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COMBAT LOGISTICS FORCE SIZING TO ENSURE ENDURANCE RELIABILITY

by

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Thesis Advisor: Michael P. Bailey

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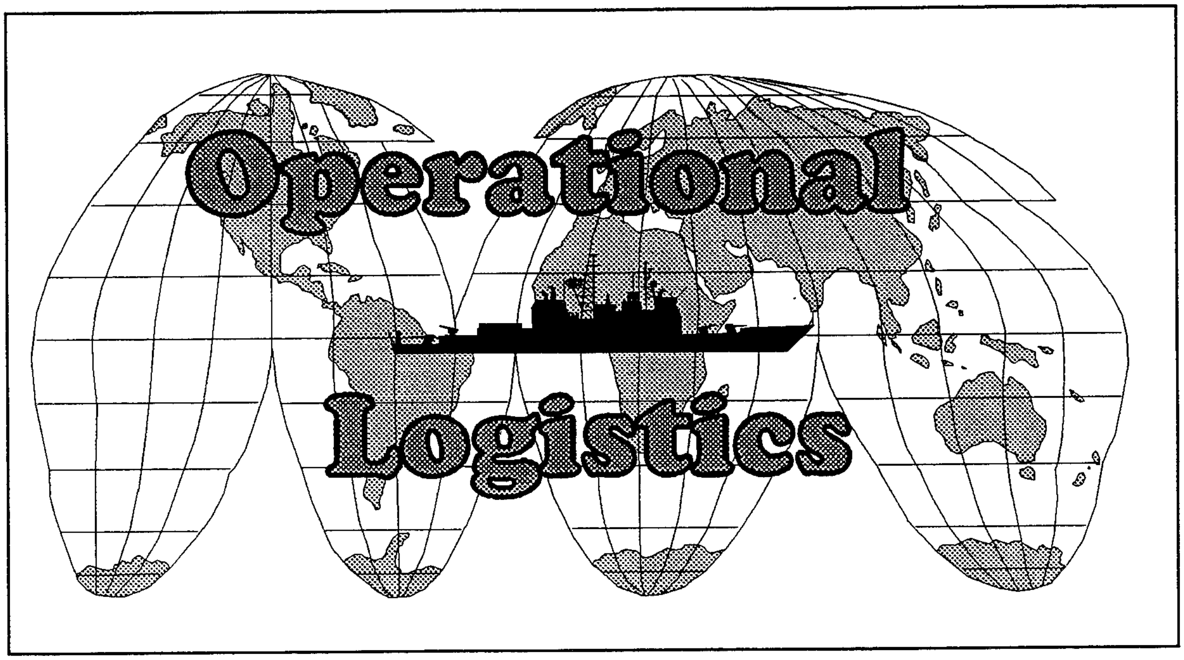
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COMBAT LOGISTICS FORCE SIZING TO ENSURE ENDURANCE RELIABILITY

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EXECUTIVE SUMMARY

The need to *right-size* the Combat Logistics Force is motivated by both fiscal and operational requirements. These pressures typically oppose one another. The primary responsibility of war planners is to prepare their forces to meet with any range of anticipated challenges, and to succeed against the unexpected as well. In order to wage logistics, a fundamental element of any well-conceived strategy, these planners must have available to them an appropriate proportion of tail to tooth.

A significant amount of study has been dedicated to optimizing the relationship between logistics assets and their customers. The great majority of this work has been in the techniques with which a multi-product station ship minimizes the time required to reach and replenish the units of a battle group. Other studies have focused on determining the requirement for surge sealift deployment of men and equipment from their U.S. ports of embarkation to their destinations in theater. Taken together, these studies cover the two *ends* of the spectrum, the tactical and strategic ends.

Here, the focus is on *operational logistics*, the science of sustaining forces engaged in theater combat operations from support bases in and around that theater. Specifically, the question is not *how* to employ the logistics ships, but rather *how many* of *which types* are required to sufficiently resupply the various kinds of naval forces. First, agreement must be reached as to the composition and operational tempo of the supported forces. A worst case approach is selected, where two nearly simultaneous major regional

contingencies require the entirety of the U.S. aircraft carrier fleet, and the bulk of the surface combatant and amphibious forces. These conflicts are geographically segregated so that logistics assets may not overlap their service. Advance logistics support bases are modelled in each scenario, and their significance is tested by their removal.

The computer simulation which generates the performance data is object-oriented, so that ship movement, daily consumption and transfer rates can be treated as stochastic variables. The actual behavior of Combat Logistics Force assets is non-homogenous, or lumpy in that there is no constant value representing a smooth rate of flow of goods to the battle groups. Simply put, there are no pipelines at sea. The novelty of this study is in the use of simulation to capture this dynamic aspect of logistics operations.

The performance measure is days of supply for F76, JP5, provisions, and non-specific ordnance. The output data is then analyzed to construct cumulative distributions for the carrier battle groups. The concept of *satisfaction criteria* is developed, where a probability is provided for being at or below a *given percentage* of capacity, or equivalently, in days of supply. Using these probabilites as the basis for comparison, the improvement in overall endurance reliability with the addition to the theater of each shuttle ship is graphically demonstrated. Further, the contribution of multi-product station ships to carrier battle group endurance reliability is quantified. Finally, various Combat Logistics Force configurations are compared for the purpose of minimizing the probability of exhausting any of the four commodities. Thus, the central theme of this analytical study is the familiar and extremely relevant question, *how much is enough*?

I. INTRODUCTION

> *You cannot make decisions simply by asking yourself whether something might be nice to have. You have to make a judgement on how much is enough.*
>
> Robert S. McNamara
> April 20, 1963

Determining the required composition of the Combat Logistics Force (CLF) is a timely issue of long term importance thanks to growing emphasis on logistical feasibility in planning for naval warfare. At present, the outlook for CLF strength is bleak. Without long-term fiscal commitment to new ship construction, steady degradation to logistical impotence, notwithstanding ongoing debate over ship life extension, is certain. Traditionally, tacticians and *shooters* have dominated the procurement process in the Navy, but the need for logistics infrastructure to support combat operations is tantamount to that of all other issues in war planning, and is especially critical in the analyses which preceed decisions for future defense needs.

In 1992, the Center for Naval Analyses prepared a Combat Logistics Force study for consideration by the CNO Executive Steering Committee on a FY1999 force structure plan, the results of which are disputed by Commander, Logistics Group Western Pacific (CLWP), at the time RADM Ron Tucker. Briefly, as a fleet operator, RADM Tucker argued that the CNA analysts' conclusions regarding the size and composition of the CLF fall short of what is actually required to sustain the fleet at the tempo of operations which it may be expected to maintain in the future.

In response to the CNA study, RADM Tucker provided Commander, Seventh Fleet with his own staff report on CLF requirements, specifically arguing on behalf of multi-product station ships (AOEs) as essential complements of carrier battle groups. Fundamentally, his report held that there must be an AOE for each of the planned twelve carrier battle groups. The distinction here is between station ships which remain in company with operating battle groups deployed in their forward positions, and shuttle ships which operate from secure bases to resupply these station ships, as well as to replenish those groups without station ships by consolidation with the individual units.

For any discussion of logistics requirements to have meaning, the participants must agree on several fundamental points, the most troublesome of which is simply establishing the scope of operations which the logistics force must support. The implications of underestimating the requirement are obvious, however, in an era of shrinking resources and extreme competition for shares of the defense budget, large safety margins are no longer possible, and even risk defeat for the program. The question of how much is enough is also complicated by disagreement on the criteria for satisfaction. For example, the number of transports required in order to be 100% certain that no commodity will ever be exhausted may be dramatically higher than the number required for 90% confidence.

The principal reference on the issue of force structure for naval logistics is the Mobility Requirements Study (Classified SECRET). It is similar to previous work on Combat Logistics Force *structure*, as opposed to *employment*, in that it is limited to deterministic analyses of strategic sealift capability, and does not treat the operational logistics of sustaining engaged forces. In general, the mathematics of these studies extend only slightly beyond division of expected values for total expended quantity of material in a surge cycle by the total capacity of a transport ship, yielding the required number of transport ships, then summing over the cycles. Linear programming optimizations have been used to minimize cost objective functions, but none have specifically addressed the dynamics of CLF support in combat scenarios where there are few, if any, constant values.

Much work in operations research has been done on optimizing the delivery techniques of underway replenishment ships to individual battle group members, but these studies have focused on employment, not, as we have indicated, on determining force composition. Deterministic models lack treatment of such *real world* complexities as emergent crises, redeployment, battle damage, surprise, or breakdown as *random variables*. To bridge this gap with reality, a model must handle stochastic events.

Enhanced realism is the great advantage of using computer simulation in this study which models CLF support of non-static naval operations (including USMC expeditionary forces) during combat scenarios anticipated by the Pentagon. The U.S. paradigm for long term planning focuses upon the following global contingencies:

1) Latin American conflict centered in Panama requiring amphibious landing;
2) Baltic war ultimately requiring six CVBGs and a MEF;
3) Persian Gulf recurrence with three CVBGs and a MEF;
4) Korean Conflict drawing five CVBGs and two MEFs;
5) Philippines crisis involving two MEFs in amphibious landings;
6) Emergence of a new global enemy, akin to a Soviet superpower;
7) Simultaneous occurrence of Korea on the heels of the Persian Gulf crisis.

