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A Study of Aviation Resources and Readiness Relationships

Volume III

The Resupply System for Naval Aviation Spare Parts

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CENTER FOR NAVAL ANALYSES

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Study 32

A STUDY OF AVIATION RESOURCES AND READINESS RELATIONSHIPS

VOLUME III

THE RESUPPLY SYSTEM FOR NAVAL AVIATION SPARE PARTS

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ABSTRACT

The resupply system for Naval aviation spare parts is an important factor in fleet aviation readiness. This volume documents a resupply structure used to investigate the various processes that constitute the resupply system. The investigation determines the improvements in resupply time that are obtainable under alternative budget levels. The major results are that the performance of the CONUS resupply system for high priority aviation spares is poorer than is acknowledged and that the critical resource in the system (of those we could examine) is spare parts for filling incoming requisitions.

Volume II of this study examines the relationship between aircraft readiness and the aircraft, maintenance labor, and spare parts available at the squadron level.

Volume I is a summary volume and contains a description of the project, the methodologies used, and the principal conclusions and recommendations.

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INTRODUCTION

BACKGROUND

The readiness of Naval aviation in the fleet is supported by the squadron which uses the resources at its disposal -- maintenance activities, spare parts, planes -- and by the complex logistics system which makes these resources available.

The spare parts used by deployed squadrons to repair aircraft are available either because the parts were stocked aboard the carrier prior to its deployment or because the parts were resupplied to the carrier during its tour. This presents a fundamental tradeoff to decision makers in the system. Parts which are initially stocked aboard a ship are, for all practical purposes, "lost" to the rest of the system but are immediately available to the squadrons on that ship. Parts which must be resupplied involve a waiting time for the part but before shipment, are simultaneously available to all squadrons supported by the system.

The random nature of part failures makes the tradeoff between initial stockage and resupply difficult to quantify. Successful resolution of this problem, however, certainly requires a study of the resupply system for aviation parts, including expected resupply times. Expected resupply time is a necessary factor in analyzing the tradeoff between expenditures on resupply and on initial stockage: the shorter the expected resupply time, the lower the requirements for initial stockage in order to maintain a given level of aviation readiness.

PURPOSE

This study had four tasks:

1. To investigate and structure the resupply system for aviation spare parts.
2. To estimate expected completion times for different categories of parts. The primary data source for completion of this task was the MILSTEP system (see appendix A). This data system contains the vital dates in the history of requisitions for all types of spare parts.
3. To determine the costs and benefits of improvements in each sub-process of the system.
4. To determine the optimal combination of improvements for a given budget with respect to 2 measures of effectiveness: expected (average) resupply time, and the probability of completion by a given day.

ASSUMPTIONS

The principal assumptions in this analysis are:

1. The percentages of IG-1 requisitions (high priority) filled locally and in CONUS remain fixed.

2. The system operates under the current policy on the use of forward supply points in the pre-screening of requisitions.

3. The rate at which requisitions are generated in the fleets remains constant, as does the mix of requisitions by type and priority.

These assumptions arise because of the significant interdependence of the resupply system and other aspects of Naval aviation support. To violate these assumptions might result in sub-optimization of the resupply system, which would be detrimental to the overall objective of readiness.

PRINCIPAL RESULTS AND CONCLUSIONS

The following are the principal results from the study of the present resupply system:

1. The average completion time for IG-1 requisitions filled in CONUS is about 35 to 38 days (depending on location), with almost half this time taken in processing at the ICP. In each fleet, about 60 percent of the requisitions were completed by the 35th day, 16 to 19 percent were completed by the 10th day, and 80 percent were completed by the 50th day. These results represent resupply times only for requisitions filled in CONUS, however; the standard for IG-1 requisitions, regardless of where the requisitions are filled, is 7 days.

2. The mix of requisitions for consumable and repairable items is about the same for each fleet within an issue group: about 30 percent of IG-1 requisitions and 60 percent of IG-2 requisitions (lower priority) are for consumables from both the Pacific and Atlantic fleets. Although these percentages were expected, it was anticipated that the mix of requisitions from the Pacific, where forward supply points have sophisticated repair capabilities, would be different from the mix for the Atlantic fleet. This suggests that repairables are ordered from CONUS without waiting for their local repair. Further, the average submission time for repairables is greater than for consumables.

3. The majority of requisitions filled in the fleet are for consumables. This also supports the observation just made that few repairables requisitions are completed locally. This does not mean that local repair facilities are not performing their mission; it suggests merely that squadrons are ordering replacement components from CONUS while the damaged carcasses are being repaired locally.

As a result, squadrons often receive two parts for each failed repairable. Incentives in the system produce this behavior, the principal one being that squadrons are not charged for components. Since the average cost of a component is $2,810, this action is expensive to the system.

4. Only about half of the IG-1 requisitions from deployed carriers reaching the Aviation Supply Office (ASO) are for parts ready for issue. This highlights a definite problem with ASO's procurement policies: 32 percent of the parts must be purchased and 19 percent must come from a NARF. Average backorder times, either against a buy or against NARF production, are long, resulting in an average 18-day delay at the inventory control point.

The major results of the cost-benefit analysis of the CONUS resupply system are as follows:

1. When the resupply system is burdened with the availability of parts, there are only two potential improvements which are more cost-efficient than the purchase of spare parts to increase the probability of availability at ASO: altering the percentage of issues from the major stock points, and eliminating the use of surface overseas transportation.

2. When about $12 million is spent on the system on an annual basis ($6 million for each fleet), the average resupply time is decreased by about 5 days (or 14 percent) in the Atlantic and 8 days (or 21 percent) in the Pacific fleet.

3. The optimal combination of potential improvements for any given budget constraint is the same regardless of whether one minimizes the expected resupply time or maximizes the probability of completion by the 15th day.

4. Considered independent of the rest of the support system, there is nothing that can be done to the resupply system to increase its response time for CONUS-filled requisitions significantly beyond the results discussed above.

THE RESUPPLY SYSTEM

REQUISITION CLASSES

The resupply system is defined as the sequence of logistics activities used in the requisitioning, processing, and transporting of aviation spare parts to deployed carriers. This is a subset of the total Naval resupply activities since we are only interested in aviation parts and, further, only those aviation parts which are destined for carriers.

Requisitions for spare parts which fall into the above category differ in many ways. Some of these are the type of part requisitioned, the location of the requisitioner, and the priority attached to the requisition. Naturally, each requisition is treated in accordance with its individual characteristics. However, for this study it is necessary to group requisitions in classes which may be considered homogeneous. To this end, we assign each requisition to a class based on the following 3 criteria:

- Type of material ordered – We consider only whether material is an end-use component (repairable) or a bit-and-piece (consumable). We will only be concerned with those parts under the cognizance of the Aviation Supply Office (ASO), and thus we use 1-R COG material for consumable and 2-R COG for repairable spares. (Approximately 97 percent of material under ASO cognizance is either 1-R or 2-R.)

- Location of requisitioner – Since we are only interested in requisitions from deployed carriers, we consider the location to be either the Atlantic or the Pacific Fleet.

- Priority of requisitions – The priority which may be assigned to requisitions is covered in the Uniform Material Movement and Issue Priority System (UNMIPS). UNMIPS delivery standards are established by issue group, and we will consider only the requisitions in Issue Group 1 or 2 (IG-1 or IG-2). IG-1 requisitions consist of priorities 1 to 3 and include the great majority of all NORS (Not Operationally Ready, Supply) and NFE (Not Fully Equipped) requests. Issue Group 2 requisitions include priorities 4 to 8 and generally represent requisitions for replenishment of stock. Priorities above 8 are rarely used by deployed carriers ordering aviation parts.

RESPONSIBILITIES OF THE SYSTEM

One can view the resupply system to be the series of activities required to deliver available spare parts to carriers. Such a view of resupply considers only processing and transportation resources and ignores the availability of parts.

Another view of resupply burdens this system with the management of spares and spares placement and thus penalizes the system for the unavailability of parts. Although availability is a crucial question in the resupply system, the purchasing and management of spares is not the responsibility solely of the resupply system but rather of the entire support system of which resupply is but a part.

The resolution of this ambiguity in definition is beyond the scope of this study, and we will consider and report results for both definitions of the resupply system.

LEVELS OF RESUPPLY

Worldwide

Once a part fails on a plane there are 3 possible sources for replenishment – from carrier stock, from activities local to the carrier, and from the continental United States (CONUS).

If the part is in stock on the carrier, it is issued and the demand is met. If the inventory has to be replenished, a request is made of the system but on low priority (usually priorities in IG-2 are used).

If the part is not in stock (NIS), a requisition of higher priority (probably IG-1) will leave the ship. (If the absence of the part is causing a plane to be grounded, the requisition, in addition to being assigned a high priority, is coded as "NORS.")

Upon leaving the carrier, requisitions are said to enter the supply system. There are 2 echelons of this system which can effect resupply. The ultimate issuing activity can be either local to the requisitioner – that is an activity such as another carrier or a forward stock point in the Atlantic or Pacific – or in CONUS. The present Naval system has several forward supply depots and intermediate maintenance activities for the resupply of carriers in the Pacific (primarily Naval Supply Depot (NSD), Subic, NSD Guam, and NSD Yokosuka). There are no major stock points comparable to these in the Atlantic, and as a result the great percentage of requisitions originating in the Atlantic are filled from CONUS.

The percentage of IG-1 resupply requisitions from both locations filled at each echelon of the supply system is shown in table 1. (These results are based on a report of a 1968 tour of the USS America in the Pacific and a study of requisitions from the Atlantic done by the Aviation Material Office, Norfolk, in 1969.)

TABLE 1

PERCENTAGE OF IG-1 REQUISITIONS FILLED
LOCALLY AND IN CONUS

	Local	CONUS
Atlantic	10	90
Pacific	55	45

This study assumes that these percentages are fixed. We have addressed the question of optimal resource allocation assuming adherence to the current policy on pre-positioning of spares and pre-screening of spares requisitions. The question of spares positioning is discussed fully in the last section. We also assume the rate at which requisitions are generated in the fleets remains constant as well as the mix of requisitions (by type – 1-R or 2-R – and priority – IG-1 or IG-2).

CONUS Resupply

If a resupply requisition cannot be filled by a local activity, it enters the CONUS resupply system. The general flow of the requisition through this process is shown in figure 1. The sub-processes are discussed below.

Submission to Inventory Control Point (ICP) – After being screened for possible local resupply,* requisitions are transmitted, generally via AUTODIN, to the appropriate ICP. (As indicated previously, ASO is the primary ICP for aviation spares and the only one considered in this study.)

ASO processing – ASO first enters the system when the requisition is received via AUTODIN, mail, or message. ASO receives over 200,000 requisitions each month. The ASO computer then performs the following operations for each requisition:

- If the message cannot be deciphered, it is canceled, and the requisitioning activity is requested to resubmit the requisition.

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* The ASO policy on this procedure is in a state of transition. While ASO currently discourages screening of requisitions by the forward supply points, this has had little, if any, effect on the actions of activities in the Pacific. ASO's ability to act as a central inventory manager is severely limited by their restricted visibility of parts worldwide. In the Atlantic, the ASO policy has resulted in requisitions being routed directly to ASO rather than to NSC Norfolk which used to perform a screening function.

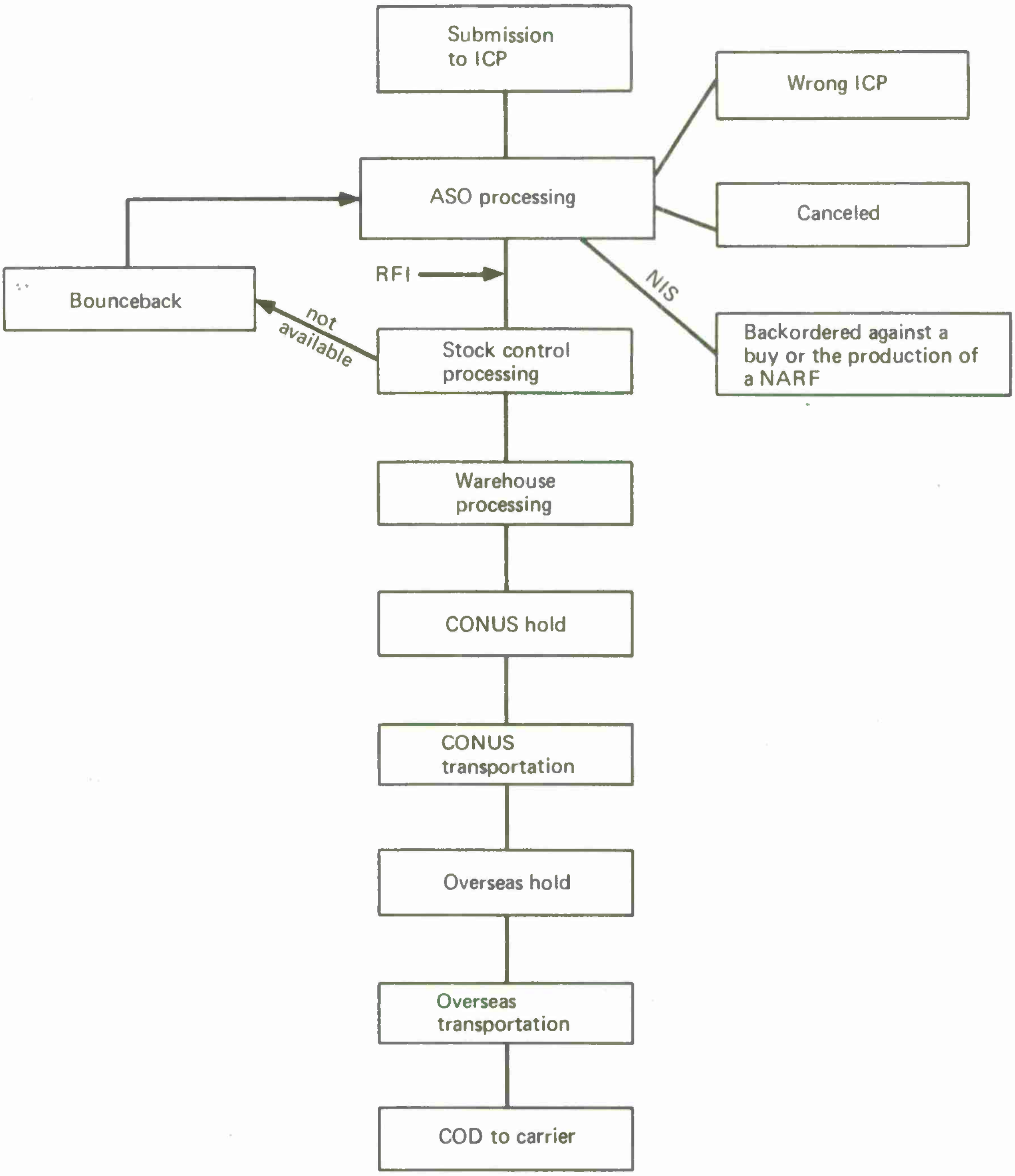

FIG. 1: CONUS RESUPPLY SYSTEM

• If the part requested is not controlled by ASO, it is automatically passed to the appropriate ICP.

