11)=.33;
network;
        resource/jumprk(2),4;
        resource/starprk(5),5;
        resource/tacprk(7),6;
        resource/allprk(16),7;
        resource/taclift(250),10;
        gate/jumgte,close,1;
        gate/stargte,close,2;
        gate/tacgte,close,3;


;-----Create Strategic Airlift-------------
;          This subsection accomplished three purposes;
;               1. Creates entities at uniform intervals
;               2. Established an arrival time based on
;                  deviations from a scheduled uniform
;                  interarrival time.
;               3. Determined what kind of aircraft arrives at
;                  the airfield.
;-------------------------------------------------------------
        create,26;
        act;
tbc     assign,atrib(3)=rnorm(234,60,7),1;
        act,,atrib(3) .lt. 0,tbc;
        act/1,atrib(3);
        colct,between,strat intarvl;
        act;
        assign,atrib(3)=unfrm(0,1,4);
        act;
star    goon,1;
```

```
       act/50,,atrib(3) .le. .16,jupk;
       act/40,,atrib(3) .gt. .16,sprk;
;C5 Start--------------------------------------------------------
; Assigns attributes to an entity to define it as a C5
jupk   assign,atrib(1)=70;
jupl   assign,atrib(2)=1;
       assign,atrib(3)=tnow;
       assign,atrib(4)=1;
       assign,atrib(5)=8;
       assign,atrib(6)=0;
       assign,atrib(7)=4;
       assign,xx(50)=xx(50)+1;
       act;
       colct,between,C5 intarv;
       act;
cuel   assign,xx(91)=1,1;
       act,,nnrsc(jumprk) .ge. atrib(4),prkl;
       act,,nnrsc(allprk) .ge. atrib(5),prk4;
       act;
jgte   await(1),jumgte;
       act;
       assign,xx(91)=0;
       act;
       close,jumgte,1;
       act,,xx(91) .eq. 0,cuel;
       act,,xx(91) .eq. 1,jgte;

prkl   assign,xx(80)=tnow-atrib(3),1;
       act,,xx(80) .gt. 45,disp;
       act;
       await(4),jumprk/atrib(4);
       act;
jnld   assign,xx(51)=xx(51)+1;
       act;
       colct,intvl(3),C5 time to prk,6,0,15;
       act,,,rway;
;---------------------------------------------C5 Landing
jarp   goon,1;
       act,,atrib(1) .eq. 71,intl;
       act/55,unfrm(150,195,1);
carl   assign,xx(90)=xx(11)*atrib(1);
       assign,xx(1)=xx(1)+atrib(1);
       assign,xx(5)=xx(5)+xx(90),2;
       act,,,tacst;
       act,,,brk;
; ----------------------Branch to tacst creates C130 mission
brk    goon,1;
       act,,unfrm(0,1,9) .lt. .15,mx;
       act,,,depl;
```

```
depl   goon,1;
  act,,atrib(6) .eq. 1,aprl;
  act;
  free,jumprk/atrib(4);
  act;
  open,jumgte;
  act,,,rway;
;-----------------------------C5 takeoff
jdep   assign,xx(51)=xx(51)-1;
       act;
       assign,xx(50)=xx(50)-1;
       act/59;
       colct,intvl(3),C5 Sys Time,6,60,60;
       term;

;-C141 START-------------------------
; This section parallels the C5 subsection by defining an
; entity as a C141 by assigning attributes
;-------------------------------------------------------
sprk   assign,atrib(1)=20;
sprl   assign,atrib(2)=2;
       assign,atrib(3)=tnow;
       assign,atrib(4)=1;
       assign,atrib(5)=4;
       assign,atrib(6)=0;
       assign,atrib(7)=2;
       assign,xx(40)=xx(40)+1;
       act;
       colct,between,C141 intarv;
       act;
cue2   assign,xx(91)=1,1;
       act,,nnrsc(starprk) .ge. atrib(4),prk2;
       act,,nnrsc(allprk) .ge. atrib(5),prk4;
       act;
sgte   await(2),stargte;
       act;
       assign,xx(91)=0;
       act;
       close,stargte,1;
       act,,xx(91) .eq. 0,cue2;
       act,,xx(91) .eq. 1,sgte;
;-------------------------------------------------
prk2   assign,xx(80)=tnow-atrib(3),1;
       act,,xx(80) .gt. 45,disp;
       act;
       await(5),starprk/atrib(4);
       act;
```