The purpose of this study is to quantify the impact of varying CLF composition on battle group endurance; specifically, to test the validity RADM Tucker's contention that multi-product station ships (AOEs) are essential complements to carrier battle groups. In addition, comparisons are made between alternative configurations of CLF station and shuttle ships in order to examine their ability to logistically support U.S. Naval operations during what is generally considered to be the worst case, or two (nearly) simultaneous major regional contingencies.

The objective in taking a *worst case* approach in establishing any requirement is to plan for war, not for peace. To do otherwise is surely irresponsible. Here, unclassified approximations of the Baltic and North Korea scenarios are examined simply because, when taken together, they effectively exhaust the Navy's available forces, especially when consideration is given to training requirements and the need to concurrently maintain other treaty obligations. Clearly, success depends on the availability of logistics bases in host nations to support the operating forces. This is assumed to be the case with Japan and the UK, though the impact of losing the former is demonstrated.

The methodology of the study is to independently simulate each of the two scenarios with various configurations of CLF, the experimental variable. The endurance data for the operating forces is collected, analyzed, and used to develop a cumulative probabilty distribution (CDF) for the likelihood of groups' endurance status over the entire duration of each conflict. With this information, the decision maker has a basis for comparing satisfaction criteria for a given composition of CLF, specifically, the probability for being at or below some percentage (α%) of maximum capacity or endurance.

The answer to *how much is enough* may still elude its counterpoint, *it depends*, but such an approach provides a critical foundation upon which to begin building a decision-making paradigm for sizing the CLF. The unique properties of this operational approach using simulation offer more utility than the analytical model of the CNA study, where a smooth and homogenous flow of material is assumed for the battle groups. The analytical model fails to capture the tremendous variability which may occur among the different groups due, for example, to their respective isolation from the logistics sources. Using simulation, more accurate representation is given the "lumpy" performance behavior of consumers and their support ships dispersed over a large theater of operations. The goal, then, is to develop a more robust and representitive model with which to determine required CLF composition by comparing the performance of logistics forces under projected conditions.

II. MODEL DESCRIPTION

A. OBJECT-ORIENTED PROGRAMMING

Object-oriented computer simulation requires the programmer to encapsulate the articles of the model into tightly defined and efficiently coded packages, called objects, which may share attributes through an inheritance relationship. Naming conventions are important, and objects, their properties, and unique procedures are titled in order to quickly identify their purpose in the simulation. Writing the simulation in MODSIM II, a powerful object-oriented computer language, provides ready-made tools for managing data arrays as well as performing statistical calculations and other analysis functions. MODSIM II provides a discrete time event scheduler to manage the movement and activities of the objects as they execute their methods and procedures.

The logistics simulation developed for this study is a coarse-grained model approximation for studying the movement of logistics ships and the consumptive behavior of notional forces. While randomizing variables brings the model closer to reality, each variable requires justification for its parameters, but this may not always be possible. Many *common sense* values are used by convention, but others are highly contested. Model resolution must be balanced with problem integrity, therefore the complexity of this simulation is limited to those variables for which CLWP's planning factors are available to use as input parameters.

The ConsumerObj is the fundamental article in the simulation. The object can represent a single ship or an aggregated group of ships operating together. In this simulation the consumers are both nuclear and conventionally powered aircraft carrier battle groups (CV/CVNBG), amphibious task groups (ATG), and surface action groups (SAG). CLWP's logistics planning factors for theater operations are aggregated values for these notional groups, where the consumption rates for each unit type are identical, as is the composition of each type group. CV/CVNBGs contain the carrier, two cruisers, and four destroyers(DD and DDG). ATGs are composed of an LHA/LHD, three LPDs, and three LSDs. SAGs are two cruisers and four destroyer types.

By modelling groups rather than units, the *tactical* advantage of using AOEs in battle group operations is not represented. A logistics appendage allows the battle group units greater flexibility in formation stationing and warfighting by easing the supply tether and the requirement to reposition for replenishment. This flexibility has a profound impact during a prolonged engagement or transit, and it is a principle aspect of RADM Tucker's argument on the behalf of AOEs. Optimizing the *intra*-battle group relationship has been the subject of previous studies. Here we will take a much broader *theater* perspective in studying the structure of the logistics force.

As the name implies, the mission of the ConsumerObj is to deplete its inventories in a behaved, or prescribed manner. Each consumer begins with 95% of its capacity. Depletion is accomplished by using a daily consumption rate for each of four commodities: propulsion fuel (F76), aviation fuel (JP5), provisions, and non-specific ordnance. The units associated with these commodities are barrels for the fuels, and tons for both provisions and ordnance. The consumption rates are recalculated and updated every fourth day in order to reflect different activity levels of the forces. These short periods of sustained operating tempo dissuade the implication that daily consumption rates are independent from one day to the next. At midnight of each day, the consumer reports the status of its inventories as days of supply (DOS) on hand, then calculates a 24-hour projection, and requests replenishment of any commoditiy for which the projection falls below a threshold value which is input in terms of percentage of capacity and may be thought of as a reserve level or reorder point. Here, the replenishment threshold is 70%.

The replenishment request may be handled in one of two ways. If a ConsumerObj has a StationShipObj assigned to it, then the first of the consumer's commodity projections to reach the reserve level causes an underway replenishment (UNREP) of all four commodities from the StationShipObj who will either top off its ConsumerObj, or exhaust its own inventory in an effort to do so. The overall transfer time is the maximum of the individual transfer times calculated for each commodity, since each commodity is transferred simultaneously. Figure 1 illustrates the handling of a replenishment request.

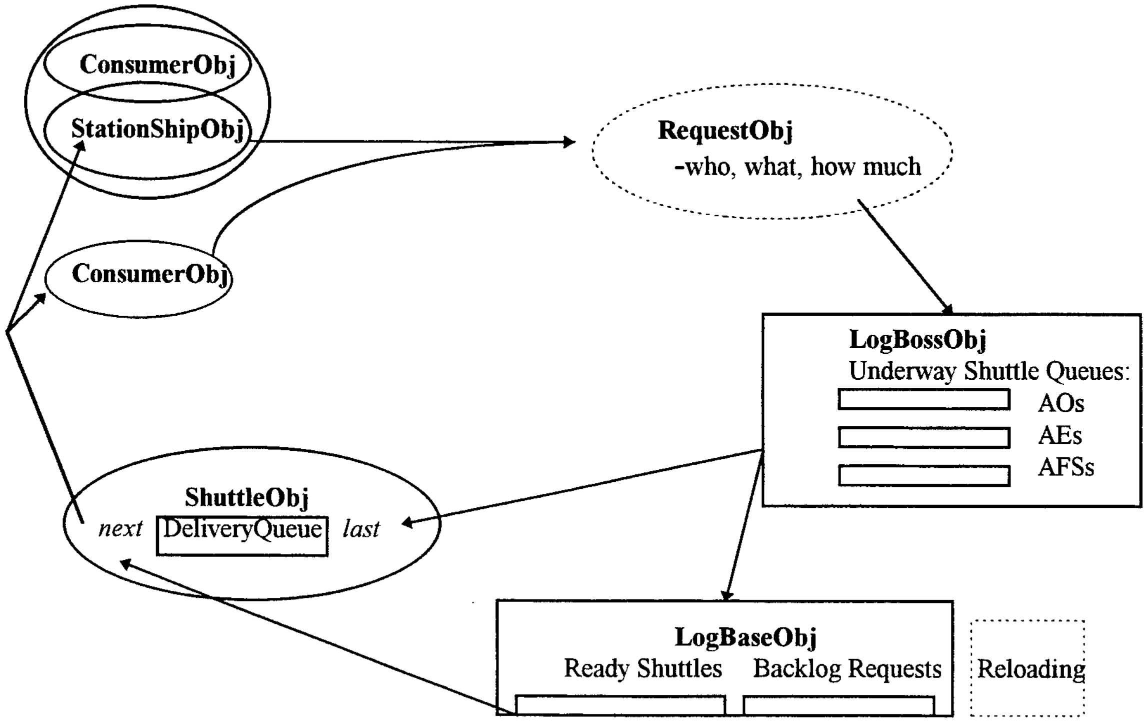

Figure 1. Processing a Replenishment Request

If no station ship is assigned to the consumer, the replenishment request for a particular commodity is sent to the logistics coordinator. In both of the scenarios studied here, consumer groups other than carrier battle groups are replenished solely by shuttle ships. The impact of this arrangement is modeled by a six hour *extension* to the shuttles' commodity transfer time during a delivery. The *gas station* technique is assumed, where the ships of the group converge to close proximity in order to expedite the replenishment evolution. The delay factor is intended to conservatively represent the formation, approach, rig, and unrig time for each notional unit in the group.