• If the part is obsolete or cannot be identified by ASO, the requisition may be canceled.

If the requisition passes these 3 screening actions the computer will search through its inventory records for the item. The depth to which the computer will search through the inventory at each of its stock points will depend on the priority of the requisition. For example, a NORS-designated requisition will signal the computer to search for the item at all levels of inventory, while a lower priority requisition will consider some reserves at each stock point to be inviolate.

Once the item is located, the requisition is automatically referred to the stock point. The requisitions that are completed in this manner are handled completely within the computer. (There are some items under fleet control which require special handling regardless of the priority of the requisition.)

If the item is not in stock (NIS) in the inventory of the various stock points, the computer will print out the requisition for handling by an ASO commodity manager. The options open to this manager are (1) to see if the item is on contract order, and if so have the contractor send the item directly; (2) to back-order the requisition against a future buy (if the requisition is of high priority, it might stimulate an emergency buy of the item); or (3) if the item is repairable but is not in ready-for-issue (non-RFI) condition, a carcass may be inducted into a Naval Air Rework Facility (NARF) with the requisition held for completion of the rework.

Stock Control Processing - When the requisition is received at the stock point, the item is located in the inventory files and papers are cut to authorize issuance of the material. In a significant percentage of cases, however, the stock point reports a part not-in-stock. This occurs because the stock point either does not actually have the part available or because it does not wish to issue it for fear of depleting its stock. These requisitions are returned to ASO, and the cycle is repeated.

It should be noted at this point that there are at least 3 categories of stock points in aviation.

• The industrial air stations (so called because they are co-located with the NARFs) are the largest supplier of aviation parts. These first-line air stations are charged with the support of the NARF on their base, the squadrons stationed on their base, and deployed squadrons. These air stations provide approximately 63 percent of the total parts for support of deployed squadrons.

- The second category of air stations are the master jet bases. These second-line air stations are smaller than the first-line stations and are charged primarily with the support of the squadrons on their base or a particular type of aircraft. Their interest in deployed squadrons is clearly secondary and does not constitute a major percentage of their day-to-day workload. (As a result, the bounceback rates of these activities is considerably higher than that of the first-line activities.) These air stations ultimately fill about 27 percent of the requisitions which flow through the CONUS system.

- The Naval Supply Centers are the third source of parts, providing about 10 percent (a percentage which has been decreasing in recent years as ASO has attempted to move aviation parts to the air stations). The NSC's are of substantial size and are treated as comparable to the first-line air stations.

Warehouse Processing – At the warehouse, the item is located and packed and prepared for shipment.

CONUS-hold – Once the item is turned over to the transportation officer at the stock point, it is his responsibility to coordinate its movement to the appropriate port of embarkation in the U. S. On items to be shipped overseas, the shipper will either send it parcel post or, if the item exceeds certain specifications (generally based on size and weight), he will contact the Naval Transportation Coordinating Office (NavTransCo) for routing and designation of the port of embarkation. In certain cases NavTransCo will contact the requisitioner to challenge the priority which is attacked to the shipment.

While NavTransCo is coordinating the movement, or while the item is awaiting pickup by the appropriate equipment, it is in a hold status at the stock point. This hold status prior to movement within CONUS is referred to as CONUS hold.

CONUS Transportation – If the port of embarkation for the item is near the issuing activity, CONUS transportation will consist of sending the shipment only a short distance. If the distance warrants it, movement will generally be via the QuickTrans system. QuickTrans is a commercial air carrier under contract to the Navy to run on a designated schedule between major points in the U. S. The time necessary to send parts to Military Airlift Command (MAC) airports or Military Sea Transportation System (MSTS) ports from the nearest QuickTrans airport is included in CONUS transportation.

Overseas-hold – The overseas shipment of aircraft spares will take place via the Military Airlift Command (MAC) or the Military Sea Transportation System (MSTS). Once an item arrives at a MAC airport or an MSTS port, there is generally a delay in consolidating and repacking in preparation for overseas shipment and in awaiting departure.

Overseas Transportation - MAC is a cargo transportation system operated by the Air Force to serve the DOD and operates on an established schedule from certain airports in the U. S. to overseas bases. MSTS also runs on a schedule from U. S. ports to overseas bases.

At this point it should be noted that while about 60 to 70 percent of IG-1 parts are sent directly by parcel post, thus avoiding the QuickTrans - MAC/MSTS systems, these parts are subject to a very similar transportation system. While the mail does not routinely travel in military aircraft, its CONUS and overseas travels should parallel an item sent via QuickTrans and MAC. We will thus assume that, while many parts actually do not go the exact route shown in figure 1, their travel time may be satisfactorily described by the time experienced by parts which move through the QuickTrans - MAC systems.

COD to Carrier - At the forward supply point, a Carrier Onboard Delivery (COD) aircraft will transport the items (including all mail) to the carrier. Where COD's are not available, other replenishment procedures are used.

Figure 2 is a redrawing of figure 1 to reflect the above description. There are 6 major sub-processes in the CONUS resupply system, with each having one or more components. The purpose of creating different boxes within a sub-process is that there is a strong belief, supported by the data, that requisitions going through one box are subject to fundamentally different processing - and therefore different processing delays -from requisitions going through another box. For example, requisitions for 1-R and 2-R material are submitted in significantly different lengths of time, and thus are treated as separate processes. It is clear from figure 2 that a requisition must pass through each of the 6 sub-processes but only along any one branch within a sub-process.

A fundamental assumption of this paper is that the 6 major sub-processes are independent of each other, that is, the time to complete any sub-process is independent of the processing delays it experienced prior to and experiences after leaving the sub-process. (The requirement for and implications of this assumption are discussed in the section titled Cost Benefit Curves for the CONUS Resupply System.)

Submission times and the transportation sub-processes also depend on the location - Atlantic or Pacific - of the requisitioner. Although figure 2 does not indicate this distinction, we will always distinguish between location when presenting data and results.

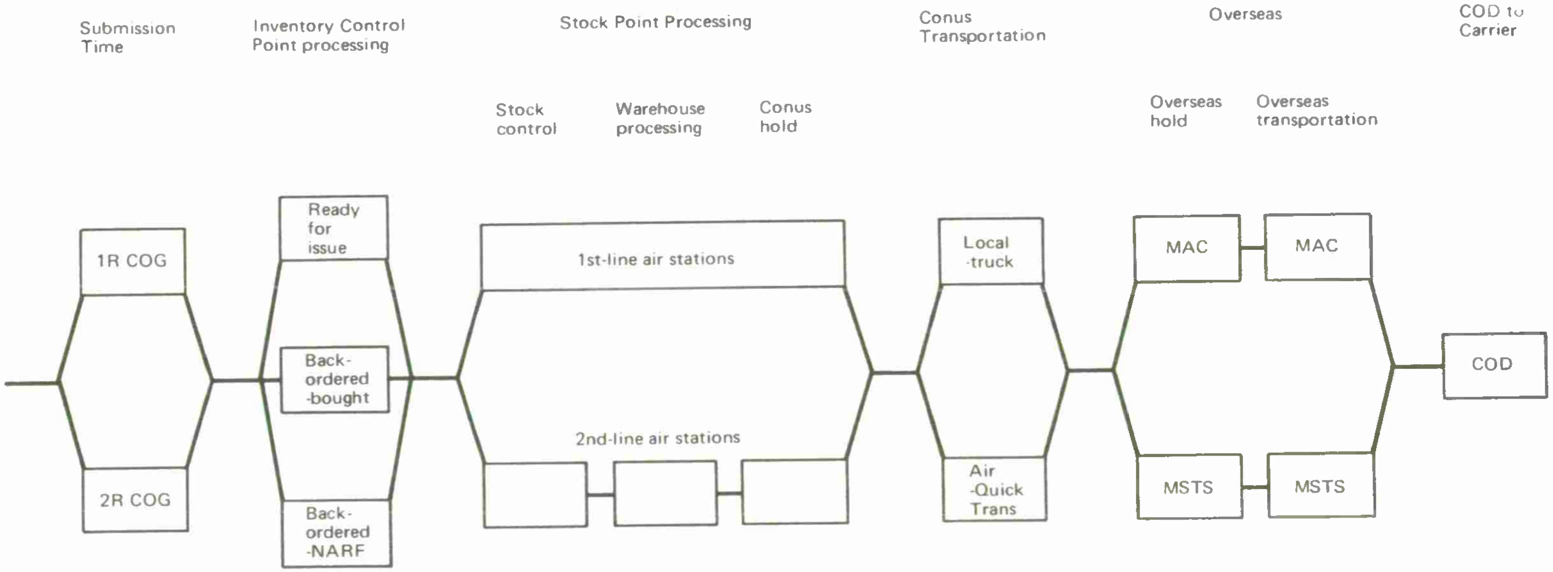

FIG. 2: REVISED CONUS RESUPPLY SYSTEM FLOW-CHART

DATA ANALYSIS

PRELIMINARY COMMENTS

Inputs to the Model

The optimization model presented in the next section requires two sets of inputs for each of the sub-processes shown in figure 2.

First it requires an estimation of the "elements" of the present system. The elements of each sub-process are the parameters of one or more probability distributions and the appropriate probabilities for each type of processing within a sub-process. For the CONUS transportation sub-process, for example, the elements are the parameters of the 2 probability distributions–QuickTrans air transportation and the local transportation by truck–and the probability that an item will be shipped via air or via truck. Each of the elements of the present system are estimated by the techniques discussed below.

The second input required for the model is the estimation of how each of the elements of the system will change as money is spent for improvements. Some of the elements of the system, such as the mix of 1-R and 2-R requisitions from each fleet, are unaffected by increased expenditures. Other elements, however, such as the probability distribution for CONUS air transportation as the QuickTrans contract is increased, are subject to improvement. While we estimate the elements of the current system for IG-1 and IG-2 elements, we will only present improvements for IG-1 requisitions.

Each of the 6 major sub-processes are considered below. The elements of the current operations are estimated, and, for those elements which are potentially improvable, the improvements and their associated costs are estimated.

Use of Gamma Distribution

It has been noted that the time to complete each sub-process of the resupply system is a random variable. We assume that this random variable can be described by a gamma distribution (or, more exactly in some cases, by a convex combination of gamma distributions). There is strong precedent for such use.

The gamma distribution is a two-parameter distribution with the following density:

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \quad x^{\alpha-1} \quad e^{-\frac{x}{\beta}}, \quad x \geq 0 .$$

It represents the occurrence of the α^{th} event when each event occurs with mean time β. This distribution is commonly used in queueing theory to represent the random time to completion of several independent processes. Since this is exactly the situation present in this analysis, we feel confident in the use of this distribution. (We will be using a special form of the gamma distribution by restricting α to an integer, a common use in queueing applications.)

The gamma distribution is zero for values less than or equal to zero (which correctly reflects the fact that there is zero probability of completion in less than zero days) and has some finite probability at every point greater than zero. The mean of a gamma distribution is equal to the product of the parameters ($\alpha \cdot \beta$), and its variance is equal to $\alpha \cdot \beta^2$.

Our estimation of the gamma distributions from historical data and of the improvement estimates for each sub-process will be by the well-known method of "maximum likelihood." The technique used for this estimation is presented in reference (a).

Data Source

In our attempt to achieve an optimal system, it was necessary to estimate a probability distribution for the time to complete each sub-process of the resupply system.

The data maintained by Military Supply and Transportation Evaluation Procedures (MILSTEP) was ideally suited for this purpose. Of particular interest in this analysis was the fact that MILSTEP follows all resupply requisitions from their origin to ultimate completion, noting, among other data, the date of completion (and in some cases the time) of each of the sub-processes shown in figure 2 (except COD delivery time), as well as the priority, stock number, requisitioning activity, and issuing activity. A fuller discussion of MILSTEP and the data that was extracted for each requisition given in appendix A.

There were several problems in the use of the MILSTEP system. The most crucial of these was attributable to the newness of this system in the Navy. The only aviation ASO COG requisitions which were followed through the system are those which were filled by one of 3 master jet bases or the Naval supply centers. Thus the major supplier of parts, the first-line industrial air stations, were not included.

This made it necessary for us to supplement MILSTEP with some other data from the first-line air stations. The fact that items which are mailed back to the requisitioner do not appear on MILSTEP precluded the use of this time frame and led to the assumption, discussed earlier, that this time was close to the time for the QuickTrans-MAC movement. Other problems with the MILSTEP data and some recommendations are included in the appendix.