```
unld    assign,xx(41)=xx(41)+1;
        act;
        colct,intvl(3),C141 time to prk,6,0,15;
        act,,,rway;
;------------------------------------C141 Landing
sarp    goon,1;
        act,,atrib(1) .eq. 71,int2;
        act/45,unfrm(90,135,2);
car2    assign,xx(90)=xx(11)*atrib(1);
        assign,xx(1)=xx(1)+atrib(1);
        assign,xx(5)=xx(5)+xx(90),2;
        act,,,tacst;
        act;
; --------------------Branch to tacst creates C130 mission
        goon,1;
        act,,unfrm(0,1,9) .lt. .10,mx;
        act,,,dep2;
dep2    goon,1;
        act,,atrib(6) .eq. 1,apr2;
        act;
        free,starprk/atrib(4);
        act;
        open,stargte;
        act,,,rway;
sdep    assign,xx(41)=xx(41)-1;
        act;
        assign,xx(40)=xx(40)-1;
        act/49;
        colct,intvl(3),C141 Sys Time,6,0,60;
die     term;


;C130 START________________________________________

tacst   assign,atrib(1)=12;
        act/30;
        assign,atrib(2)=3;
        assign,atrib(4)=1;
        assign,atrib(5)=2;
        assign,atrib(6)=0;
        assign,atrib(7)=2;
        assign,atrib(8)=0;
        act;
C130    assign,xx(10)=xx(5)-xx(9),1;
        act,,xx(10) .gt. 12,gn;
        term;
gn      assign,xx(9)=xx(9)+atrib(1),2;
        act,,,arrv;
        act,,,C130;
```

```
arrv    assign,atrib(3)=rnorm(17,3,5),1;
        act,,atrib(3) .lt. 0,arrv;
        act;
        queue(8);
        act(1)/31,atrib(3);
        await(10),taclift/1;
        act;
        assign,atrib(3)=tnow;
        act;
        assign,xx(30)=xx(30)+1;
        act;
tprk    assign,xx(91)=1,1;
        act,,nnrsc(tacprk) .ge. atrib(4),prk3;
        act,,nnrsc(allprk) .ge. atrib(5),prk4;
        act;
tgte    await(3),tacgte;
        act;
        assign,xx(91)=0;
        act;
        close,tacgte,1;
        act,,xx(91) .eq. 0,tprk;
        act,,xx(91) .eq. 1,tgte;
;--------------------------------------------------------
prk3    assign,xx(80)=tnow-atrib(3),1;
        act,,xx(80) .gt. 45,disp;
        act;
        await(6),tacprk/atrib(4);
        act;
        colct,intvl(3),C130 Time to Prk,5,0,15;
        act;
upld    assign,xx(31)=xx(31)+1;
        act/34,,,rway;
;-----------------------------------------Landing
tarp    goon,1;
        act/35,unfrm(75,120,3);
        goon,1;
        act,,unfrm(0,1,9) .lt. .05,mx;
        act,,,lv;
lv      assign,xx(9)=xx(9)-atrib(1);
        act;
        assign,xx(5)=xx(5)-atrib(1),1;
        act,,atrib(6) .eq. 1,apr3;
        act;
fpkt    free,tacprk/atrib(4);
        act;
        open,tacgte;
        act,,,rway;
```

```
;-------------------------takeoff ---

tot2    assign,xx(30)=xx(30)-1;
        act;
        colct,intvl(3),C130 Sys Time,4,0,60;
        act;
        assign,xx(31)=xx(31)-1;
        assign,xx(2)=xx(2)+atrib(1);
        act;
nxt     goon,1;
        act/37,1440,unfrm(0,1,8) .le. .5,nx2;
        act/38,720,,nx2;
nx2     free,taclift/1;
        act/39;
        term;