A station ship functions as a floating warehouse which adds tremendous endurance to a battle group by increasing the group's organic inventory. For this reason, the DOS figure for an accompanied consumer includes the inventory of its station ship. In this study, the AOE-6 is modelled. The station ship depletes its inventories by replenishing its consumer group. When the StationShipObj approaches its own inventory percentage threshold, or reorder point of 70% in any particular commodity, it notifies the logistics coordinator, the LogBossObj, who arranges consolidation from a shuttle ship of the appropriate type. Once a StationShipObj or a solo ConsumerObj sends off a RequestObj for replenishment of a particular commodity, it will not repeat or update a request until that commodity is replenished, after which, if the inventory is below threshold at the next reporting cycle, a new request will go out.

The LogBossObj and LogBaseObj function as queue managers for shuttle ships. The difference is that the LogBossObj handles shuttles which are underway making deliveries, while the LogBaseObj controls shuttles which are either in port reloading or standing by to get underway. The replenishment request is itself an object (RequestObj) which is passed first to the LogBossObj who takes the request and executes a decision algorithm to determine whether it controls any shuttles of the appropriate type to service the request. If so, it selects the closest shuttle. If not, the request is passed to the primary LogBaseObj which either dispatches a shuttle, passes the request to a secondary LogBaseObj if one exists, or backlogs the request for the next shuttle to finish reloading.

In each case, the decision algorithm is essentially the same. When searching for the closest shuttle, the LogBossObj takes into account where the shuttle will be when it finishes with the last customer currently on its delivery queue. The time it will take for the shuttle to get through the pending deliveries and finally reach the requesting consumer is considered when determining whether or not the shuttle has enough cargo remaining uncommitted in order to fill the request. Though any of the objects representing naval units have the ability to move, only the ShuttleObj actually does so in the simulation. The consumer groups, as they are treated here, occupy area stations, and represent engaged groups between which the shuttles travel in their replenishment duties.

There are three types of shuttles corresponding to the basic commodities. The T-AO-187 class oilers carry both F76 and JP5, while the T-AFS-8 class provisions ship, and the T-AE-26 class munitions ship are both single product carriers for this simulation. Once dispatched from their base, the shuttles report to the LogBossObj and add requests to their delivery queues as the LogBossObj hands them out. Since the assignment algorithm checks the shuttle for the amount of cargo which remains uncommitted to other deliveries, it prevents the shuttle from taking a request it cannot fill, thus limiting the size of the delivery queue.

Once the queue is emptied and the last delivery is completed, the shuttle returns to its homeport. If sufficient cargo remains, the shuttle can be assigned a delivery enroute and diverted. Once home, the shuttle checks out with the LogBossObj and undergoes its reload for a period of time depending on the amount of inventory with which it returned to base. If the shuttle returns empty, then the reload time is seventy-two hours, after which the shuttle enters the ready queue in standby status and waits for its turn to redeploy. When a shuttle's reload is complete, if there are requests in the backlog for the shuttle's commodity type, then the shuttle takes as many of these onto its delivery queue as it can accomodate, and departs immediately. Clearly, crew rest is not considered, and the port is assumed to operate continuously.

B. PARAMETERS

Input for the simulation include the criteria provided by CLWP staff, in particular, the planning factors for high and low intensity wartime commodity consumption rates, transfer rates, composition of consumer groups, and capacities for replenishment assets. Stochastic factors are modeled by imposing randomness on movement (shuttle speed), transfer rates, and consumption rates using a triangle distribution function with a random number generator. CLWP's planning factors provide natural min/max parameter bounds for the triangle distribution.

Since optempo is never static, treating the combat forces' consumption rates as random variables allows for the effect of factors such as escalation, emergent requirements, and indirectly, combat losses and replacement. The impact of the station ships' delivery delay and the random variable for shuttle ships' speed reflects administrative time, the mechanical reality of engineering casualties, weather complications, and the need to consider defensive measures against enemy forces engaged in counter-logistics operations.

DOS is a widely accepted measure of performance for logistics readiness, and is the basic unit for analysis of model output. The model provides a measure by which to evaluate the effectiveness of a limited CLF in supporting the prescribed operating force by analyzing the ability to maintain an acceptable DOS level of each of the four basic commodities. The number is simply the current inventory of each commodity divided by *maximum* consumption rate. Without this standardization, any comparative discussion of performance in terms of DOS is meaningless since daily consumption rates are variable. The simulation handles consumer groups of different types with significantly different parameters. Input data are summarized in Tables 1 through 4.

Consumer Groups				
Consumption Rates (daily)				Capacity
	MAX	NORM	MIN	
CVNBG F76	5597	4305	3013	97000
JP5	7000	6500	4500	69000
Provisions	37	31	25	1600
Ordnance	122	111	85	2200
CVBG F76	10140	5460	7800	141000
JP5	6500	4500	2500	48000
ATG F76	5440	4185	2930	161000
JP5	650	500	350	13000
Provisions	22	17	12	1100
Ordnance	3	2	1	1000
SAG F76	6000	4300	3000	84000
JP5	40	30	20	3000
Provisions	6	5	4	330
Ordnance	14	11	7	200

Table 1. Consumption Data in Barrels and Tons

Replenishment Ships				
	AOE	AO	AE	AFS
Transfer Rate (barrels or tons/hr)				
F76 MAX	10400	10000		
NORM	8050	8000		
MIN	5200	6000		
JP5 MAX	8570	7000		
NORM	5100	6000		
MIN	3700	5000		
Provisions MAX	140			144
NORM	112			130
MIN	83			120
Ordnance MAX	200		165	
NORM	187		150	
MIN	135		130	
Capacity		89000/91000	4500	3510

Table 2. Replenishment Ship Transfer Data

Transit Speed (kts)	AO	AE	AFS
MAX	**20**	**20**	**18**
NORM	**18**	**18**	**16**
MIN	**14**	**14**	**14**

Table 3. Shuttle Ship Speeds

AOE Loadout	**F76**	**JP5**	**Provisions**	**Ordnance**
For CVNBG	**60000**	**97000**	**2050**	**1800**
For CVBG	**89000**	**68000**	**2050**	**1800**

Table 4. AOE-6 Station Ship Loadout (Barrels and Tons)

Alternate capacities of F76 and JP5 for CVBG and CVNBGs coincide with the different loadouts for the AOE-6 depending on the type of carrier group. The nuclear-powered carrier obviously has a lesser requirement for propulsion fuel, and the additional JP5 which replaces it extends the endurance for aviation operations. Amphibious groups consumption of ordnance is trivialized due to the nature of their actual employment. These forces typically take position in a secure area, essentially dormant from the standpoint of ordnance consumption, then surge ashore.

C. MODEL LIMITATIONS

Status reports and subsequent replenishment requests are tied to discrete, twenty-four hour intervals. The non-continuous nature of these processes limit the frequency of replenishment and the resolution of the supply performance measure. If reporting and reorder were hourly functions, another performance measure might be hours of supply, but this is not the case. For the simulation to properly execute the delivery processes, it is necessary to prevent redundant assignments. Consequently, it is possible for a fully loaded shuttle to sit idle in port while a consumer waits on another shuttle to work through its delivery list to the waiting consumer's request.

If distances are great, the wait may be extensive as inventories continue to deplete. Similarly, if consumption rates are high, the magnitude of a single day's depletion may hold down inventory levels. Reorganizing the shuttles' delivery queues upon receipt of each new request is beyond the capacity of the current model. The human factors involved in dynamic, on-scene optimization defy modeling by simulation or mathematics. In reality, this optimization is performed by a scheduler who weighs the effect of mission priority, relative isolation, seniority of commanders, and groups' future tasking among other considerations. His solution involves continually redistributing the delivery requests among his available assets. This is an extraordinarily difficult problem to model and optimize, which is why, at the Fleet level, logistics scheduling is done by experienced staff members on large sheets of graph paper with pencil and eraser.

III. EXPERIMENT DESCRIPTION

To demonstrate the impact of adding AOEs to battle groups as well as additional shuttles to the theater, each scenario is run as a baseline configuration without station ships, and then iteratively repeated adding a shuttle of each type. AOEs are then joined to each carrier battle group, and the runs are repeated, again iteratively adding shuttles for comparison. Table 5 lists each experimental CLF configuration.

Configuration	AOs	AFSs	AEs	Log-Base	AOE Status
N. Korea 1	**1**	**1**	**1**	**Sasebo**	**none**
2	**2**	**2**	**2**	**Sasebo**	**none**
3	**3**	**3**	**3**	**Sasebo**	**none**
4	**3**	**3**	**3**	**Guam**	**none**
***4**	**same as 4, but with shuttles at maximum speed**				
5	**1**	**1**	**1**	**Sasebo**	**1 /CV group**
Baltic 6	**3**	**3**	**3**	**UK**	**none**
7	**4**	**4**	**4**	**UK**	**none**
8	**5**	**5**	**5**	**UK**	**none**
9	**2**	**2**	**2**	**UK**	**1 /CV group**
10	**3**	**3**	**3**	**UK**	**1 /CV group**
11	**4**	**4**	**4**	**UK**	**1 /CV group**

Table 5. Experimental CLF Configurations

In shuttle ship operations, since their capacities are fixed, the key to keeping consumers supplied, given the rates of depletion, is the frequency of deliveries. The two primary factors behind this frequency are the distance separating the consumers from the resupply base, and the speed at which the shuttles make their transits between consumers and the logistics port. To demonstrate this, a run is conducted substituting Guam for Sasebo in the North Korea scenario. Then, using the same composition of CLF, the speed of the shuttles is increased to their maxima in order to test whether delivery performance is substantially improved.