One recurring problem with the use of MILSTEP was that we were able to obtain elapsed times only by subtracting dates. Thus, whether a requisition started a sub-process at 2350 or at 0001 on a given date and was finished on the following day, we would conclude that the process took one day when in fact anywhere from just a few minutes to up to 48 hours might have elapsed. The convention we adopted was to weight a completion time of zero days (date completed the same as date commenced) as 0.5 of a day and to accept all other completion times as whole numbers of days.

THE RESUPPLY SUB-PROCESSES

Submission Time

Submission time is defined here as the elapsed time between the date on the requisition and the date the requisition arrives at ASO. This period includes communication time and the screening of the requisitions aboard the ship and at forward supply points.

Since the screening of requisitions in the Pacific is known to be more extensive than in the Atlantic, we would expect submission time to also be greater. Similarly, since the failure of a repairable part is often correctable while the failure of a consumable is not, we would expect requisitions of repairables to bounce around locally to a greater extent before being requisitioned from CONUS.

Both of these hypotheses are verified in table 2, which shows the average number of days elapsed for each issue group, each destination, and each type of material, and the percentage of requisitions completed on or before the fifth day. (The data in this section is all derived from the MILSTEP system unless otherwise noted.) Note that although the average number of days is high, the majority of requisitions arrive well before the average. The high average is caused by a small percentage of the requisitions taking a long period of time. This occurs throughout the analysis.

TABLE 2

SUBMISSIONS: TIMES AND PERCENTAGES

Number of days—average

(Number of requisitions observed)

	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	6.17 (92)	9.33 (208)	8.35 (307)	9.80 (908)	11.82 (625)	10.68 (1542)
Pacific	6.99 (188)	11.42 (420)	10.08 (616)	10.86 (752)	18.73 (484)	13.94 (1244)
Percentage completed in 5 days or less						
Atlantic	62.74	59.54	61.11	42.60	37.87	40.56
Pacific	58.63	45.52	49.08	43.20	31.67	38.76

In general, consumables are submitted before repairables, and requisitions from the Pacific take longer than from the Atlantic. Not surprisingly, the requisitions taking the longest time are for repairables from the Pacific, where numerous efforts might be made to fix a repairable before it is ordered. While ASO indicates that the average age of a requisition upon receipt by them is 6-7 days for IG-1 and 9 to 10 days for IG-2, these figures include requisitions from CONUS-based squadrons where the submission time is clearly lower.

The evidence presented in table 2 suggests that the 2 types of requisitions from each location should be treated separately. We have thus estimated gamma distributions for each category of parts for each issue group. (The parameters for this sub-process as well as the entire CONUS resupply system are presented in figures 5A and 5B.)

An example of the fit provided by the gamma distribution is presented in table 3. It is clear that a gamma distribution with parameters $\alpha = 1$ and $\beta = 6.17$ (a gamma distribution with $\alpha = 1$ is also referred to as an exponential distribution) provides an excellent fit for the submission time of IG-1 requisitions from the Atlantic. This is indicative of the type of fit we experienced for each of the sub-processes using the technique of maximum likelihood.

TABLE 3

COMPARISON OF ACTUAL AND ESTIMATED SUBMISSION TIME DISTRIBUTIONS FOR IG-1/1-R ATLANTIC REQUISITIONS

	Actual percentage completed on this day	Actual accumulative percentage completed on or before this day	Estimated completed on or before this day -gamma distribution (1, 6.17)**
Day 0*	9.80	9.80	14.96
1	17.65	27.45	27.69
2	3.92	31.37	38.50
3	10.78	42.15	47.70
4	14.71	56.86	55.53
5	5.88	62.74	62.18
6	5.88	68.62	67.84
7	2.94	71.56	72.65
8	3.92	75.84	76.74
9	1.96	77.44	80.22
10 or more	22.56		

*This is the number of days between commencement and completion of the process. When this value is 0, the process was begun and finished on the same day.

**See text.

Table 4 shows the ratio of 1-R and 2-R requisitions to the total in each location. It is interesting and surprising that the ratio of 1-R to 2-R is about the same from either fleet in both issue groups. Given the large repair facilities in the Pacific, it was expected that a smaller percentage of the Pacific mix would be repairables. In actuality there is a slight effect in the other direction. (This observation will be discussed later in this section.)

TABLE 4

PERCENTAGE OF 1-R AND 2-R REQUISITIONS BY FLEET

Issue group	Fleet	COG	Number	Percent
1	Atlantic	1-R	102	32
		2-R	215	68
		Total	317	100
	Pacific	1-R	191	30
		2-R	446	70
		Total	637	100
2	Atlantic	1-R	920	59
		2-R	639	41
		Total	1559	100
	Pacific	1-R	787	60
		2-R	521	40
		Total	1308	100

The surprising figures shown in table 2 (the UMMIPS' standard for the entire resupply process for IG-1 is 7 days) stimulated a NavSup study (reference (b)) which, examining submission time for all types of parts, came up with the following problems:

- The date on the requisition was not the date it left the ship. The supply and IMA activities on board a carrier attempt to repair a part or find a substitute after the requisition is cut. Thus it might be several days or weeks before a requisition is finally sent off. In addition, requisitions being mailed might suffer a delay before being picked up. While this last point is not relevant for high priority aviation requisitions which are generally sent by message, it is clear that the requisition date is often not the date that resupply activities commence. Therefore, while the total resupply time does reflect time that the ship is without the part, it does not necessarily reflect the time required by the logistics support system to replace it.

- The date of receipt was not being logged in at the first point of entry in the supply system. Although it was the policy for the first point of entry in the supply system to log in the date of receipt, thus completing the submission timeframe, NavSup discovered, and this was supported by ASO, that most items arrive at ASO without this date. This allows us to use MILSTEP for our definition of submission time but represents another ambiguity in the system.

Despite the difficulties in pinning down submission times, there are no clear improvements which can be proposed in the context of this study. It would be rash to assert that immediate forwarding of all requisitions to ASO, while certainly decreasing submission time on CONUS-filled requisitions, is beneficial for the overall system. Since we are taking the current policy on forward supply points as fixed, no improvements can be suggested at this time.

ASO Processing

Once a requisition is received at ASO, one of at least five possible actions may be taken:

(1) The requisition might be canceled, because the part is obsolete, or otherwise unobtainable, or because the request is unintelligible, or because the requisitioner asked for its cancellation;

(2) It may be passed to another inventory control point if ASO does not manage the part;

(3) It may be backordered against the appropriate NARF if the item is not ready-for-issue (non-RFI) and is 2-R COG;

(4) It may be purchased from the contractor or on the open market if the item is not RFI;

(5) If the item is RFI, it will be referred to the appropriate stock point.

During April 1970 ASO took the following action on the 222,500 requisitions which they were called to fill:

- 65.2 percent referred to stock point for issue
- 25.8 percent backordered from NARF or against future buy
- 7.6 percent canceled
- 1.4 percent passed to another ICP.

These percentages include all issue groups and requisitions from both CONUS and the fleets. Since ASO does not have a breakdown of the percent of IG-1 and IG-2 requisitions from the fleet, it was necessary to derive individual probabilities. This was accomplished by formulating seven equations involving the following seven unknowns.

F_R = percent of requisitions which are for repairables (2-R COG) and are filled at the forward supply points.

F_C = percent of requisitions which are for consumables (1-R COG) and are filled at the forward supply points.

A_R = percent of requisitions for repairables which are RFI at ASO.

A_C = percent of requisitions for consumables which are RFI at ASO.

B_R = percent of requisitions for repairables which have to be purchased.

B_C = percent of requisitions for consumables which have to be purchased.

N = percent of requisitions filled by the NARF.

We have derived 7 equations involving these variables. A separate set of equations is solved for IG-1 and IG-2 requisitions. The system parameters in which we are finally interested are functions of these 7 variables, defined below:

$$P_{RFI} = \frac{A_R + A_C}{A_R + A_C + B_R + B_C + N} = \text{RFI at ASO}$$

$$P_{BUY} = \frac{B_R + B_C}{A_R + A_C + B_R + B_C + N} = \text{Backordered against a buy}$$

$$P_{NARF} = \frac{N}{A_R + A_C + B_R + B_C + N} = \text{Backordered against a NARF}$$

These are the 3 probabilities which govern the flow of requisitions in figures 5A and 5B.

We now proceed to discuss the 7 equations which will allow us to solve for the 7 unknowns. We know that the sum of the 7 probabilities must be one. (We are considering net availabilities and thus exclude those requisitions which are canceled or passed.) Equation (1) is therefore:

$$F_R + F_C + A_R + A_C + B_R + B_C + N = M_I = 1 \qquad (1)$$

The second equation reflects the percentage of requisitions in the total mix which are for consumables. ASO data gives this for each issue group but not exclusively for deployed squadrons. It is ASO's estimate, however, that this mix is about the same for a carrier as for a CONUS-based stock point.

$$F_C + A_C + B_C = M_{II} \qquad (2)$$

(M_{II}, as well as the values of all other constants (to be defined below) is shown for IG-1 and IG-2 in table 5.)

TABLE 5

CONSTANTS AND RESULTS FOR THE SEVEN-EQUATION AVAILABILITY MODEL

	IG-1	IG-2
Parameter	Constants	
M_I	1.0	1.0
M_{II}	.60	.72
M_{III}	.76	.79
M_{IV}	.62	.57
M_V	.69	.40
M_{VI}	.75	.75
M_{VII}	.43	.39
Variable	Results	
F_R	.01	.04
F_C	.42	.35
A_R	.24	.12
A_C	.04	.21
B_R	.04	.03
B_C	.14	.15
N	.11	.09
P_{RFI}	.49	.54
P_{BUY}	.32	.30
P_{NARF}	.19	.16

The third and fourth equations are the net system availabilities of consumables and repairables respectively. The parameters M_{III} and M_{IV}, also shown in table 5, were estimated from 8 months of ASO data.

$$\frac{F_C + A_C}{F_C + A_C + B_C} = M_{III} \tag{3}$$

$$\frac{F_R + A_R}{F_R + A_R + B_R + N} = M_{IV} \tag{4}$$

The fifth equation is the percentage of repairables in the mix of requisitions that reach ASO. Taking the requisitions on MILSTEP as a sample, the parameter M_V is estimated and used in the following equation:

$$\frac{A_R + B_R + N}{A_R + A_C + B_R + B_C + N} = M_V \tag{5}$$

Equation 6 reflects the ratio of NARF production items in the total of repairables which are backordered. This comes from the percentage observed in April 1970 ASO data for all issue groups. It is assumed that this ratio holds for IG-1 and IG-2.

$$\frac{N}{N + B_R} = M_{VI} \tag{6}$$

The percentage of requisitions filled by the local supply activities is reflected in equation 7. The values for M_{VII} were derived from two sources: Using the estimates (as discussed above) that 55 percent of Pacific and 10 percent of Atlantic requisitions are filled locally, we used MILSTEP data to compute the percentage of requisitions filled overseas (net of those canceled); these figures were confirmed by independent estimates from ASO.

$$F_R + F_C = M_{VII} \tag{7}$$

The 7 equations presented above were solved with the values of the constants on the right hand sides as shown in table 5. The results, also shown in table 5, are quite unexpected. They indicate that less than half of IG-1 requisitions from deployed squadrons which reach ASO have parts ready for issue. It is interesting to note that of the 43 percent of requisitions satisfied by overseas stock points, only 2 percent are repairables: The remaining 98 percent of the requisitions filled overseas are consumables. The majority of parts which are RFI at ASO are repairables. The ASO availability of the IG-2 items is slightly better than IG-1.

The observation that very few of the requisitions filled in the fleet are for repairables is supported by the discussion on the consumable-repairable mix from table 4. We do not interpret this result to reflect on the capability of the repair facilities at forward bases. Rather we contend that the squadrons are ordering repairables from CONUS while simultaneously having their damaged carcasses repaired locally. The result in many cases (and this has been documented by Naval supply officers) is that 2 working parts are obtained for a given failed part. The incentives for the squadrons to behave in this manner are clear since they are not charged for repairable components.

It should be pointed out that the percentages cited above are a direct result of the constants estimated for $M_{II} - M_{VII}$. There can be no argument with the formulation of the 7 equations, and only the values for the right hand side are open to question and further verification. Limited sensitivity analyses were performed on the questionable values for the parameters, and the effects were insignificant.

For the purposes of this model we consider the 3 possible routes for a CONUS-filled requisition discussed above. As shown in table 5 and figure 5, with probability .49 an IG-1 requisition will be for a part which is RFI, with probability .32 the part must be purchased, and with probability .19 it will be produced by the NARF. It is now necessary to estimate the time to completion for each of these categories of parts.

Since the MILSTEP data used in this study did not contain requisitions which were filled by one of the industrial air stations, we did not have data on the delay for NARF-backordered IG-1 requisitions. In discussions with supply people at NAS Norfolk, it was estimated that the average backorder time is about 30 days but that 30 percent of the items going into the NARF were out within 5 days and 70 percent were out within 20 days. These 3 points were used to estimate an exponential distribution which has a mean of 28 days, a probability of .193 for completion by day 5 and .645 by day 20. We assume this holds for both issue groups.

The ASO processing distribution from the MILSTEP data contains time for requisitions which are RFI and many of which are purchased. It was necessary to estimate 2 separate distributions - one for processing time when the item was RFI and one for time to purchase - from the single observed distribution. Although RFI requisitions are processed quite quickly, these requisitions often bounce back from stock points and may be sent out several times before finding their eventual issuing activity (if one is to be found).

This was accomplished by setting up 4 equations, for the first 4 moments of the convex combination of 2 gamma distributions, and solving for the 4 unknown parameters.

The results for IG-1 show an average ASO processing time of 1.48 days for the items which are RFI and 37 days when the item must be purchased. For IG-2 the average purchase back order time is 53.5 days. The exact parameters for each issue group are shown in figures 5A and 5B.