;---------------------------------------------------
;Common Parking
prk4    assign,xx(80)=tnow-atrib(3),1;
        act,,xx(80) .gt. 45,dis1;
        act;
        await(7),allprk/atrib(5);
        assign,atrib(6)=1,1;
        act,,atrib(2) .eq. 1,cpju;
        act,,atrib(2) .eq. 2,cpst;
        act,,atrib(2) .eq. 3,cptc;
cpju    assign,xx(52)=xx(52)+1;
        act,,,cplv;
cpst    assign,xx(42)=xx(42)+1;
        act,,,cplv;
cptc    assign,xx(32)=xx(32)+1;
        act,,,cplv;

cplv    goon,1;
        act/70,,atrib(2) .eq. 1,jnld;
        act/71,,atrib(2) .eq. 2,snld;
        act/72,,atrib(2) .eq. 3,upld;

apr1    free,allprk/atrib(5);
        event,1;
        act;
        assign,xx(52)=xx(52)-1;
        act,,,rway;
```

```
apr2    free,allprk/atrib(5);
        event,1;
        act;
        assign,xx(42)=xx(42)-1;
        act,,,rway;
        term;

apr3    free,allprk/atrib(5);
        event,1;
        act;
        assign,xx(32)=xx(32)-1;
        act,,,tot2;
;---------------------------------------------------------
;Runway
rway    queue(9);
        act(1)/20,atrib(7);
        goon,1;
        act,,atrib(8) .eq. 0,in;
        act,,atrib(8) .eq. 1,out;
in      assign,atrib(8)=1,1;
        act,,atrib(2) .eq. 1,jarp;
        act,,atrib(2) .eq. 2,sarp;
        act,,atrib(2) .eq. 3,tarp;
out     goon,1;
        act,,atrib(2) .eq. 1,jdep;
        act,,atrib(2) .eq. 2,sdep;
        act,,atrib(2) .eq. 3,tot2;
;---------------------------------------------------------------
;Displaced Cargo
disp    goon,1;
        act,,atrib(2) .eq. 1,dspj;
        act,,atrib(2) .eq. 2,dsps;
        act,,atrib(2) .eq. 3,dspt;
dis1    event,1,1;
        act,,atrib(2) .eq. 1,dspj;
        act,,atrib(2) .eq. 2,dsps;
        act,,atrib(2) .eq. 3,dspt;
dspj    assign,xx(50)=xx(50)-1;
        assign,xx(58)=xx(58)+1;
        assign,xx(3)=xx(3)+atrib(1);
        act;
        colct,intvl(3),C5 Would Have,6,30,15;
        term;
dsps    assign,xx(40)=xx(40)-1;
        assign,xx(48)=xx(48)+1;
        assign,xx(3)=xx(3)+atrib(1);
        act;
        colct,intvl(3),C141 Would Have,6,30,15;
        term;
dspt    assign,xx(30)=xx(30)-1;
```

```
        assign,xx(9)=xx(9)-atrib(1);
        assign,xx(38)=xx(38)+1;
        act;
        colct,intvl(3),C130 Would Have,6,30,15;
        term;
;-----------------------------------------------------------
;Maintenance Delay
mx      assign,atrib(9)=triag(0,35,240,6);
        act/60;
        assign,xx(16)=xx(16)+atrib(9),1;
        act,,atrib(2) .eq. 1,jumx;
        act,,atrib(2) .eq. 2,stmx;
        act,,atrib(2) .eq. 3,tcmx;

jumx    assign,xx(57)=xx(57)+1;
        act,,,mxlv;
stmx    assign,xx(47)=xx(47)+1;
        act,,,mxlv;
tcmx    assign,xx(37)=xx(37)+1;
        act,,,mxlv;
mxlv    goon;
        act/61,atrib(9);
        goon,1;
        act,,atrib(2) .eq. 1,dep1;
        act,,atrib(2) .eq. 2,dep2;
        act,,atrib(2) .eq. 3,lv;

;-----------------------------------------------------------
;Statistics

        create,18720,18720;
        act;
        assign,xx(58)=0;
        assign,xx(48)=0;
        assign,xx(38)=0;
        assign,xx(57)=0;
        assign,xx(47)=0;
        assign,xx(37)=0;
        assign,xx(3)=0;
        assign,xx(2)=0;
        assign,xx(1)=0;
        assign,xx(16)=0;
        act;
        colct,xx(51),C5 start;
        act;
        colct,xx(41),C141 start;
        act;
        colct,xx(31),C130 start;
        act;
        colct,xx(5),air cargo start;
```