For this study, the actual geographic location of the different forces is not significant; rather, their *numbers* and *relative separation* are the factors affecting the results. Positions of consumers and bases are in terms of Cartesian coordinates with the units in nautical miles to simplify the mathematics of object movement in the simulation. The locations of the groups in the North Korea scenario reflect the stationing of two CVBGs and two SAGs in the Yellow Sea with the remaining groups off the east coast of the Korean Peninsula in the Sea of Japan. The Baltic scenario models three CVNBGs in the Baltic Sea, a conventionally-powered CVBG with the ATGs west of Denmark, two CVNBGs off the Norweigian North Cape, and four SAGs similarly dispersed. The relative positions of forces and bases are summarized in Table 6.

North Korea											
Logistics Base			CV/CVNBGs			SAGs			ATGs		
Name	X	Y	#	X	Y	#	X	Y	#	X	Y
Sasebo	**500**	**500**	1	**900**	**500**	1	**800**	**500**	1	**800**	**400**
Guam	**500**	**-1000**	2	**1000**	**700**	2	**200**	**500**	2	**800**	**400**
			3	**10**	**500**	3	**200**	**500**	3	**800**	**400**
			4	**110**	**500**						
			5	**700**	**500**						

Baltic											
UK	**5**	**500**	1	**-1500**	**500**	1	**1000**	**500**	1	**500**	**400**
			2	**-1800**	**500**	2	**-1000**	**500**	2	**600**	**400**
			3	**1200**	**500**	3	**600**	**500**	3	**650**	**400**
			4	**1500**	**500**						
			5	**1800**	**500**						
			6	**500**	**500**						

Table 6. Forces' Cartesian Positions

IV. ANALYSIS

Each run of the 180-day simulation generates daily DOS values of each commodity for every group. These values are tabulated to determine the frequency with which the consumer is at or below a percentage of its maximum capacity in DOS for each of the four commodities. A summary of the steps involved in collecting the data and the formulation for calculating the cumulative distribution of DOS is provided.

Let the indices **i, j, k** and **α** represent the following:

i = 1, 2, 3, .., 180th day of the conflict;
j = the specific consumer group;
k = commodity (F76, JP5, provisions, ordnance);
α = 10, 20, 30, .. , 90 %.

Define the following variables:

$\mathbf{DOS}_{i,j,k}$ = Days of Supply on day **i** for consumer **j** of commodity **k**;
$\mathbf{p(\alpha)}_{j,k}$ = The probability of consumer **j** being at or below **α%** of commodity **k**.

For each configuration run, execute the following formulation steps:

1) Collect $DOS_{i,j,k}$ $\forall$ **i, j, k**;
2) Compute: $\alpha\%$ = 0, 10, 20, .. , 90 percent of max capacity $DOS_{j,k}$ $\forall$ **j, k**;
3) Count # of days' reports where $DOS_{j,k} \leq \alpha$ $\forall$ **j, k, α**;
4) Compute: $COUNT_{j,k,\alpha} \div N = p(\alpha)_{j,k}$ $\forall$ **j, k, α**;
5) $AVERAGE_{CVs}\{ p(\alpha)_{j,k} \} \Rightarrow CDF_{CVs,k}$ $\forall$ **k**.

As essential support for any analysis, a study of performance measure variance must be conducted to assess the quality of the data. It is important to establish the stability of the simulation, and consequently the stability of its output. The range of output is provided for a probability estimator $\mathbf{p(\alpha)}_{j,k}$. Fifty replications of the baseline configuration for the North Korea scenario are run, and the estimator for the first carrier battle group's F76 performance with $\alpha = 50\%$ are collected for comparison. These fifty values are sorted into order statistics, and the highest and lowest form the bounds of a non-parametric confidence interval for the estimator such that:

$$\text{Range of } \mathbf{p(50\%)}_{cvbg1,F76} = [.700\ ,\ .794\ ]$$

This range is comparable to a large-sample confidence interval (CI) which requires normally distributed data. For the same fifty observations of $\mathbf{p(50\%)}_{cvbg1,F76}$, the mean, μ is .7429 and standard deviation, σ is .0244. The 95% CI bounds are [.695, .791]. Figure 2 graphically illustrates the distribution of the fifty sample observations.

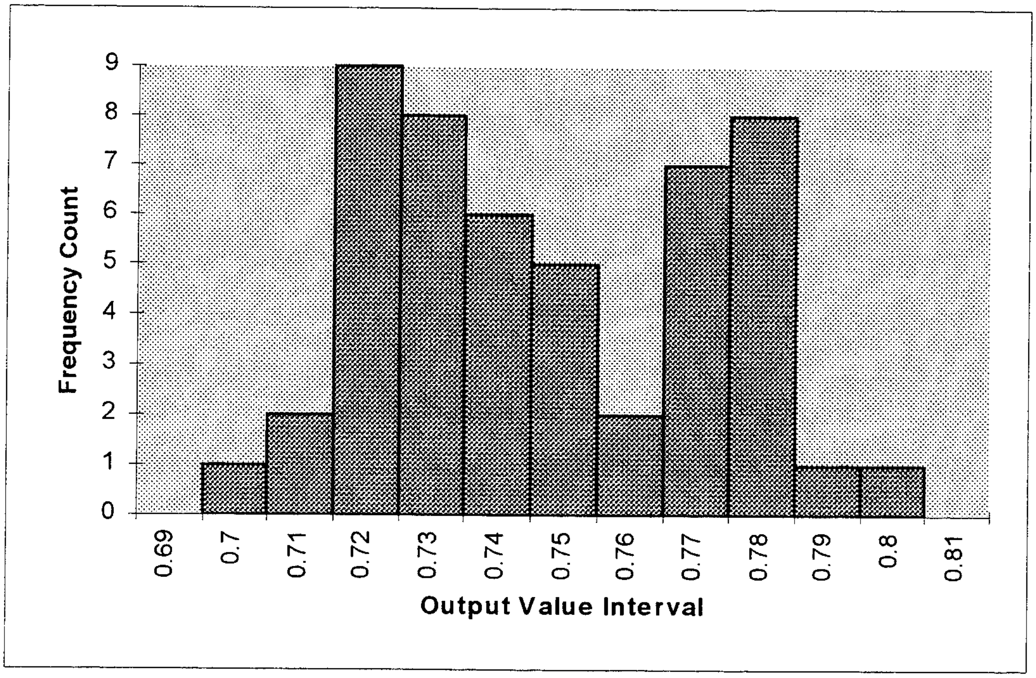

Figure 2. Historam of $p(50\%)_{cvbg1,F76}$ Values for Fifty Replications

An operational type of examination for output variance is a comparison, for each α and a given commodity, between the average of the $\mathbf{p(\alpha)}_{j,k}$ values over all the CVBGs in a configuration run, and the highest of the CVBG values. Though the average is more representitive of the configuration as a whole, the difference in the two CDF graphs reflects the variability in the performance of individual groups. This spread also provides some sense of how geographic separation affects the variability in a group's DOS performance. Intuitively, the most removed consumer is likely to wait longer for deliveries than those in closer proximity to the support base.

Figure 3 illustrates the relationship between the CDF of the averaged carrier battle groups, and the *worst case* CDF which represents the carrier groups' highest values of each $\mathbf{p}(\alpha)_k$. The difference is indicative of the effects of extended travel time for the replenishment ships due to wide dispersal of forces. It is also a direct reflection of how much worse DOS performance will be for the most isolated group relative to the rest of the combat forces operating in the theater.