The potentially improvable elements of this sub-process were taken to be the probabilities of an item being not in stock or requiring processing from the NARF. The time distributions were considered fixed, since there were no obvious improvements to suggest for processing time of RFI items or items which are bought. While there is potential in improving the NARF to reduce this delay time, this subject was not analyzed. This is, however, an important area for future research.

It should be noted that improvements directed toward increasing the availability of parts are only relevant to the second philosophy of resupply discussed earlier - when the system is charged with responsibility for spares availability. When availability is not the responsibility of the resupply system - the other philosophy discussed earlier - all items are considered to be RFI and thus subjected only to ASO processing for RFI items. Therefore, an attempt was made to estimate the costs of spares, which if they had been purchased, would alter the probability that requisitions would be for parts which are RFI. In other words, we estimated the value of the spares investment required to change P_{BUY} and P_{NARF}. The purpose of this cost estimation is to permit comparison of this alternative with other alternative means of improving the resupply system. It is to be stressed that this cost exercise is not a substitute for a provisioning model that would determine the actual depth and range of parts to purchase and pre-position at this point in the resupply system.

The average number of requisitions processed by ASO each month (after accounting for those that are canceled, passed, and redundant) is 187,000. On average 38 percent of these are IG-1, resulting in 852,720 IG-1 requisitions per year of which 25 percent or 213,180 requisitions are from deployed carriers. Applying the probabilities derived above 104,458 of these will be RFI, 68,217 will be purchased (of these, 53,209 are consumables and 15,008 are repairables), and 40,504 will come out of a NARF.

To alter these probabilities, we assumed simply that if the parts had been purchased beforehand and dedicated for use by the resupply system for issue to deployed carriers, they would have been available when needed. We assume that 50 percent of the parts bought would eventually be used (the current fleet experience), and that this percentage holds constant until the probability P_{BUY} decreases to .15. These values are somewhat arbitrary but are reasonable for our purpose.*

Using an average cost of $10.00 for each consumable and $2810 for each repairable,** we calculated the number of parts represented by a decrease in the probabilities for bought and NARF items and multiplied by the appropriate costs (parts being bought are bought in proportion to the current mix of consumables and repairables; parts that are purchased to avoid having to go into the NARF are all repairables). For example, to reduce P_{BUY} from its current value of .32 to .20, we calculated that the number of requisitions for parts which are subsequently purchased should go from 68,217 to 42,636. Assuming the mix of consumable and repairable parts remains the same, this represents a required investment in 19,953 consumable parts and 5628 repairable parts for a total investment of about $16 million. Doubling this to account for the wrong parts being purchased, we arrived at a required investment of $32 million.

However, this investment will not be an annual expenditure; rather it will be a one-time expense while the same parts are in service in the fleets. We therefore want to represent this expenditure on an annual basis in order to compare it with the other potential investments which are expressed as annual expenditures. To avoid the problem of determining the expected life of a spare in the system, we assume this life to be about three years a very conservative estimate. Therefore, the annual expenditure on spares for the example discussed above is about 10 million dollars. This estimate is no doubt high, but useful for our purposes. We emphasize again that we are not developing a tool for the purchase of spare parts, but rather a model which will highlight the critical resources and potential improvements in the resupply system. The improvements in P_{BUY} and P_{NARF} based on these assumptions and calculations are shown in figure 3.

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*One could argue that the current probability of unavailability could be improved by buying the correct parts rather than just dedicating more money with the current buying procedure. This alternative was beyond the scope of our study and thus we probably overstate the cost of increasing the probability of availability.

**These figures are the averages of all parts reported on the 3-M system as used by any of 5 types of aircraft over a 17-month period ending September, 1969.

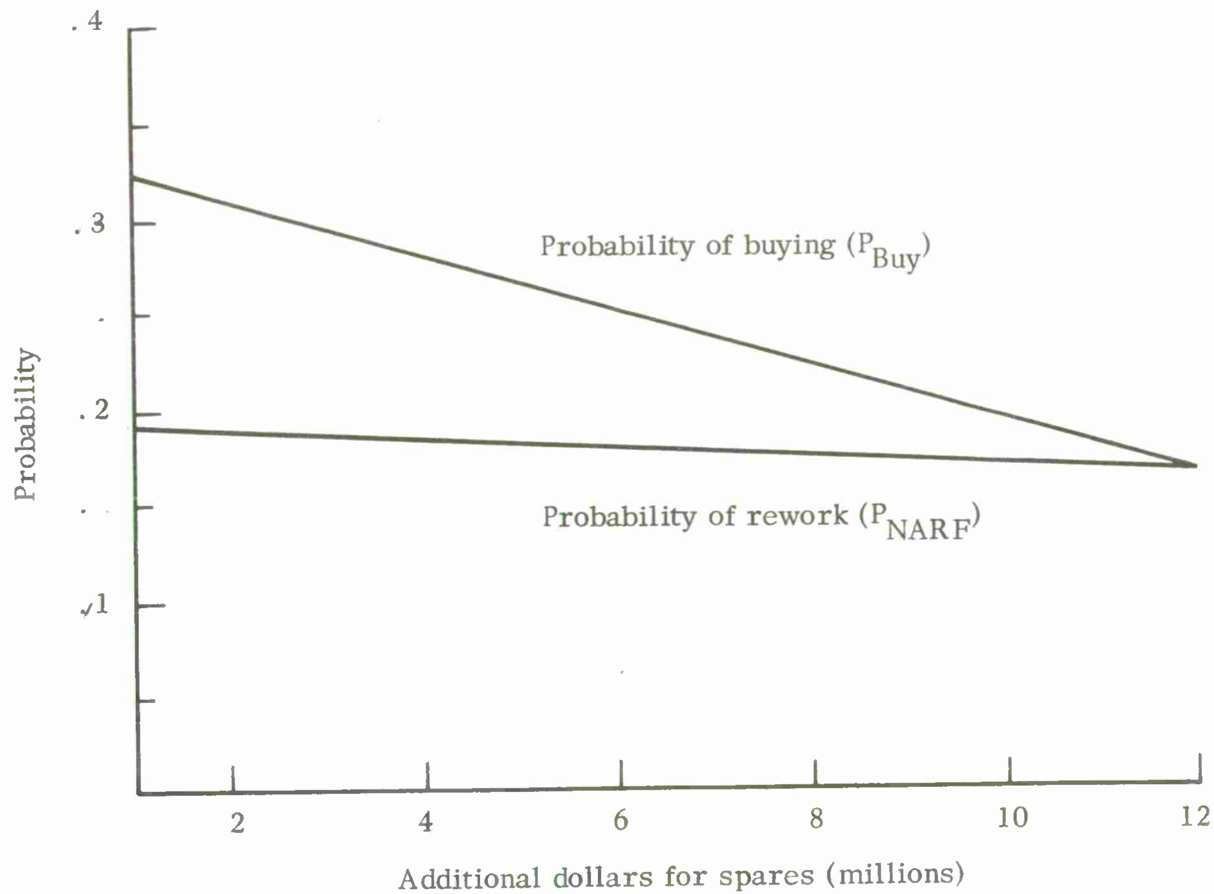

FIG. 3: ESTIMATED DECREASE IN PROBABILITY OF SPARES BEING BOUGHT OR REWORKED FOR DOLLARS SPENT ON SPARES

Stock Point Processing

General Discussion - As shown in figure 2, we consider stock point processing to consist of stock control processing, warehouse processing, and CONUS hold.

The stock control processing stage begins with the arrival of the requisition from ASO and ends with the cutting of the issue document. If the search through inventory files indicates that the item is not in stock, the request will be returned to ASO. An exception might be if stock control knows of the imminent arrival of that part. Requisitions may be held up to 24 hours at some stock points while this check is made. If a part is not in stock, the stock point may choose to provide a substitute or interchangeable part. This often requires time-consuming technical research.

Stock points charged with the support of on-station squadrons have an incentive to protect their reserves of certain parts and return an off-station requisition as not in stock when it actually is. The average return rate for 4 first-line activities in March 1970 was 19.8 percent. The average from 6 second-line activities over the same period was 54.7 percent. This indicates a problem for ASO in the management of spares for CONUS-based and deployed squadrons. In any event, it is clear that a tremendous burden in terms of cost and time (requisitions which bounce around are charged to ASO processing time) is placed on the system by these actions.

Warehouse processing includes a series of actions from delivering the issue form to the warehouse, locating the item (if this was not noted by stock control), picking the material, delivering the material to the packing area, and packing it for shipment. Potential delays in this process are caused by parts placed in the wrong bins, parts still not uncrated and stored after their arrival at the stock point, and difficulties in packing large and fragile material for shipment.

CONUS-hold time begins when the material is offered to NavTransCo for shipment and ends when the item actually leaves the stock point. For most items, this will only be a few hours. Delays of up to 5 days may be observed, however, if NavTransCo challenges the priority of the shipment. In these cases, the original requisitioner is contacted, and delays are inevitable. Delays are also caused if special equipment is required to provide the transportation.

We used the method of least-squares to analyze the time spent in CONUS-hold. It was of particular interest to determine what single characteristic of an order - its destined mode of shipment, its reason for being held (the hold code is given on MILSTEP), its originating activity, or its ultimate destination—has the greatest effect on the time spent awaiting shipment. Somewhat to our surprise, the results show that it is the originating activity which exerts the strongest effect on CONUS-hold time.

Although the Naval time standards for stock point processing are the same regardless of the issuing activity, it is clear that there are substantial differences between the 2 types of stock points considered in this study. (The evidence cited on CONUS-hold time supports this statement with regard to the activities reporting on MILSTEP.) The differences in magnitude of the operations at first-line and second-line air stations are indicated in table 6. Since MILSTEP data only reflects processing by the second-line air stations and the supply centers (which are considered similar to first-line activities), we visited 2 industrial air stations (NAS Norfolk and NAS North Island) to gather supplementary data.

TABLE 6

AVERAGE DAILY TOTAL AND OFF-STATION ISSUES FOR SELECTED AIR STATIONS

	Air station	Total	Off-station
First-line	NAS Norfolk	2500	500
	NAS North Island	2250	675
Second-line	NAS Miramar	400	80
	NAS Oceana	1000	135

<u>First-line Air Stations</u> - One of the primary missions of the industrial missions of the industrial air stations is the support of deployed squadrons. Industrial air stations are viewed as "wholesale" stock points in ASO's support system. We were able to estimate a probability distribution for first-line stock point processing - encompassing the 3 sub-processes discussed above - from data obtained at NAS Norfolk (shown in table 7). MILSTEP data for the supply centers indicates comparable timeframes.

TABLE 7

OFF-STATION REQUISITION PROCESSING - NAS NORFOLK
(Average of three months data)

	Percent of IG-1 requisitions completed by		Percent of IG-2 requisitions completed by
Day 0 -	98.3	Day 0 -	48.4
1 -	99.4	1 -	77.0
2 -	100.0	2 -	97.8
Mean	0.5 (13 hours)		1.3 (32 hours)

As is clear from table 7, any improvement in processing of IG-1 requisitions at the first-line activities would certainly be marginal, and we did not pursue this alternative.

Second-line Air Stations – The philosophy dominating supply activities at the master jet bases and other second-line air stations is clearly different from that at the industrial air stations. Charged with the mission of supporting on-station squadrons or a particular model aircraft, ASO labels these activities as "retail" points.

(1) Stock Control Processing – Table 8 contains summary information on stock control processing for the 3 master jet bases reporting on the MILSTEP system: NAS Miramar, NAS Oceana, NAS Cecil. The parameters estimated for this sub-process are included in figure 5.

TABLE 8

STOCK CONTROL AT THREE MASTER JET BASES: TIMES AND PERCENTAGES

	Number of days-average (Number of requisitions observed)					
	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	0.57 (34)	0.79 (90)	0.72 (137)	2.99 (254)	3.51 (257)	3.22 (518)
Pacific	0.73 (92)	0.86 (234)	0.83 (334)	2.16 (414)	1.63 (222)	1.96 (640)
Total			.795 (471)			2.53 (1158)

	Percentage completed in 1 day or less					
	IG-1			IG-2		
	1-R	2-R	Total	1-R	2-R	Total
Atlantic	82.98	81.11	82.01	66.67	49.42	58.40
Pacific	72.83	72.65	72.46	58.70	60.81	59.32

The greatest delay in processing incoming requisitions is due to the build-up at the end of the day. It was indicated to us at the various air stations that a significant percent of the daily requisitions from ASO arrive at the end of the working day. These would normally be held in stock control until the next day. We thus propose an improvement which would introduce a swing shift to clear out the requisitions at the end of the day. The effect of this swing shift on the stock control distribution is estimated in table 9.

TABLE 9

CURRENT AND ESTIMATED IMPROVEMENTS IN SECOND-LINE STOCK CONTROL PROCESSING

	Current percent completed by	Estimated percent with a swing shift
	Day 0 - 76.7	Day 0 - 93
	1 - 91.8	1 - 95
	2 - 95.1	2 - 96
	3 - 96.1	3 - 97
	4 - 97.9	4 - 99
	5 - 99.3	5 - 99
Parameters	$\alpha = 2$	$\alpha = 1$
	$\beta = .395$	$\beta = .635$
Mean	.79	.635
(Standard deviation)	(.56)	(.635)
Cost	$0	$50,414

The first column of table 9 shows the cumulative distribution observed from MILSTEP data. The second column represents our estimate, based on discussion with supply people at 2 master jet bases, of the improvement which would be experienced with the addition of a swing shift. The basic effect will be to almost eliminate those requisitions which remain overnight but not substantially affect those that previously took over 2 days.

We assumed that one man could perform the duties specified. Using the appropriate skill level, we determined the cost of maintaining a one-man swing shift.* Multiplying by the number of second line stock control points (7), we determine the cost of a swing shift in stock control for all second-line stock points.