```
        act;
        colct,nnq(1),C5 wait;
        act;
        colct,nnq(2),C141 wait;
        act;
        colct,nnq(3),C130 wait;
        act;
        term;


        create,20160,20160;
        act;
        colct,nncnt(61),AC Delayed;
        act;
        colct,xx(16),Time Delayed;
        act;
        colct,xx(57),  C5 Delayed;
        act;
        colct,xx(47),C141 Delayed;
        act;
        colct,xx(37),C130 Delayed;
        act;
        colct,xx(58),  C5 Displaced;
        act;
        colct,xx(48),C141 Displaced;
        act;
        colct,xx(38),C130 Displaced;
        act;
        colct,xx(3),Displaced Cargo;
        act;
        colct,xx(1),Cargo Delivered;
        act;
        colct,xx(2),Thruput;
        term,1;

        endnetwork;
sim;
fin;
```

Fortran Insert: Queue Discipline for Common Parking

```
program main
dimension nset(25000)
common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,
+mstop,nclnr
1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,
+xx(100)
common qset(25000)
equivalence(nset(1),qset(1))
nnset=25000
ncrdr=5
nprnt=6
ntape=7
open(7,status='scratch')
call slam
stop
end

subroutine event(i)

common/scom1/attrib(100),dd(100),ddl(100),dtnow,ii,mfa,
+mstop,nclnr
1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,
+tnow,xx(100)

dimension ja(12),sa(12),ta(12)
CASE 1 --- ALL THREE QUEUES OCCUPIED
goto (1),i
1     if (nnq(1) .gt. 0 .and. nnq(2) .gt. 0 .and. nnq(3)
   + .gt. 0) then

  call copy(1,1,ja)
  call copy(1,2,sa)
  call copy(1,3,ta)
  if (ja(3) .le. sa(3) .and. ja(3) .le. ta(3)) then
    call open(1)
    endif
  if (sa(3) .lt. ja(3) .and. sa(3) .le. ta(3)) then
    call open(2)
    endif
  if (ta(3) .lt. ja(3) .and. ta(3) .lt. sa(3)) then
    call open(3)
    endif
endif
```

```
CASE 2 --- TWO OF THREE QUEUES OCCUPIED
if (nnq(1) .eq. 0 .and. nnq(2) .gt. 0 .and. nnq(3) .gt. 0)
+ then
  call copy(1,2,sa)
  call copy(1,3,ta)

if (sa(3) .le. ta(3)) then
    call open(2)
    else
      call open(3)
    endif
endif
if (nnq(2) .eq. 0 .and. nnq(1) .gt. 0 .and. nnq(3) .gt. 0)
+ then
  call copy(1,1,ja)
  call copy(1,3,ta)
  if (ja(3) .le. ta(3)) then
    call open(1)
    else
      call open(3)
    endif
endif
if (nnq(3) .eq. 0 .and. nnq(1) .gt. 0 .and. nnq(2) .gt. 0)
+then
  call copy(1,1,ja)
  call copy(1,2,sa)
  if (ja(3) .le. sa(3)) then
    call open(1)
    else
      call open(2)
    endif
endif
CASE 3 --- ONE OF THREE QUEUES OCCUPIED
if (nnq(1) .gt. 0) then
  call open(1)
  endif
if (nnq(2) .gt. 0) then
  call open(2)
  endif
if (nnq(3) .gt. 0) then
  call open(3)
  endif
end
```

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Vita

Daniel L. Cuda was born in Los Angeles, California on 27 March 1954. After graduation from high school in Los Angeles in 1972, he entered the USAF Academy. In 1976, he graduated with a commission from the Academy. He graduated from undergraduate pilot training at Vance AFB, Oklahoma in 1977, and was flight qualified in the C-130 aircraft the same year at Little Rock AFB, Arkansas. At Little Rock AFB he progressed from co-pilot to aircraft commander to instructor pilot. In 1982, he was assigned as a liason officer for tactical airlift to the U.S. 2nd Infantry Division and the Combined Field Army (ROK/US) at Camp Red Cloud, Republic of Korea. He entered the School of Engineering, Air Force Institute of Technology in 1983. In 1985, he graduated and was assigned to the Mobility Branch, HQ USAF, Studies and Analysis.

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