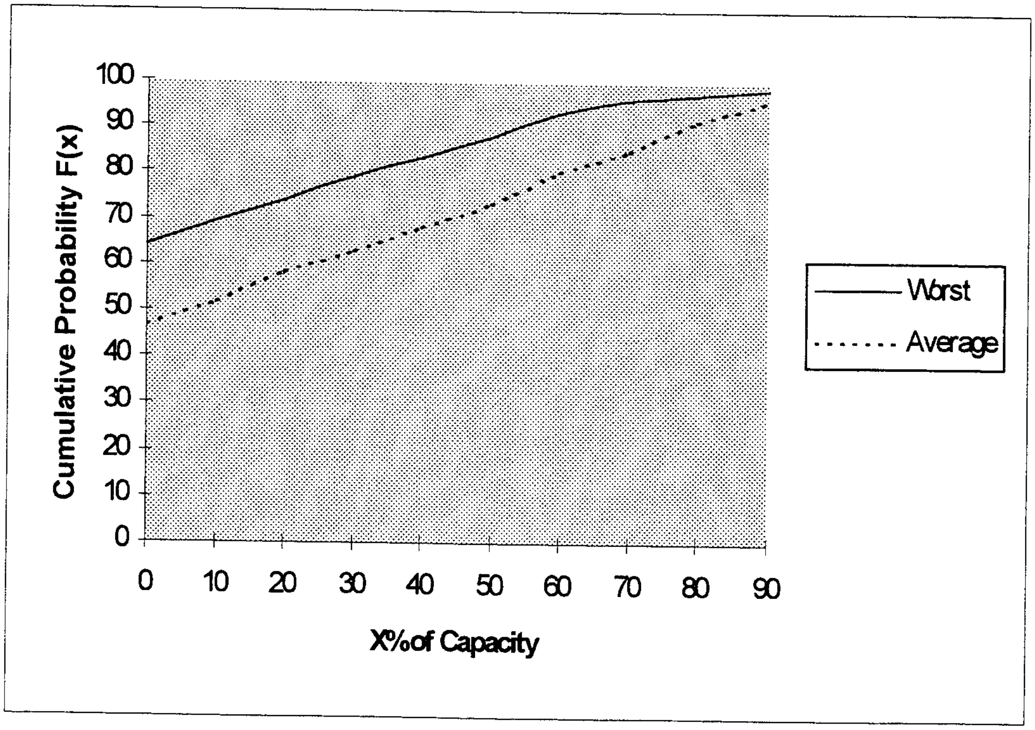

Figure 3. CDF of Baltic CVBGs for F76 Supported by Three AOs and no Station Ships

The random variables which induce the statistical variance in the first illustration are the daily consumption rates of the commodities, the transfer rate from station ship to consumer as well as the shuttle transfer rates, and finally the transit speed of the shuttles. Though not random, the amount of time a shuttle spends inport for reloading varies with the amount of cargo with which it returns to port. The operational variability is related to the separation of forces. It is essential to remain consistent in the comparisons, therefore the consumers' performances are segregated by type. Here, CV/CVNBGs are studied.

V. RESULTS

A. SHUTTLES, STATION SHIPS, AND ENDURANCE RELIABILITY

The quantitative result of adding shuttle ships into the theater, and station ships to carrier battle groups is a substantial improvement in the groups' endurance reliability as illustrated in Figures 4 and 5. Over the duration of a conflict, the magnitude of fluctuation in DOS values is dampened by the addition of shuttles, or more precisely, by the increased frequency of delivery due to higher availablity of shuttles. This reduces the probability of exhaustion, and the liklihood of being at or below the lower percentages of DOS.

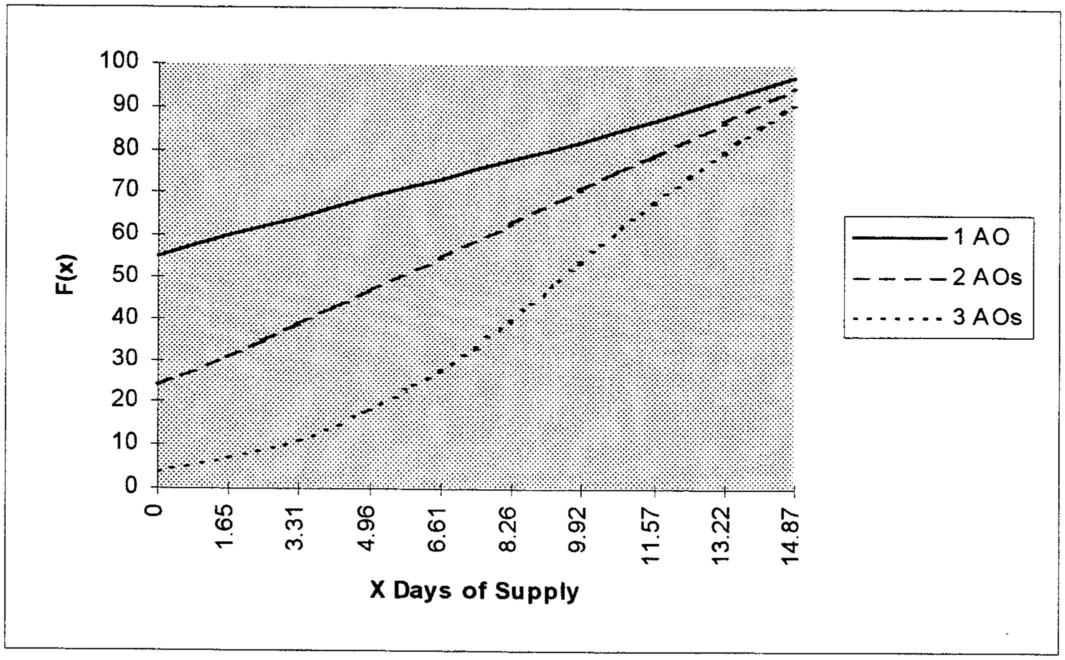

Figure 4. North Korea CDF for F76 Without AOEs

The addition of station ships raises actual DOS values of each commodity since the capacity of the station ship, considered organic to the group, is included in the capacity of its consumer. Therefore, when considering the satisfaction criteria, it is important to realize that 50% of max capacity *with* stationships is significantly more than 50% of max capacity *without* them. For clarity, a graphic comparison using actual DOS is provided.

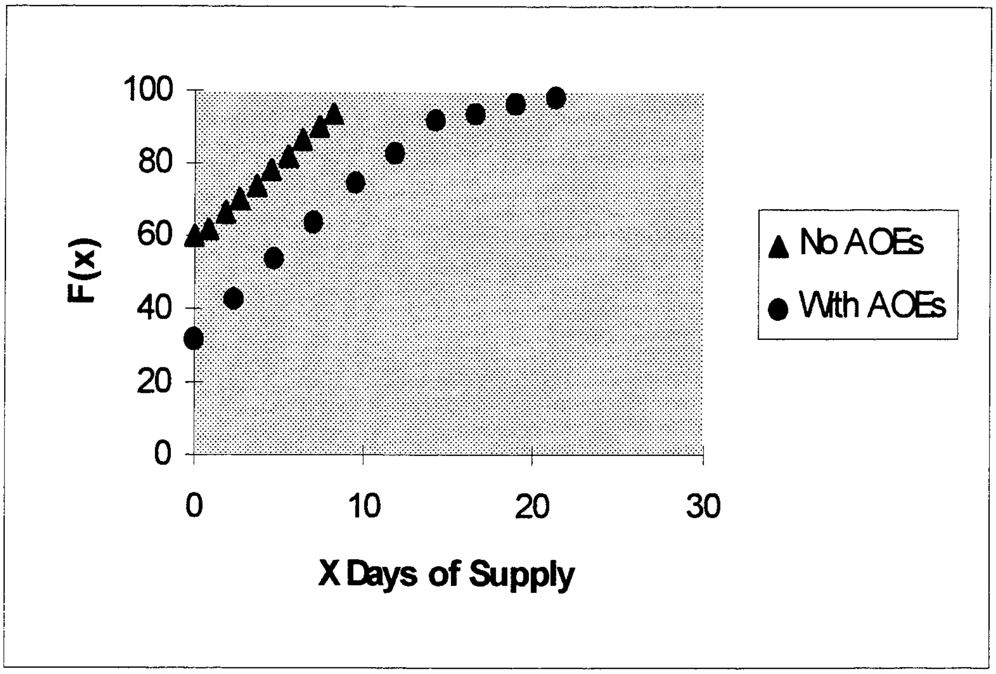

Figure 5. Baltic CDF for JP5 With Four AOs

The probability estimates which are derived from the $DOS_{j,k}$ values provide a basis for comparing the performance of the different configurations of CLF. The CDF demonstrates the impact which additional shuttles and multi-product station ships have on the probability estimates for the CVBGs. The addition of these ships shifts the probability mass to the right, and reduces the probability of being at or below the lower DOS levels.

B. DISTANCE AND SHUTTLE SPEED

Delivery frequency, and consequently endurance reliability is improved when resupply distances are shortened and shuttle speed is increased. The degradation in replenishment performance as a result of displacing the advance logistics support base is demonstrated by replacing Sasebo with Guam. This change adds 1500 miles to the shuttles' initial deliveries. From Figure 6 it is clear that the reduction in delivery frequency results in comparatively high probability of exhaustion of commodity inventories. If an advance base is removed altogether, the CDF collapses to the left axis and vanishes.