(2) Warehouse Processing – The warehouse processing time for 3 master jet bases is summarized for each requisition type in table 10. Since the processing time for each requisition category is so similar, we assume all items to be homogeneous within an issue group. Figure 5 shows the estimated parameters.

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*The cost estimation for all categories of personnel is discussed in further detail in reference (c).

TABLE 10

WAREHOUSE PROCESSING AT THREE MASTER JET BASES: TIMES AND PERCENTAGES

	Number of days-average (Number of requisitions observed)					
	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	1.34 (47)	1.19 (90)	1.26 (139)	2.82 (258)	2.63 (259)	2.74 (524)
Pacific	1.39 (92)	1.19 (234)	1.25 (334)	2.56 (413)	2.12 (222)	2.40 (643)
Total			1.25 (473)			2.55 (1167)
	Percentage completed in 2 days or less					
	IG-1			IG-2		
	1-R	2-R	Total	1-R	2-R	Total
Atlantic	74.47	76.67	74.82	27.52	32.05	29.77
Pacific	64.13	78.20	73.95	48.31	55.85	51.24

The major improvements which can be suggested at this sub-process are a swing shift to work on the end-of-day backlog and a Saturday morning shift to prevent an item from suffering a two-day delay over the weekend. The impact of these improvements are estimated and shown in table 11. The costs of a swing shift and an additional Saturday morning shift are derived in the reference cited above.

TABLE 11

CURRENT AND ESTIMATED IMPROVEMENTS
IN SECOND-LINE WAREHOUSE PROCESSING

	Percent completed by	Estimated percent with a swing shift	Estimated percent with a swing and Saturday shift
	Day 0 - 27.2	73	75
	1 - 69.0	81	85
	2 - 80.8	85	88
	3 - 94.6	95	95
	4 - 98.7	99	99
	5 - 99.6	99	99
Parameters	$\alpha = 2$ $\beta = .63$	$\alpha = 1$ $\beta = 1.048$	$\alpha = 1$ $\beta = .968$
Mean (Standard deviation)	1.26 (.89)	1.048 (1.048)	.968 (.968)
Cost	$0	$48,608	$63,462

(3) CONUS-hold – The length of time in a hold status is shown for each requisition category in table 12. It is interesting to note that material destined for the Pacific is held in this status longer than material for the Atlantic. (We thus estimate separate distributions based on destination.) Table 13 shows the percentage of items destined for each fleet in each of the commonly appearing hold codes. Examination of these figures reveals that the "challenge" privilege of the NavTransCo is very rarely an explanation of major delays in CONUS-hold time. Rather the requirement for a traffic release is a major cause of delays in the Pacific. (Our least-squares analysis discussed above shows that items with this hold code experience more than 2 1/2 days additional delay time over items with one either awaiting carrier equipment or else ready to go in less than 24 hours.)

TABLE 12

WAREHOUSE HOLD AT THREE MASTER JET BASES: TIMES AND PERCENTAGES

	Number of days-average (Number of requisitions observed)					
	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	0.59 (47)	0.91 (90)	0.79 (139)	0.89 (257)	1.18 (259)	1.03 (523)
Pacific	1.11 (92)	1.13 (234)	1.14 (334)	4.20 (413)	2.80 (222)	3.72 (643)
	Percentage completed in 2 days or less					
	IG-1			IG-2		
	1-R	2-R	Total	1-R	2-R	Total
Atlantic	91.49	78.89	83.45	76.36	69.88	72.90
Pacific	66.30	64.96	64.37	25.36	40.09	30.43

TABLE 13

PERCENT OF EACH ITEM CATEGORY WITH VARIOUS CONUS-HOLD CODES

	IG-1		IG-2	
Code	Atlantic	Pacific	Atlantic	Pacific
Shipment consolidation	1.0	0.3	3.7	8.0
Awaiting carrier equipment	52.0	6.4	72.2	9.1
Awaiting export/domestic traffic release	4.0	13.3	1.2	37.7
Challenge action	0.0	0.3	0.2	0.3
Hold action of less than 24 hours	42.9	79.6	22.7	44.9
Total	99.9	99.9	100.0	100.0

The only resource improvement which can be recommended for IG-1 items at this time is the addition of a truck (or greater utilization of an existing truck) for the faster shipment of items to airports (which most of the IG-2 items are destined for). The reason that this is not currently done is because shipments are geared to the QuickTrans and MAC schedules. This is one example where the essential independence assumption discussed previously is subject to criticism. This issue is addressed in the next section. The effect of an additional truck would be to empty the warehouse at night and thus get more items out in the same day.

The estimated effect of an additional late night run to the airport is shown along with the current processing time distribution in table 14. The cost of additional utilization of a government truck is taken from reference (c).

TABLE 14

CURRENT AND ESTIMATED IMPROVEMENTS
IN SECOND LINE CONUS HOLD TIME

		Percent completed by	Estimated percent with an additional truck
ATLANTIC			
Day	0	83.5	93.0
	1	90.6	92.0
	2	93.5	95.0
	3	99.3	99.0
Parameters		$\alpha = 2$ $\beta = .395$	$\alpha = 1$ $\beta = .66$
Mean (standard deviation)		.79 (.56)	.66 (.66)
PACIFIC			
Day	0	64.4	78.0
	1	82.6	85.0
	2	88.6	90.0
	3	93.4	95.0
Parameters		$\alpha = 2$ $\beta = .57$	$\alpha = 1$ $\beta = .95$
Mean (standard deviation)		1.14 (.81)	.95 (.95)
Total cost			$19,425

Another obvious potential improvement is to increase the percentage of issues from the first-line stock points. ASO has been attempting to do this but has not been completely successful, as the probabilities attest. Although there are other considerations which determine the positioning of spare parts, increasing the probability of first-line issues from .73 to at least .95 seems feasible. Since most master jet bases are near an industrial air station, they can still obtain the parts on short order if needed. This involves a policy change and at most would require an additional person in stock control and in the warehouse to handle the extra burden at the first-line air station. As derived in reference (c), this would incur a cost of $97,000 to alter the probabilities as above.

CONUS Transportation

CONUS transportation involves the time between the date material is shipped from the stock point to the date it is received at the MAC/MSTS port of embarkation (POE). Although we were able to distinguish different mode codes on MILSTEP, such as QuickTrans, commercial air, air van, LogAir, etc., the codes were changed twice over the time period covered by our data. We decided therefore, to divide movements between air (the majority of which are QuickTrans) and surface (truck, local movers, and, on rare occasion, rail).

The percentage of requisitions which travel via each mode for each destination is shown in table 15. We assume that the 60 percent of IG-1 and IG-2 items which move via parcel post are subject to the same proportional CONUS travel times as those which move in the military system.

TABLE 15

CONUS MODE OF REQUISITIONS

		Surface		Air	
		Number	Percent	Number	Percent
IG-1	Atlantic	5	3	168	97
	Pacific	75	23	248	77
IG-2	Atlantic	72	12	521	88
	Pacific	151	23	511	77

We would expect the amount of time required for CONUS transportation to be very sensitive to the distance from the issuing activity to the MAC/MSTS POE. Table 16 shows the average distance traveled by each type of requisition from origin to destination. (Approximations were made for inter-city distances: zero was used for intra-city movements.) It is interesting to note that IG-1 items destined for the Atlantic travel a shorter distance within CONUS than items destined for the Pacific, and 1-R items travel a shorter distance in each of the 8 categories except one. It is also interesting that while IG-2 items which travel by surface travel a longer distance than those in IG-1, the IG-2 items moving by air actually travel a shorter distance on average than IG-1 air items.

TABLE 16

AVERAGE DISTANCE TRAVELED BY
REQUISITIONS IN CONUS TRANSPORTATION (MILES)
(Numbers of requisitions in each category are shown in table 15)

	Atlantic		Pacific	
Issue group one				
	Surface	Air	Surface	Air
1-R	0	739	0	1070
2-R	0	882	13	1346
Total	0	833	8	1271
Issue group two				
	Surface	Air	Surface	Air
1-R	164	625	0	663
2-R	79	771	56	1042
Total	110	682	28	772

The differences in distance traveled for each requisition are reflected in the average transportation times shown in table 17. A clear implication of these tables is that IG-1 surface mode items are sent locally and take less time than air mode items. The parameters of the appropriate gamma distributions are shown in figure 5.

(We also examined the effect of weight on CONUS transportation time. The marginal effect on items shipped by air was positive but extremely small. While it was greater for surface items, the effect was still small.)

TABLE 17

CONUS TRANSPORTATION: TIMES AND PERCENTAGES

SURFACE
Number of days-average
(Number of requisitions observed)

	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	1.00 (1)	1.00 (4)	1.00 (5)	5.15 (23)	4.32 (44)	4.61 (70)
Pacific	1.00 (24)	1,15 (51)	1.10 (75)	4.61 (23)	6.51 (73)	5.62 (137)
	Percentage completed in 1 day or less					
Atlantic	100.00	100.00	100.00	26.09	36.37	34.28
Pacific	87.50	76.48	80.00	31.75	20.54	25.54

AIR
Number of days-average
(Number of requisitions observed)

	IG-1 1-R	IG-1 2-R	IG-1 Total (All cogs)	IG-2 1-R	IG-2 2-R	IG-2 Total (All cogs)
Atlantic	2.57 (54)	3.09 (103)	2.90 (158)	3.42 (289)	3.51 (209)	3.45 (500)
Pacific	3.28 (61)	4.07 (186)	3.88 (248)	4.33 (328)	5.38 (176)	4.75 (505)
	Percentage completed in 2 day or less					
Atlantic	65.45	55.33	59.49	50.53	44.98	48.19
Pacific	44.26	32.62	35.31	18.18	23.29	20.01

It is clear that the greatest improvement that can be realized for IG-1 items in this sub-process would be a greater utilization of surface transportation. This could be achieved if the activity nearest the MAC/MSTS port of embarkation were the issuing activity. Such action might come in conflict, however, with other objectives in the supply system. This is part of a larger problem of spares positioning which is discussed briefly later.

The potential improvements which are established are directed at the time distribution of CONUS air travel. (It was not clear what improvements are feasible for the surface transportation, and the potential benefits for IG-1 are certainly minimal.) After discussion with NavTransCo-Norfolk we have estimated how increases in the QuickTrans contract for larger types of airplanes and more frequent flights will affect CONUS air transportation. These improvements and their estimated additional costs over the present QuickTrans contract are contained in table 18.

TABLE 18

CURRENT AND ESTIMATED IMPROVEMENTS
IN CONUS AIR TRAVEL

	Current percent completed	Larger airplanes	More flights	More flights and larger airplanes
ATLANTIC				
Day 0	15	22	30	39
1	40	52	65	75
2	61	73	84	91
3	76	86	93	97
4	87	96	97	99
5	92	96	99	99
Parameters	$\alpha = 2$ $\beta = 1.45$	$\alpha = 2$ $\beta = 1.16$	$\alpha = 2$ $\beta = .895$	$\alpha = 2$ $\beta = .75$
Mean (Standard deviation)	2.90 (2.05)	2.32 (1.64)	1.79 (1.27)	1.50 (1.06)
PACIFIC				
Day 0	2	15	26	39
1	11	41	59	75
2	35	62	80	91
3	55	77	91	97
4	78	86	96	99
5	88	92	98	99
Parameters	$\alpha = 2$ $\beta = 1.94$	$\alpha = 2$ $\beta = 1.44$	$\alpha = 2$ $\beta = 1.0$	$\alpha = 2$ $\beta = .75$
Mean (Standard deviation)	3.88 (2.74)	2.88 (2.84)	2.00 (1.44)	1.50 (1.06)
Additional cost of QuickTrans contract (millions)		\$3.05	\$9.55	\$14.35

Overseas Hold and Transportation

This sub-process is divided into two components: a hold status, and the actual transportation time. The hold status is the time between arrival at the MAC/MSTS POE and the date of actual shipment. Overseas transportation time commences with the date of shipment and ends with the date of arrival at the forward supply point.

The percentage of each issue group in each fleet which travels via MAC and MSTS is shown in table 19. The actual figures have been adjusted to reflect the assumption that the 60 percent of the items which move via parcel post are to be considered described by the MAC distribution. It is interesting to note that the percentage going via air and surface is the same for each ocean only within an issue group. This contrasts with CONUS transportation where the mode percentages were very similar for each fleet destination regardless of issue group.

TABLE 19

PERCENTAGE OF ITEMS MOVED BY MAC AND MSTS

		MSTS		MAC*	
		Number	Percent	Number	Percent
IG-1	Atlantic	9	1	1111	99
	Pacific	8	1	1812	99
IG-2	Atlantic	532	10	4526	90
	Pacific	357	10	3087	90

*MAC numbers are increased by the percentage estimated to move by mail.

Overseas Hold – It was expected that repacking, consolidating, and awaiting movement would take longer for MSTS shipments than for MAC. This is borne out in table 20, which gives the averages for each category of parts. The estimated parameters for each mode of transportation are shown in figure 5.