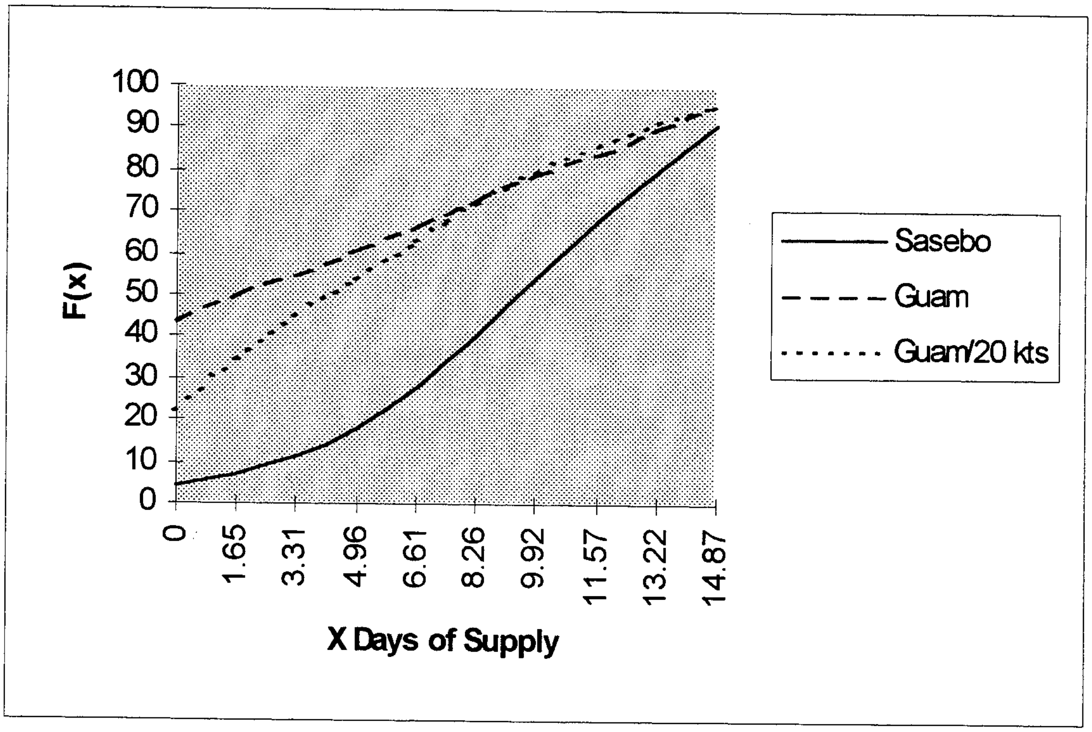

Figure 6. North Korea CDF for F76 WithThree AOs

Realizing that speed, in addition to separation, drives delivery frequency, the shuttles are accelerated to their maximum of twenty knots for performance comparison. The aggregate result is a substantial reduction in endurance reliablity when a forward logistics base is not available, whereas higher speeds for shuttle ships lessen the impact. The implications for investment in design improvement to increase speed rather than the size of the force are latent, and suggest another application for the simulation architecture.

C. SIZING TO MINIMIZE EXHAUSTION

As a minimum, an AOE is required for every carrier battle group. Further, *in excess* of nine AOs, two AFSs, and four AEs are required to operate *continuously* in order to sustain naval forces involved solely in the two separate MRCs represented here. In this final experiment, a free hand is taken in incrementing the numbers of each type of shuttle, both with and without station ships, in order to search for the CLF composition which will reduce the probability of exhaustion to the lowest possible value. Figures 7 and 8 illustrate these results, specifically the relationship between logistics force size and the improvement in endurance reliability.

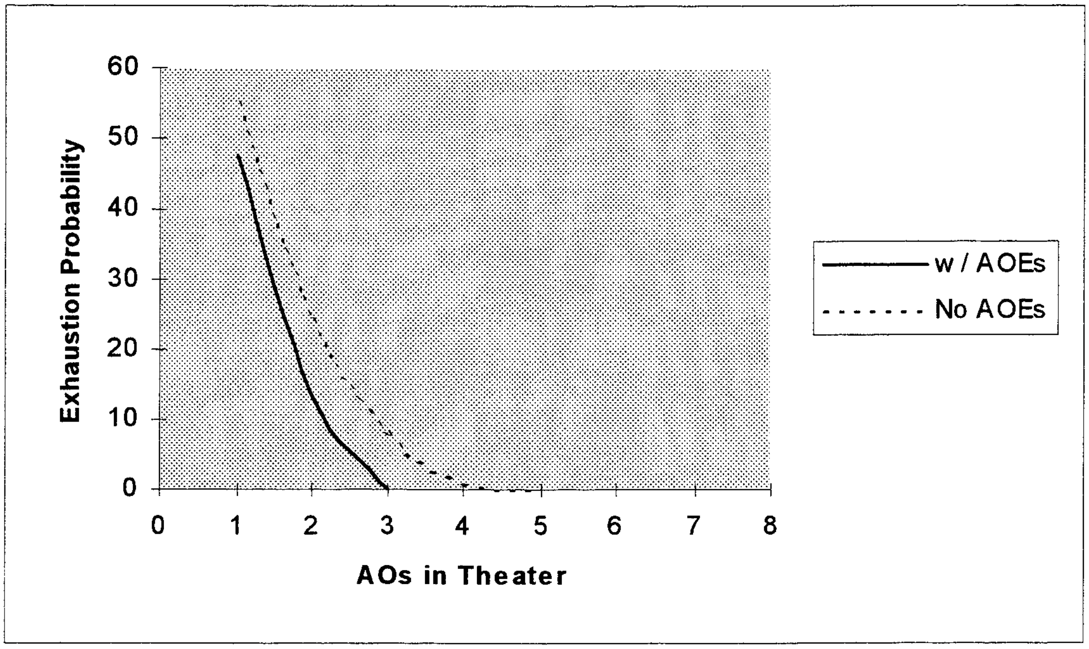

Figure 7. Exhaustion Probability for F76 in North Korea Scenario

For North Korea, the probability of exhaustion of any commodity was reduced to zero with a CLF composition which required AOEs for each carrier battle group in addition to three AOs, one AFS and two AEs. In the Baltic scenario, the greater distances manifested the limitation of the discrete model. The lowest attainable probabilities of exhaustion were .14 (F76), .26 (JP5), 0.0 (provisions), and .36 (ordnance). The Baltic CLF composition included AOEs for each carrier battle group as well as six AOs, a single AFS, and two AEs.

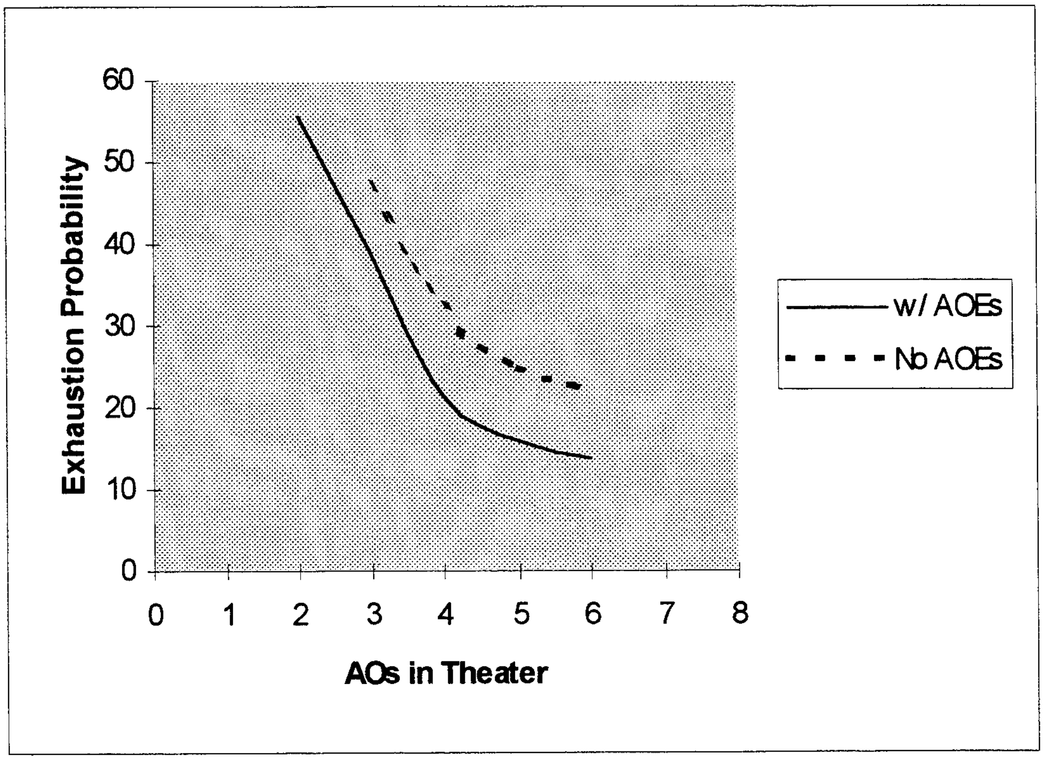

Figure 8. Exhaustion Probability for F76 in Baltic Scenario

VI. CONCLUSION

Experimental results of the simulation demonstrate that multi-product station ships substantially enhance the endurance reliability of the groups which they support. No suggestion is made that station ships are a substitute for some percentage of shuttles; on the contrary, the best performance is due to the mutual support of adding both shuttles and station ships in reducing the probability of falling below the lower-end percentages of capacity. There is great utility in providing output as cumualtive probablilites for being at or below any given percentage of maximum capacity measured in DOS. The benefit of offering a range of satisfaction criteria is unique to this analysis. Individuals may be interested in the endurance reliability for different levels of DOS. No commander is likely to be interested in the probability of being at or below 80% of capacity, nor any minimum satisfaction criteria much above 50%. The lower ranges, including exhaustion, is the realm within which operational requirements may dictate widely varying acceptable thresholds. The use of a satisfaction criteria offers flexibility in comparing performance.