TABLE 20

OVERSEAS HOLD:
TIMES AND PERCENTAGES

MAC
Number of days-average
(Number of requisitions observed)

	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	1.16 (101)	1.34 (202)	1.27 (310)	1.84 (562)	1.65 (344)	1.77 (908)
Pacific	1.31 (143)	1.33 (363)	1.32 (508)	1.34 (422)	1.53 (200)	1.40 (623)

Percentage completed in 1 day or less

	IG-1			IG-2		
	1-R	2-R	Total	1-R	2-R	Total
Atlantic	72.27	71.42	71.93	51.41	57.64	53.78
Pacific	69.93	67.58	68.36	76.59	59.60	71.14

MSTS
Number of days-average
(Number of requisitions observed)

	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	5.0 (1)	23.25 (8)	20.11 (9)	22.17 (281)	19.51 (189)	21.08 (474)
Pacific	6.0 (1)	11.29 (7)	10.63 (8)	17.79 (211)	15.48 (127)	16.88 (339)

Percentage completed in 10 days or less

	IG-1			IG-2		
	1-R	2-R	Total	1-R	2-R	Total
Atlantic	100.00	0.00	11.11	19.18	26.20	21.99
Pacific	100.00	28.58	37.50	35.36	29.81	31.65

Overseas Transportation – The average transportation times for each mode of transportation are included in table 21. It is reasonable to expect that the ending data on this time period represents the date the material is unloaded from the plane or ship rather than the date of actual arrival. Thus this subprocess also includes unloading time, which can be substantial in the case of MSTS vessels. MSTS times are also affected by the fact that ships rarely run from an origin port directly to a destination port. They usually make several stops in CONUS and perhaps several overseas before all parts are delivered. This is reflected in the high average MSTS delivery times.

TABLE 21

OVERSEAS TRANSPORTATION:
TIMES AND PERCENTAGES

MAC
Number of days-average
(Number of requisitions observed)

	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	2.00 (9)	1.25 (6)	1.84 (16)	2.81 (70)	2.69 (51)	2.75 (122)
Pacific	2.32 (42)	1.99 (119)	2.07 (162)	1.32 (328)	2.07 (104)	1.50 (432)

Percentage completed in 1 day or less

	IG-1			IG-2		
	1-R	2-R	Total	1-R	2-R	Total
Atlantic	44.44	66.67	50.00	48.57	27.45	39.35
Pacific	69.04	65.00	66.26	85.10	66.34	80.60

MSTS
Number of days-average
(Number of requisitions observed)

	IG-1			IG-2		
	1-R	2-R	Total (All cogs)	1-R	2-R	Total (All cogs)
Atlantic	36.00 (1)	20.14 (7)	22.13 (8)	32.26 (251)	28.42 (184)	30.66 (440)
Pacific	32.00 (1)	27.00 (6)	27.71 (7)	27.42 (224)	26.14 (140)	26.93 (365)

Percentage completed in 10 days or less

	IG-1			IG-2		
	1-R	2-R	Total	1-R	2-R	Total
Atlantic	0.00	42.86	37.50	2.22	12.00	6.31
Pacific	0.00	0.00	0.00	2.20	5.42	3.47

Improvements - It was suggested to us by NavTransCo that only minimal improvements were possible in the MAC hold and transportation times, and that the best way to speed IG-1 items would be to ensure that they all traveled via MAC rather than MSTS. (All items can travel by air if the Navy is willing to pay the higher per pound rates.) As would be expected, the small percentage of IG-1 items which did travel by ship were rather heavy (average weight = 2622 pounds). The costs to send these items via MAC are estimated in table 22.

TABLE 22

ESTIMATED COST OF SHIPPING ALL IG-1 ITEMS VIA MAC

Number of MSTS IG-1 items shown on 12 months of MILSTEP = 17

Assuming that the rest of the system ships items in the same proportion - $= 17 \times \frac{7}{3} \div .27$*

Total IG-1 MSTS items in a year = 148

Assuming that these are sent equally to both fleets:

To Atlantic -	74 x 2622 =	194,028 lbs/year
	average difference in MSTS and MAC rates	.14
		$27,164
To Pacific -	74 x 2622 =	194,028 lbs/year
	average difference in MSTS and MAC rates	.29
		$56,268

*The correction factors applied here reflect the fact that we have data on 3 of the 7 master jet bases, which collectively issue 27 percent of the material.

COD Delivery to Carrier

The last sub-process in the resupply system is the transportation of the part to the carrier. How long this takes is subject to great variability, depending on the location of the carrier relative to the stock point.

Most parts are transported on COD aircraft, which are also used for transporting mail and people. It is assumed that all parts in both fleets are subject to the COD delivery time delay, even though replenishment might not be by COD.

Data on the time necessary for transportation from the forward supply point is scarce. The MILSTEP system does not follow requisitions past the forward supply points. The only previous study of COD utilization indicated that the average resupply time for COD delivery was around 3 days. ComNavAirPac estimates this figure to be high for an overall average and suggested a histogram which was translated by us into the probability distribution shown in the first column of table 23. From this distribution, we have estimated the parameters of a gamma distribution which is assumed to hold for all items regardless of issue group and location.

TABLE 23

ESTIMATED CURRENT AND POTENTIAL COD DELIVERY TIMES
(by day from forward supply point)

	Percentages		
	Current	Addition of one more COD	Addition of two more COD
Day 0	15.4	18	20
1	53.9	65	70
2	80.8	83	85
3	88.5	88	89
4	92.4	95	96
5	96.3	98	99
6	98.2	99	99
7	99.2	100	100
8	100.0		
Parameters	$\alpha = 2$ $\beta = .92$	$\alpha = 2$ $\beta = .82$	$\alpha = 2$ $\beta = .76$
Mean (Standard deviation)	1.84 (1.30)	1.64 (1.16)	1.52 (1.07)
Additional cost (millions)		\$1,304	\$2,608

ComNavAirPac suggested that the addition of COD aircraft would affect only slightly the time distribution for this sub-process. The primary factors causing delays in COD delivery time are the weather conditions, which would not be alleviated by the addition of more COD aircraft, and peaks and valleys of MAC delivery times and loads, which would be only somewhat mitigated with more aircraft. Based on our discussion with them, we have estimated the revised probability distributions with one and two additional COD's in each fleet. This is also shown in table 23, including the additional costs. (These costs include total investment, direct and indirect operating costs, allowance for training and attrition, and are expressed on an annual basis. Further discussion may be found in reference (d).)

COST BENEFIT CURVES FOR THE CONUS RESUPPLY SYSTEM

INTRODUCTION

Utilizing the potential improvements outlined in the previous section, the optimal combination of these improvements for any budget level can be determined. The theory which underlines the approach to be used is developed in reference (e).

Total resupply time is a random variable (that is, we are unable to state beforehand exactly how long resupply will take). We will use two measures of performance to express resupply time: the expected value (or average), and the value of the cumulative resupply system distribution at a given day (or the percent completed by the given day). The difference in these measures is illustrated in figure 4.

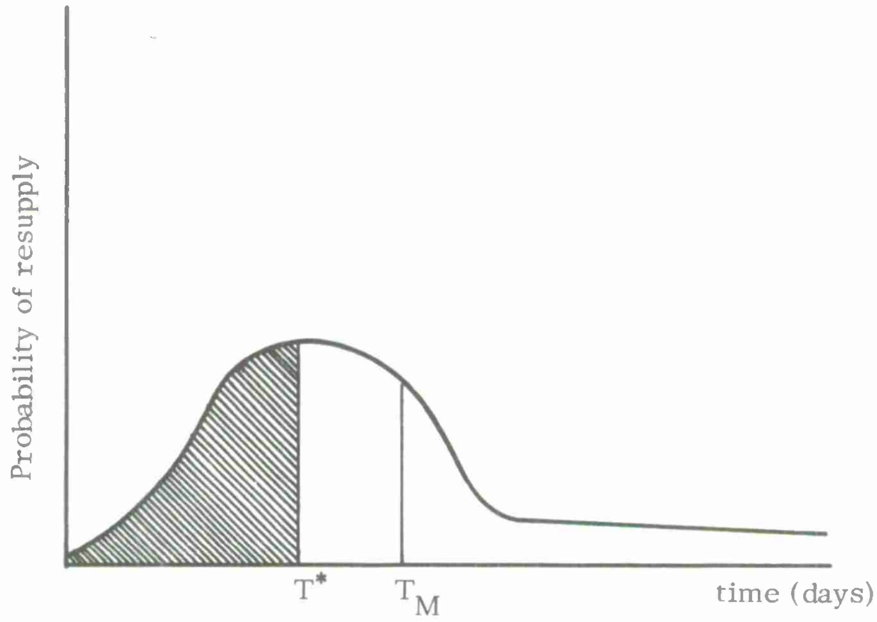


FIG. 4: HYPOTHETICAL RESUPPLY SYSTEM DISTRIBUTION

The mean of the hypothetical resupply system distribution shown here is day T_M, the day we expect the requisition to be satisfied. As was mentioned previously, however, the mean of a skewed distribution is often misleading because of the effect of a small percentage of the requisitions which take a very long time. We will therefore also consider the percentage of requisitions completed by some day T^* (the shaded area in figure 4) as a measure of performance of the resupply system.

PARAMETERS OF THE RESUPPLY SYSTEM

The resupply system as it has been developed is presented in figures 5A and 5B. Figure 5A shows the estimated parameters for each of the sub-processes for IG-1 requisitions destined for Atlantic and Pacific, figure 5B for IG-2 requisitions.

The numbers in parentheses are the parameters of a gamma distribution in the sequence (α, β). Each of the probabilities shown in these figures was derived in the previous section and the gamma distributions were estimated from data also presented there.

THE INDEPENDENCE ASSUMPTION

A crucial assumption of this paper is that each of the 6 major sub-processes in the CONUS resupply system is independent of the others. One exception to this assumption occurs in CONUS hold-time, where the item might be held in the warehouse instead of being sent to a QuickTrans airport because the transportation officer knows that the appropriate QuickTrans flight is not due for several hours (or days). The assumption is also dubious in COD delivery time, which is affected by peaks and valleys in MAC transportation time.

The assumption is necessary nevertheless to allow us to derive analytically the overall resupply time distribution. The computations of both the mean of the resupply system distribution and the percent completed by a given day require this independence assumption. Without it we would have great difficulty presenting any results for the overall system.

"LOGISTICS" AND "SPARES" RESUPPLY

Figures 5A and 5B present the resupply system for items which cannot be satisfied locally. Since we are taking as given the current policy concerning the use of forward supply points, we can only be concerned with improving the processing time for those requisitions which come to CONUS.

As mentioned in the previous section, the resupply system may or may not be responsible for the availability of parts. A philosophy of resupply which considers only the logistics resources that are committed to processing and transporting already available spare parts will be referred to as "logistics resupply." A philosophy of resupply that includes the management of spares and spares placement, and thus burdens the resupply system with the unavailability of parts, will be referred to as "spares resupply." The problem in defining the relevant philosophy of resupply stems from the fact that the resupply system is but one aspect of the total support system, which includes spares procurement and management.