In addition to the operational minimum CLF composition, war planners must consider maintaining CLF assets available in reserve to accommodate losses due to enemy counter-logistics operations. The point must be stressed that the loss of even a single shuttle ship or station ship profoundly degrades the endurance reliability of the operating forces. If it is reasonable to expect ten percent attrition of CLF assets, then that factor should be germane to any decision in sizing the CLF. At present, it is doubtful that any serious thought is given to the liklihood of losing logistics ships in combat. This is akin to planning for peace, as opposed to war; and it is equally irresponsible.

The unique success of this study is in the development and demonstration of an improved methodology for comparing the performance of CLF configurations. As the Secretary of Defense from 1961 to 1968, Robert McNamara changed the way the military thinks about itself by insisting that the tools of analysis be brought into use for planning to fight the nation's battles and to arm the services. The continuing advancements in simulation techniques offer more robust methods for studying the behavior of non-homogeneous environments.

In wartime scenarios, where mathematical models must assume away the troublesome variables which may be the most critical aspects of their study, evolving simulation methods will lead to the development of higher resolution models which can account for these variables with better integrity. More study is required in modelling the assignment problem with iterative rescheduling of the shuttles delivery queues. As it is, the problem itself requires the flexibility of the experienced staffer to achieve the proficient scheduling done under the dynamic conditions previously described.

This simulation architecture may be used to explore the CLF issue of using a two ship AO+AE equivalent in lieu of a single multi-product AOE, as well as the question of using AOEs to support multiple carrier battle groups in proximity, where the station ship acts like a shuttle, but has the better storage and transfer capabilities. The focus might be to determine the maximum distance of the overlapping service radii around the consumer groups without exceeding a given threshold endurance reliability. These force level micro-studies would take advantage of the movement and inventory management features already built into the objects of the simulation.

With the disappearance of the reliably consistent (former) Soviet threat, the input to a warfare model are only as legitimate as the day's news. The caveat to any study of force requirement is the presumption that the environment in which the operations may be expected to occur, is consistent. There is no more reason to accept this presumption now than there has been at anytime in the past, nor probably, will there be in the foreseeable future. However, as a contribution to the ongoing effort toward *right*-sizing the CLF, the probabilistic satisfaction criteria methodology and simulation architecture developed in this study, with improvements in modelling the more continuous processes, promise enormous utility in determining *how much is enough*.

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Quanbeck, David B. et al., *Combat Logistics Force Requirements Methodology*, Center for Naval Analyses, Alexandria VA, 1992.