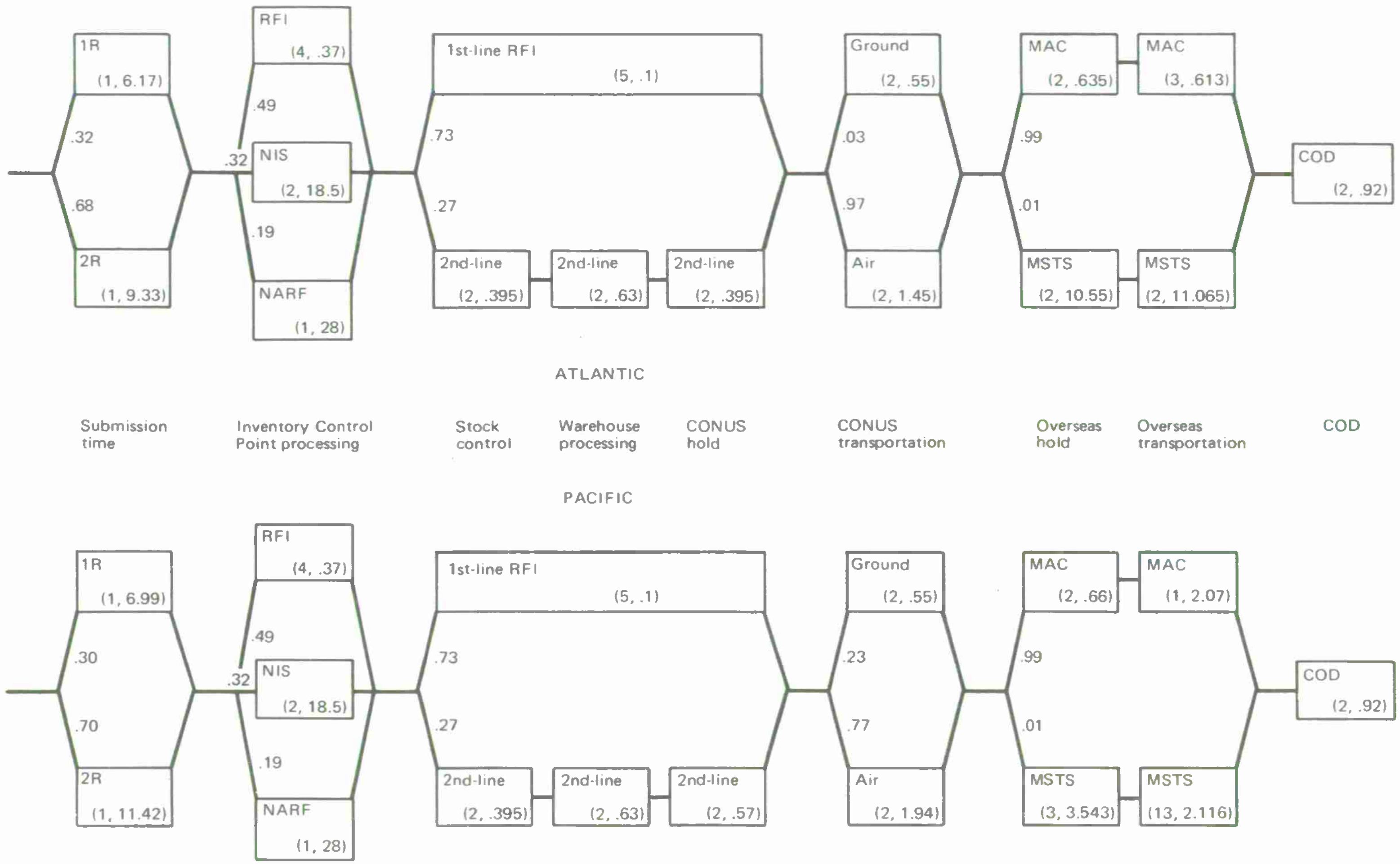


FIG. 5A: IG-1 RESUPPLY

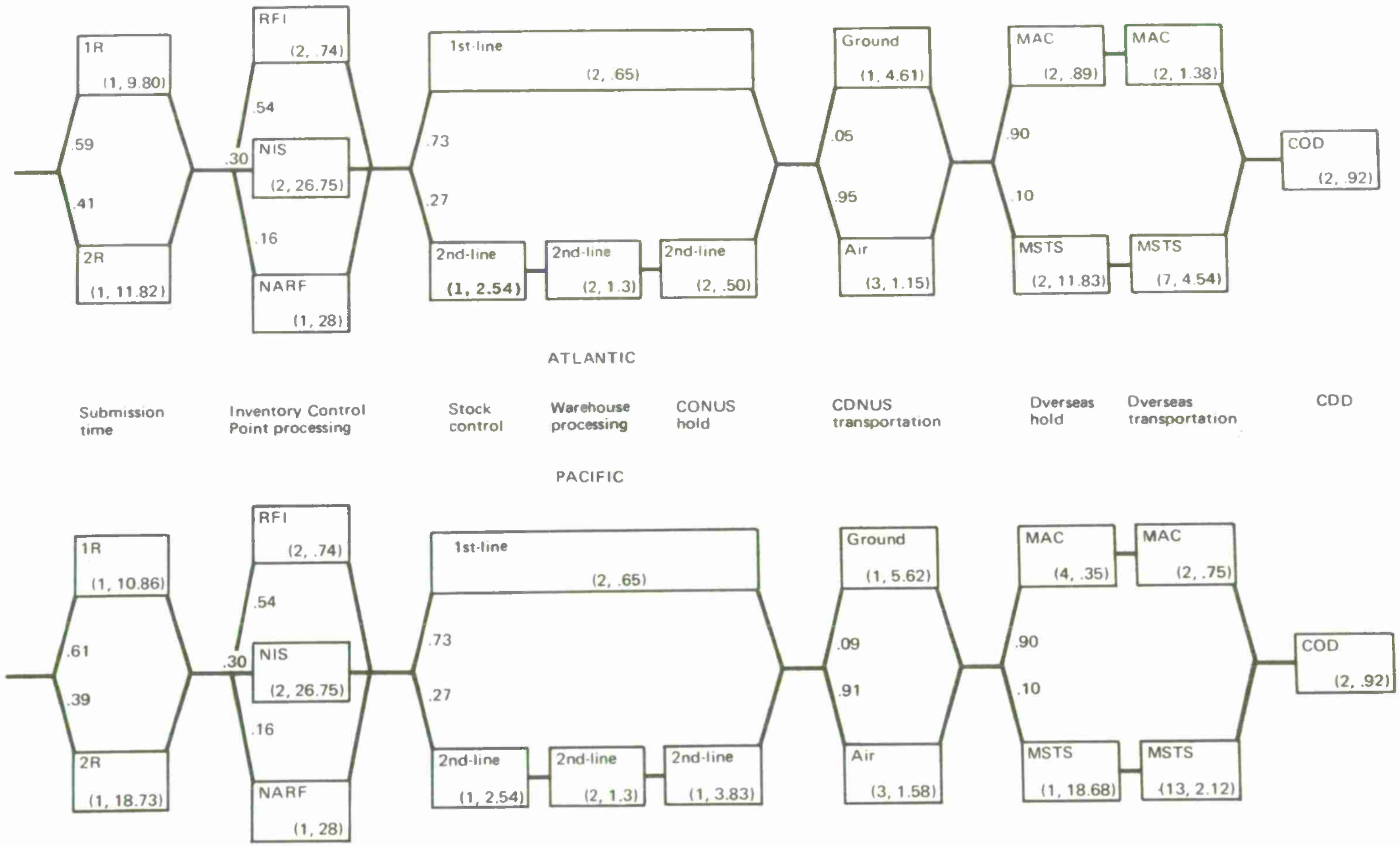


FIG. 5B: IG-2 RESUPPLY

When the "logistics resupply" system is considered, it is assumed that the probability of a part being RFI at the ICP processing sub-process is 1.0. Under the "spares resupply" philosophy, the probabilities shown in figure 5 remain in effect. Results for the present CONUS resupply system and for improved systems will be shown for each view of resupply.

CONUS RESUPPLY SYSTEM DISTRIBUTION

Several values of the cumulative resupply system distribution for both views of resupply are shown in table 24 for IG-1 requisitions and table 25 for IG-2 requisitions (page 50). The means of these distributions are also given.

These completion probabilities were approximated from the first 4 terms of an Edgeworth series expansion (the central limit approximation plus 3 correction terms). This technique and a bound on the error in approximation is discussed in detail in reference (f).

Table 26 breaks down the overall average by sub-process for each fleet and issue group. We see that processing at the ICP accounts for almost half of the total resupply time due to the low net availability of parts. While the standard for issue group one requisitions is 7 days, the total of the 3 transportation sub-processes alone exceeds this goal.

ATLANTIC - PACIFIC PROBABILITIES

Table 1, repeated below, gives the percentage of IG-1 requisitions from each location which are filled in CONUS and locally. To determine the percentage of IG-1 requisitions processed in CONUS and destined for carriers in each fleet, it is necessary to determine the rate at which requisitions are generated from each fleet.

PERCENTAGE OF IG-1 REQUISITIONS FILLED
LOCALLY AND IN CONUS

	Local	CONUS
Atlantic	10	90
Pacific	55	45

TABLE 24

PRESENT RESUPPLY SYSTEM DISTRIBUTION: IG-1 REQUISITIONS

Percent completed on or before this day

	Logistics resupply		Spares resupply	
	Atlantic	Pacific	Atlantic	Pacific
Day 10	18.9	16.0	19.0	16.5
15	42.4	34.9	26.5	23.4
20	66.2	56.3	34.8	31.1
25	76.4	73.1	43.5	39.4
30	72.6	78.2	52.5	47.9
35	81.5	76.5	61.2	56.5
40	98.0	81.8	69.0	64.5
45		94.7	75.3	71.4
50		99.0	79.3	76.5
55			80.9	79.6
Mean	19.13	21.62	35.53	38.02

TABLE 25

PRESENT RESUPPLY SYSTEM DISTRIBUTION: IG-2 REQUISITIONS

Percent completed on or before this day

	Logistics resupply		Spares resupply	
	Atlantic	Pacific	Atlantic	Pacific
Day 10	8.3	10.9	13.6	12.4
15	19.2	19.4	18.7	16.9
20	32.7	30.2	24.3	22.1
25	47.7	42.4	30.4	27.7
30	63.1	54.9	36.8	33.6
35	75.8	66.0	43.4	39.9
40	79.8	73.9	50.1	46.3
45	81.5	77.5	56.7	52.7
50	81.9	77.6	63.1	58.9
55	82.1	77.7	68.9	64.8
60	88.1	80.1	73.9	70.0
65	96.0	86.0	77.6	74.4
70	99.9	93.4	80.1	77.7
Mean	29.71	32.67	49.56	52.52

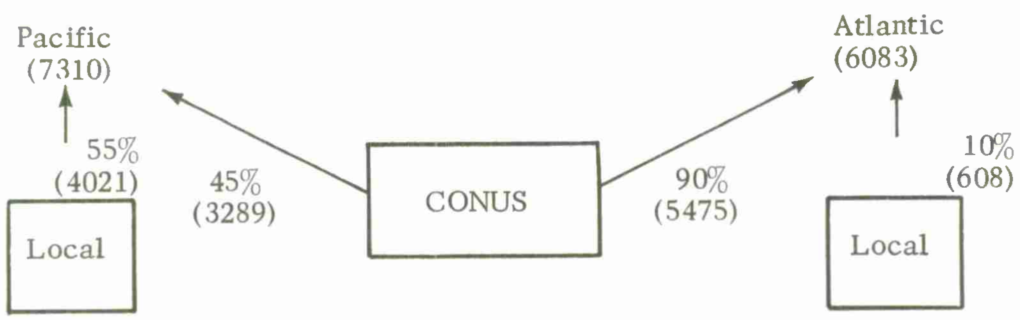
TABLE 26

BREAKDOWN OF OVERALL MEAN BY SUB-PROCESS
(days)

	IG-1		IG-2	
	Atlantic	Pacific	Atlantic	Pacific
Submission	8. 32	10. 09	10. 63	13. 93
ICP processing*	17. 89	17. 89	21. 31	21. 31
Stock point processing	1. 13	1. 23	2. 62	3. 37
CONUS trans-portation	2. 85	3. 24	3. 51	4. 82
Overseas trans-portation	3. 51	3. 74	9. 63	7. 23
COD delivery	1. 84	1. 84	1. 84	1. 84
Total system	35. 53	38. 02	49. 56	52. 52

*As is clear, the spares resupply concept is assumed here.

We sampled one month of data from NORSAIR records. These are records maintained for all NORS requisitions (a subset of IG-1 requisitions) regardless of the ultimate issuing activity. As shown in figure 6, 6083 requisitions (correcting for those that were canceled) were generated from the Atlantic and 7310 from the Pacific. Applying the percentages of table 1, we see that approximately 60 percent of the IG-1 requisitions which are filled in CONUS for deployed carriers go to the Atlantic fleet and 40 percent to the Pacific fleet. (We assume that IG-1 requisitions are generated in the same proportion as the NORS subset.)



Total CONUS-filled = 8764

$$\text{Percent Atlantic} = \frac{5475}{8764} \approx 60 \text{ percent}$$

$$\text{Percent Pacific} = \frac{3289}{8764} \approx 40 \text{ percent}$$

FIG. 6: ESTIMATED PERCENTAGE OF CONUS-FILLED IG-1 REQUISITIONS DESTINED FOR EACH FLEET

POTENTIAL IMPROVEMENTS

Potential improvements were discussed earlier for those elements of the CONUS resupply system (for IG-1 requisitions) which are controllable. Controllable implies in this context that there are alternatives open to the decision-maker to alter the system. The elements of the system are defined as either the parameters of a certain sub-process distribution (such as CONUS air transportation) or the probabilities which determine what percentage of the requisitions require different types of processing (e. g. , MAC transportation or MSTS transportation). For elements which are controllable, there are specified in section III one or more alternative improvements yielding a different value (of a probability or parameters of a distribution) at some cost.

Under the philosophy of "logistics resupply," there are 7 elements of the system at the control of the decision-maker. These are summarized as the first 7 elements in table 28.

For each element, we specify the current value of the element (from figure 5A) and the benefit and cost of each potential improvement as established earlier. All costs are on an annual basis. When the system is charged with the availability of spares ("spares resupply"), there are 2 additional controllable variables (elements 8 and 9 in table 28) whose potential improvements are given in figure 3.

OPTIMIZATION

We have now specified all of the inputs required to determine the optimal improvements in the CONUS resupply system for any given total budget. The procedure used for this optimization is a structured search among a specific number of alternatives. The procedure is described in reference (e) .

We consider both the "logistics resupply" and "spares resupply" systems and optimize under 2 objective functions – minimize expected resupply time, and maximize probability of completion within 15 days*– for both the Atlantic and Pacific fleet. (For those costs of improvement which are not separated by fleet in table 28, we use the ratio previously discussed of 60 percent of the cost for Atlantic-bound requisitions and 40 percent for Pacific-bound.)

Figures 7A and 7B show the cost-benefit curves for each resupply system under the 2 objective functions. Table 29 presents the optimal set of improvements (referring back to the alternatives in table 28) for a number of different budget constraints for "logistics resupply" and table 30 does likewise for "spares resupply." In each case the solutions under the 2 objective functions are the same (for a given fleet destination and resupply philosophy). This is quite an important result for it sanctions the decision-maker to optimize with regards to the mean

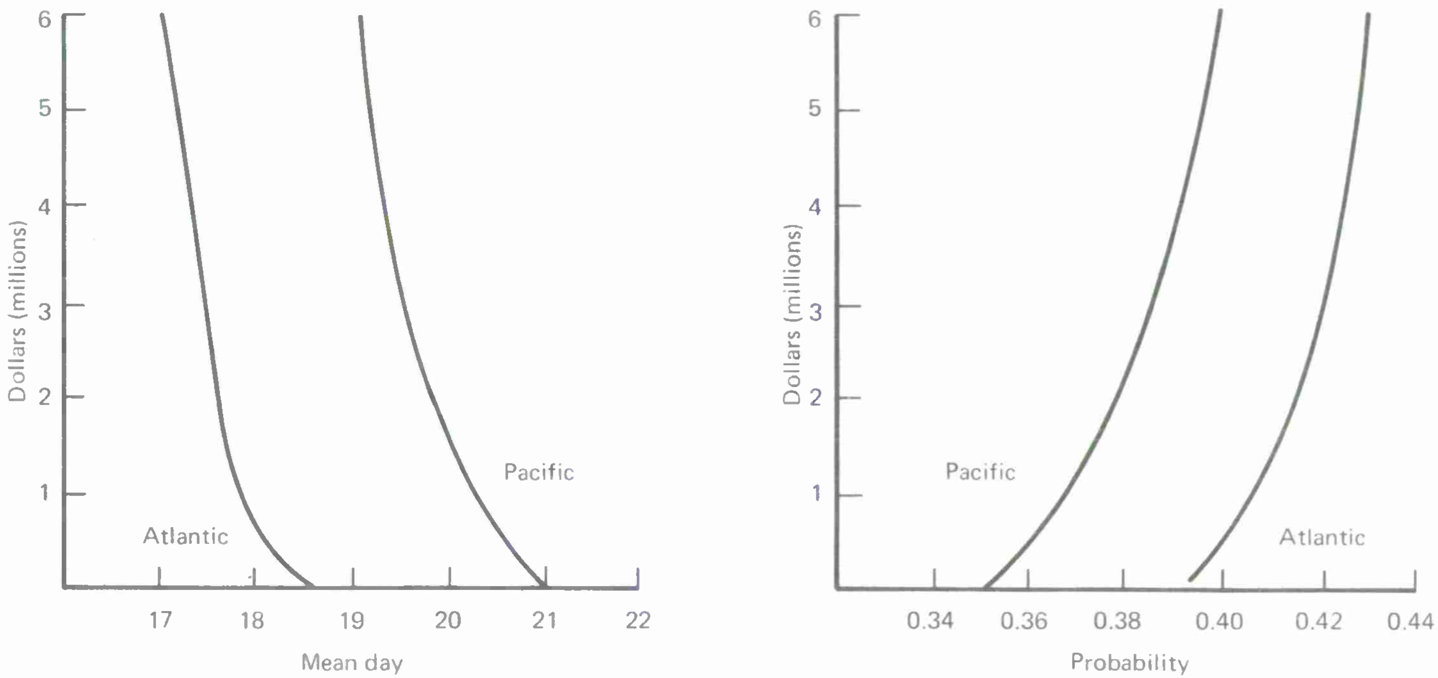
*The goal of 15 days rather than 7 days (the standard for IG-1 requisitions) was selected because of considerations of computational accuracy for the procedure discussed in reference (f).