APPENDIX. PARTIAL CODE LISTING

```
MAIN MODULE LogisticsForce;

{///////////////////////////////////////////////////////////
LT Dave Salzer, Naval Postgraduate School, Monterey CA 93943
Department of Operations Research
salzer@or.nps.navy.mil
Office phone: (408) 656-2786
///////////////////////////////////////////////////////////

ABSTRACT: This simulation models the basic paradigm of consumption and
replenishment for operating naval forces in a high optempo wartime scenario.
The force composition and parameters for calculating consumption rates are
read from an input file and used to model the stochatic nature of depletion
and movement. The output is in terms of days of supply (DOS) for four primary
commodities: F76, JP5, provisions, and ordnance over the duration of the war,
also input from the source file. A separate output file holds the daily mean
of the carrier groups' DOS for each commodity.
}


FROM IOMod      IMPORT StreamObj, ALL FileUseType;
FROM Consumer   IMPORT ConsumerObj, RNG, Strm, Dat, ADat, DataArray;
FROM LogBoss    IMPORT Boss;
FROM LogBase    IMPORT LogBaseObj;
FROM SimMod     IMPORT StartSimulation;
FROM NumCrunch IMPORT AStat, BStat, CStat, DStat, AOStat, AEStat, AFSStat;
FROM Lists      IMPORT ConsumerMasterList;

CONST  WarDuration = 180;
        Products =  4;

VAR
        ForceCount, PortCount, Carriers:  INTEGER;
        BattleGroup               :  ConsumerObj;
        Port                    :  LogBaseObj;
        i,j                   :  INTEGER;
        K                                :  STRING;



BEGIN
  NEW(RNG);
  ASK RNG TO SetSeed (23);

  NEW(AStat);
  NEW(BStat);
  NEW(CStat);
  NEW(DStat);
  NEW(AOStat);
```

```
  NEW(AEStat);
  NEW(AFSStat);

  NEW(Strm);
  NEW(Dat);

  ASK Strm TO Open("ForceNKtest.txt", Input);
  ASK Dat TO Open("clfout.txt", Output);

  ASK Dat TO WriteString("   Day  ");
  ASK Dat TO WriteString(" Fuel DOS ");
  ASK Dat TO WriteString("  JP5 DOS ");
  ASK Dat TO WriteString(" Food DOS ");
  ASK Dat TO WriteString(" Ammo DOS ");
  ASK Dat TO WriteLn;

  ASK Strm TO ReadInt(ForceCount);
  ASK Strm TO ReadInt(PortCount);
  ASK Strm TO ReadInt(Carriers);

  NEW(DataArray, 1..WarDuration, 1..(Products*ForceCount) );


  FOR i:= 1 TO ForceCount
        NEW(BattleGroup);
        ASK BattleGroup TO Register(i,Carriers);
        TELL BattleGroup TO OpSum(ForceCount, Products);
  END FOR;

  NEW(Boss);

  FOR i:= 1 TO PortCount
        NEW(Port);
  END FOR;

ASK Strm TO Close;
DISPOSE(Strm);

StartSimulation;

ASK Dat TO Close;
DISPOSE(Dat);



NEW(ADat);
ASK ADat TO Open("NKtest.txt", Output);
ASK ADat TO WriteString("Groups(#'d) daily DOS of Fuel, JP5, Food, and Ammo:");
ASK ADat TO WriteLn;
ASK ADat TO WriteString("Day   ");

FOR i:= 1 TO ForceCount
  K:= INTTOSTR(i);
  ASK ADat TO WriteString(K+"Fuel");
```

```
  ASK ADat TO WriteString(K+"JP5");
  ASK ADat TO WriteString(K+"Food");
  ASK ADat TO WriteString(K+"Ammo");
END FOR;

ASK ADat TO WriteLn;



FOR i:= 1 TO (WarDuration)
  ASK ADat TO WriteInt(i,3);
  FOR j:= 1 TO (ForceCount*Products)
        ASK ADat TO WriteReal(DataArray[i,j],7,1);
  END FOR;
  ASK ADat TO WriteLn;
END FOR;


{alternative output for averages:}
{
ASK ADat TO WriteString("Mean Days of Supply over all the carrier groups");
ASK ADat TO WriteLn;
ASK ADat TO WriteLn;
ASK ADat TO WriteString("Day     Fuel      JP5      Food      Ammo ");
ASK ADat TO WriteLn;
FOR i:= 1 TO (WarDuration)
  ASK ADat TO WriteInt(i,3);
  ASK ADat TO WriteReal(DataArray[i,1],10,2);
  ASK ADat TO WriteReal(DataArray[i,2],10,2);
  ASK ADat TO WriteReal(DataArray[i,3],10,2);
  ASK ADat TO WriteReal(DataArray[i,4],10,2);
  ASK ADat TO WriteLn;
END FOR;
}

ASK ADat TO Close;
DISPOSE(ADat);

DISPOSE(AStat);
DISPOSE(BStat);
DISPOSE(CStat);
DISPOSE(DStat);


END MODULE.
```

```
DEFINITION MODULE Consumer;

{******************************************************************************
POC:  LT Dave Salzer(salzer@or.nps.navy.mil)  408-656-2786 NPS Monterey, CA

        The ConsumerObj object is intended to represent an operating group,
like a CV(N)BG, ARG, or SAG.  The parameters it requires for enstantiation
include the consumption rates (likeliest, min and max) for each of the four
principle commodities: provisions, fuel(F76), aviation fuel, and ordnance.
The purpose of the simulation is to study the days of supply of these products,
so the consumers calculate, update their status, and report their data at
24 hour intervals.  When stock levels reach a threshold, the consumers request
replenishment from their station ships, or the logistics boss if they are
without station ships.
******************************************************************************}

FROM RandMod IMPORT RandomObj;
FROM StationShip  IMPORT StationShipObj;
FROM Request IMPORT RequestObj, ProductType;
FROM LogBase IMPORT LogBaseObj;
FROM Mover   IMPORT MovingObj;
FROM Name    IMPORT NamedObj;
FROM IOMod   IMPORT StreamObj;

CONST
  WarDuration = 180;
  CohortSize  =  4;

TYPE
  DataArrayType = ARRAY INTEGER, INTEGER OF REAL;

  ConsumerObj = OBJECT(MovingObj);

        MyNumber         : INTEGER;
        Wings            : INTEGER;
        DayOfConflict    : INTEGER;
        CarrierGroup     : BOOLEAN;
        ImAStationShip   : BOOLEAN;
        WithStationShip  : BOOLEAN;
        MyStationShip    : StationShipObj;
        PriLogBase       : LogBaseObj;
        Alternative      : BOOLEAN;
        SecLogBase       : LogBaseObj;
        FoodEnroute      : BOOLEAN;
        FuelEnroute      : BOOLEAN;
        AmmoEnroute      : BOOLEAN;
        UnrepLimit       : REAL;
        ConsolLimit      : REAL;
        FuelState        : REAL;
        JP5State         : REAL;
        FoodState        : REAL;
        AmmoState        : REAL;
        FuelCapacity     : REAL;
        JP5Capacity      : REAL;
```

```
          FoodCapacity       : REAL;
          AmmoCapacity       : REAL;
          BurnRate, JP5Rate, FoodRate, AmmoRate  : REAL;
          AvgBurnRate, MaxBurnRate, MinBurnRate  : REAL;
          AvgJP5Rate, MaxJP5Rate, MinJP5Rate     : REAL;
          AvgEatRate, MaxEatRate, MinEatRate     : REAL;
          AvgAmmoRate, MaxAmmoRate, MinAmmoRate  : REAL;


          ASK METHOD ObjInit;
          ASK METHOD Register(IN Order, Total: INTEGER);
          ASK METHOD ReInventory(IN MoreFuel,MoreJP5, MoreFood, MoreBombs: REAL);
          ASK METHOD OnLoad(IN What: ProductType; IN HowMuch: REAL);
          ASK METHOD OrderOut(IN Stuff: ProductType);
          ASK METHOD WriteUp(IN SameStuff: ProductType): RequestObj;
          ASK METHOD PriBase(IN Primary: LogBaseObj);
          ASK METHOD SecBase(IN Secondary: LogBaseObj);
          ASK METHOD InBound(IN Cargo: ProductType);
          ASK METHOD WriteTheMeans;


          TELL METHOD OpSum(IN ForceCount, Products: INTEGER);

   END OBJECT;

 VAR
   RNG              : RandomObj;
   Strm, Dat, ADat  : StreamObj;
   DataArray        : DataArrayType;

 END MODULE.
```

```
DEFINITION MODULE StationShip;

{*****************************************************************************
POC: LT Dave Salzer(salzer@or.nps.navy.mil) 408-656-2786  NPS Monterey, CA

        The StationShip, when enstatiated, is co-located with its consumer.
It differs only in that it has parameters for product transfer rates.  When
called upon to UNREP its consumer, the station ship tops off (down to exhaustion)
the consumer with each commodity.  When the station ship itself is depleted to
a level identified by the user, it requests a CONSOL for those products.

*****************************************************************************}



FROM Consumer IMPORT ConsumerObj;
FROM Request  IMPORT RequestObj, ProductType;

TYPE
  StationShipObj = OBJECT(ConsumerObj);

        TransitT: REAL;
     AvgPumpRate, MaxPumpRate, MinPumpRate :  REAL;
     AvgJPXRate,  MaxJPXRate,  MinJPXRate  :  REAL;
        AvgProvRate, MaxProvRate, MinProvRate :  REAL;
        AvgArmRate,  MaxArmRate,  MinArmRate  :  REAL;

        TELL METHOD UnRep(IN Receiver: ConsumerObj);
        OVERRIDE ASK METHOD ObjInit;

  END OBJECT;

END MODULE.
```

```
DEFINITION MODULE Request;

{********************************************************************************
POC: LT Dave Salzer(salzer@or.nps.navy.mil) 408-656-2786  NPS Monterey, CA

        The RequestObj is the fundamental unit of communication between the
working objects.  It contains the essential information required for the
shuttles and the managers to calculate and project inventory depletion and
travel time.
*********************************************************************************}


FROM Consumer IMPORT ConsumerObj;

TYPE  ProductType = (Fuel, JP5, Food, Ammo);

   RequestObj = OBJECT
       Commodity:  ProductType;
       Quantity:   REAL;
       Customer:   ConsumerObj;

   ASK METHOD ReqData(IN Who:     ConsumerObj;
                      IN What:    ProductType;
                      IN HowMuch: REAL);


   END OBJECT;

END MODULE.
```

```
DEFINITION MODULE Shuttle;

{*****************************************************************************
POC: LT Dave Salzer(salzer@or.nps.navy.mil) 408-656-2786  NPS Monterey, CA

        Shuttles are the only moving objects in the simulation, and manage
their own actual and uncommitted inventory levels.  A shuttle steams from
consumer to consumer (on its delivery list) and CONSOLs the required product.
F76 & JP5 are delivered together.  When its delivery list is exhausted, the
shuttle returns to its logistics base to reload.
*****************************************************************************}


FROM Destination IMPORT  DestinationObj;
FROM Consumer    IMPORT  RNG;
FROM StationShip IMPORT  StationShipObj;
FROM GrpMod      IMPORT  QueueObj;
FROM LogBase     IMPORT  LogBaseObj;
FROM Request     IMPORT  RequestObj, ProductType;
FROM Mover       IMPORT  MovingObj;

TYPE
  ShuttleObj = OBJECT(MovingObj);

        Commodity   : ProductType;
        HomeBound   : BOOLEAN;
        HomeBase    : LogBaseObj;
        Deliveries  : QueueObj;
        LastStop    : DestinationObj;
        FuelCapacity, JP5Capacity, FoodCapacity, AmmoCapacity : REAL;
        FuelRemaining, JP5Remaining, FoodRemaining, AmmoRemaining : REAL;
        FuelAvail,    JP5Avail,    FoodAvail,    AmmoAvail    : REAL;
        AvgXferRate,  MaxXferRate,  MinXferRate:     REAL;
        AvgJPXRate,   MaxJPXRate,   MinJPXRate:      REAL;
        AvgSpeed,     MaxSpeed,     MinSpeed:        REAL;
        StartClock,   StopClock,    UnderWayClock:        REAL;

        ASK METHOD ObjInit;
        ASK METHOD HomeData(IN Mother:LogBaseObj; IN Load:ProductType);
        ASK METHOD LookAhead(IN Cargo: ProductType;
                IN SupplyReq: RequestObj): REAL;
        ASK METHOD TopOff;
        ASK METHOD TimeCheck;
        ASK METHOD WatchStart;
        ASK METHOD AcceptRequest(IN SupplyReq: RequestObj);
        TELL METHOD Consol(IN SupplyReq: RequestObj);

  END OBJECT;

 END MODULE.
```

```
DEFINITION MODULE LogBoss;

{****************************************************************************
POC: LT Dave Salzer(salzer@or.nps.navy.mil) 408-656-2786  NPS Monterey, CA

        The LogBoss is a queue manager for underway shuttles.  The Boss will
assess whether any of these shuttles can handle a replenishment request, then
adds the task to the delivery list of the shuttle who will be closest to the
customer making the request.
****************************************************************************}

FROM LogBase  IMPORT LogBaseObj;
FROM Shuttle  IMPORT ShuttleObj;
FROM Request  IMPORT RequestObj;

TYPE
  LogBossObj = OBJECT(LogBaseObj);

        ASK METHOD OutChop(IN EmptyShuttle: ShuttleObj);
        ASK METHOD InChop(IN Steamer: ShuttleObj);

        OVERRIDE ASK METHOD ObjInit;
             ASK METHOD CanHandleIt(IN SupplyReq: RequestObj):  BOOLEAN;
             ASK METHOD TakeRequest(IN SupplyReq: RequestObj);

  END OBJECT;

VAR
  Boss: LogBossObj;

END MODULE.
```

```
DEFINITION MODULE LogBase;

{***************************************************************************
POC: LT Dave Salzer(salzer@or.nps.navy.mil) 408-656-2786  NPS Monterey, CA

        The LogBase, like its descendent the LogBoss is a queue manager for
shuttles.  The base will assess whether any shuttles in its charge can handle
a replenishment request, then assign the shuttle(s) as appropriate.  The Base
also handles the delay of inport reloading.
***************************************************************************}



FROM GrpMod   IMPORT QueueObj;
FROM Shuttle  IMPORT ShuttleObj;
FROM Request  IMPORT RequestObj;
FROM Destination IMPORT DestinationObj;

CONST
  InportWaitTime = 48.0;

TYPE
  LogBaseObj = OBJECT(DestinationObj);

        FoodShuttles:  QueueObj;
        FuelShuttles:  QueueObj;
        AmmoShuttles:  QueueObj;

        FoodBackLog:  QueueObj;
        FuelBackLog:  QueueObj;
        AmmoBackLog:  QueueObj;

        ASK METHOD ObjInit;
        ASK METHOD CanHandleIt(IN SupplyReq: RequestObj):  BOOLEAN;
        ASK METHOD TakeRequest(IN SupplyReq: RequestObj);
        ASK METHOD BackLog(IN SupplyReq: RequestObj);
        TELL METHOD ReLoad(IN EmptyShuttle: ShuttleObj);


  END OBJECT;

END MODULE.
```

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