TABLE 28

SUMMARY OF POTENTIAL IMPROVEMENTS FOR CONTROLLABLE ELEMENTS

Element Number	Description	Current value*	Reference	Alternative improvement 1			Alternative improvement 2			Alternative improvement 3		
				Resources	New value	Cost**	Resources	New value	Cost*	Resources	New value	Cost**
1	Probability that material is issued by 1st line stock point	.73	Page (30)	Additional stock control warehouse personnel at Ist line stock point	.95	97						
2	Stock control processing time -2nd line stock points	Mean=.79	Table 9	Swing shift-5 days/week	Mean=.635	50						
3	Warehouse processing time -2nd line stock points	Mean=1.26	Table 11	Swing shift-5 days/week	Mean=1.05	49	Swing shift-and Saturday shift	Mean=.97	63			
4	CONUS hold time -2nd line stock points	LANT-Mean=.79 PAC-Mean=1.14	Table 14	Additional truck	LANT-Mean=.66 PAC-Mean=.95	11 8						
5	CONUS air transportation time	LANT-Mean=2.90 PAC-Mean=3.88	Table 18	Increase Ouick Trans contract for larger planes	LANT-Mean=2.32 PAC-Mean=2.88	1647 1403	Increase Ouick Trans contract for more flights	LANT-Mean=1.79 PAC-Mean=2.00	5157 4393	Increase Ouick Trans contract for larger planes	LANT-Mean=1.50 PAC-Mean=1.50	7747 6601
6	Probability that overseas transportation is by air	LANT-.99 PAC-.99	Table 23	Send all items overseas by MAC	LANT-1.0 PAC-1.0	27 56						
7	COD transportation time	Mean=1.84	Table 24	One additional COO in each fleet	Mean=1.64	1304	Two addtional COD's in each fleet	Mean=1.52	2608			
8	Probability that a part is purchased at ASO	.32	Fig. 3	Benefit from purchasing spares shown in figure 3								
9	Probability that a part is backordered against a NARF	.19	Fig. 3	Benefit from purchasing spares shown in figure 3								

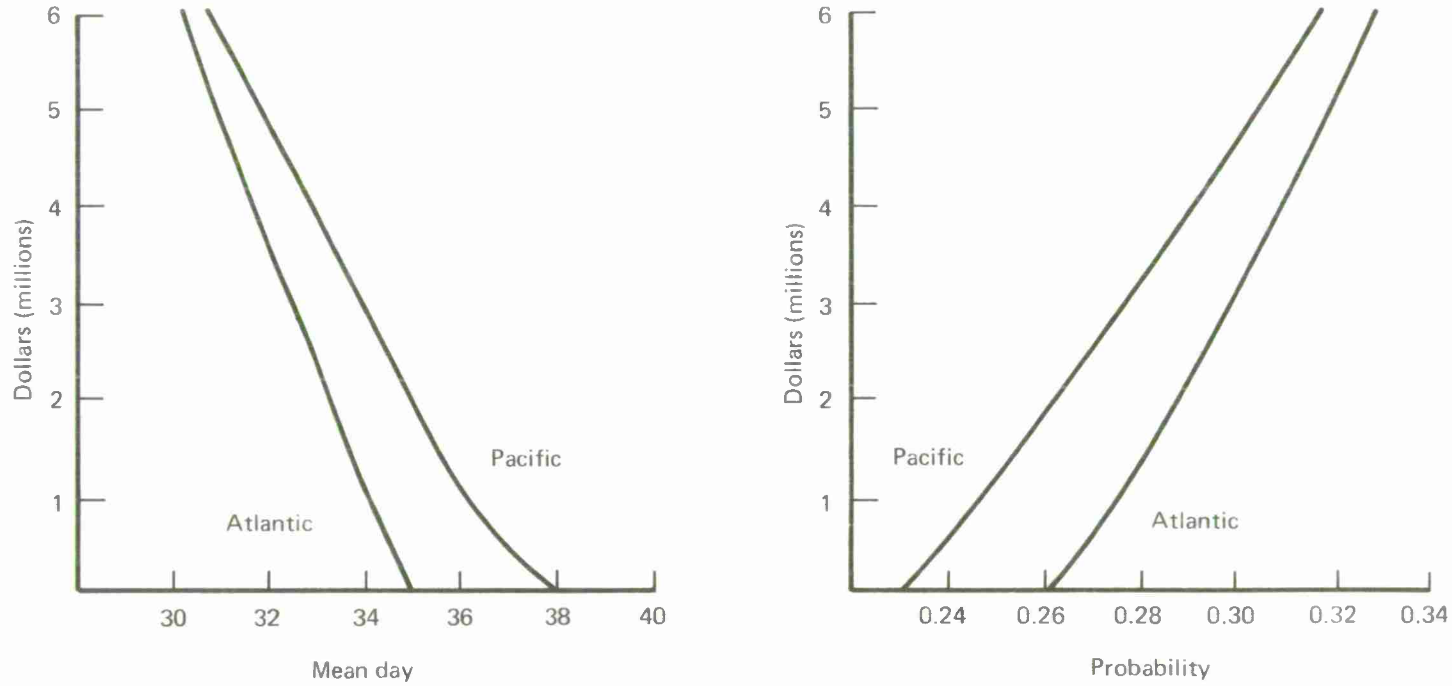
*Taken from figure 5.
**Costs in thousands of dollars.



MINIMIZING THE MEAN

MAXIMIZING THE PROBABILITY OF COMPLETION BY DAY 15

FIG. 7A: "LOGISTICS RESUPPLY"



MINIMIZING THE MEAN

MAXIMIZING THE PROBABILITY OF COMPLETION BY DAY 15

FIG. 7B: "SPARES RESUPPLY"

TABLE 29

OPTIMAL INVESTMENT IN CONUS RESUPPLY - "LOGISTICS RESUPPLY"

	Atlantic									Pacific								
Budget**	Mean	Prob. by day 15	Alternatives for each controllable element*							Mean	Prob. by day 15	Alternatives for each controllable element*						
			1	2	3	4	5	6	7			1	2	3	4	5	6	7
0	19.1	.424	0	0	0	0	0	0	0	21,6	.349	0	0	0	0	0	0	0
100	18.2	.458	1	0	0	1	0	1	0	20.7	.382	1	0	0	0	0	1	0
500	18.2	.459	1	1	2	1	0	1	0	20.6	.384	1	1	2	1	0	1	0
1000	18.2	.459	1	1	2	1	0	1	0	20.6	.384	1	1	2	1	0	1	0
2000	17.6	.491	1	1	2	1	1	1	0	19.9	.418	1	1	2	1	1	1	0
3000	17.6	.491	1	1	2	1	1	1	0	19.9	.418	1	1	2	1	1	1	0
4000	17.4	.502	1	1	2	1	1	1	1	19.7	.427	1	1	2	1	1	1	1
5000	17.3	.509	1	1	2	1	1	1	2	19.2	.447	1	1	2	1	2	1	0
6000	17.1	.520	1	1	2	1	2	1	0	19.0	.458	1	1	2	1	2	1	1

TABLE 30

OPTIMAL INVESTMENT IN CONUS RESUPPLY - "SPARES RESUPPLY"

	Atlantic											Pacific										
Budget**	Mean	Prob. by day 15	Alternatives for each controllable element*									Mean	Prob. by day 15	Alternatives for each controllable element*								
			1	2	3	4	5	6	7	8**	9**			1	2	3	4	5	6	7	8**	9**
0	35.5	.265	0	0	0	0	0	0	0	0	0	38.0	.234	1	0	0	0	0	1	0	0	0
100	34.6	.278	1	0	0	0	0	1	0	15	0	37.1	.246	1	0	0	0	0	1	0	5	0
500	34.3	.282	1	0	0	0	0	1	0	415	0	36.6	.251	1	0	0	0	0	1	0	405	0
1000	33.9	.287	1	0	0	0	0	1	0	915	0	36.1	.258	1	0	0	0	0	1	0	905	0
2000	33.3	.297	1	0	0	0	0	1	0	1915	0	35.1	.271	1	0	0	0	0	1	0	1905	0
4000	31.8	.319	1	0	0	0	0	1	0	3915	0	32.9	.298	1	0	0	0	0	1	0	3905	0
6000	30.4	.340	1	0	0	0	0	1	0	5915	0	30.8	.328	1	0	0	0	0	1	0	5095	0

*See Table 28 for identification of the elements and the associated values for each alternative. An Alternative of 0 refers to the current value of the element.

**Thousands of dollars.

of this distribution and be confident that improvements in terms of the probability completed by a given day will follow.

Figures 7A and 7B highlight the major results of this study. For expenditures of \$6 million for "logistics resupply" for each fleet the mean resupply time decreases by 2 days or 10.5 percent in the Atlantic and 1.6 days or 7.4 percent in the Pacific. The probability of completion by day 15 rises by .08 in the Atlantic and .10 in the Pacific. Table 29 shows that the first improvements selected are to shift a greater percentage of the stock issues to first-line air stations and eliminate the use of MSTS for overseas transportation of these items. Improvements for second-line stock points and the transportation sub-processes enter at higher levels of expenditure. The results for the "spares resupply" system, summarized in table 30, show that there are only 2 improvements which are more cost-effective than purchasing spares. After a greater percentage of the issues are made from first-line stock points and all IG-1 items are sent overseas by MAC, the model dictates putting all additional dollars into the purchase of spare parts to decrease the probability that a part will have to be purchased by ASO. This implies of course that these parts are truly dedicated to the support of deployed squadrons.

Until the availability of parts is considered increased, potential improvements in transportation - such as COD, QuickTrans, or MAC aircraft - are clearly undesirable. The results obtained with these solutions are shown in figure 7B.

The results shown in figures 7A and 7B are disappointing, for the improvements outlined in this study do not seem to have any major effects on the resupply system. In retrospect, it is understandable why this is so. The major delays built into the CONUS resupply system are the submission time and ICP processing time when the item is not ready for issue (RFI). Perhaps the most severe delay is the filling of requisitions from CONUS rather than locally. We have not considered these as controllable elements of the system (although, under the "spares resupply" philosophy, we can affect the probability of availability at the ICP sub-process) because of the limited nature of this study. It would require a broader study to investigate policy on spare parts placement and requisition submission. Such a study would require as an input the results present in this work on the CONUS resupply system.

SUMMARY AND CONCLUSIONS

This study has examined the resupply system for Naval aviation spare parts. Certain concessions were necessary in this study due to the significant interdependence of the resupply system with other aspects of the Navy support system. The historical policy on the use of spares positioning and requisitioning was taken as given, as were certain aspects of the system closely allied with other support functions (such as NARF production).

Since two measures of resupply time are optimized here when in reality the Navy is concerned with the optimization of readiness (where one input is resupply resources), we did not consider parameters that were not clearly the purview of the resupply system.

In examining the present resupply system, this study has estimated parameters for the probability distributions that were assumed to describe the basic stochastic processes in the system. Where a requisition might have received one of several types of processing at some point in the system, we estimated the probabilities which governed each such branch.

Analysis of the present system led to the isolation of potential improvements, either changes in the probabilities on branches in the system or changes in the parameters of the probability distribution describing time to completion of a particular sub-process.

The optimal combination of improvements for a given budget constraint was determined for many budgets, yielding the desired cost-benefit curves. Two criteria were considered for the maximization, with the results being similar for any budget regardless of the particular criterion used.

These are the major conclusions:

- When the resupply system is burdened with the availability of parts, the average resupply time for IG-1 requisitions filled in the United States is 38 days for requisitions from the Pacific and 35.5 days for the Atlantic. When about $12 million is spent on the system on an annual basis ($6 million for each fleet), these figures are decreased about 5 days in the Atlantic and 8 days in the Pacific fleet.

- In "spares resupply," there are only two potential improvements of those considered in this study that are more cost-efficient than to increase the probability of availability at ASO with the purchase of spare parts: altering the percentage of issues from 1st-line stock points, and eliminating the use of overseas transportation.

- When the resupply system is responsible just for processing requisitions and transporting parts, the average time necessary is about 19 days for the Atlantic and 21.6 days for the Pacific, both of which decrease by about 2 days when $8 million is spent.

- The optimal combination of potential improvements for any given budget constraint is the same regardless of whether one minimizes the expected resupply time or maximizes the probability of completion by the 15th day.

- Considered independent of the rest of the support system, there is nothing that can be done to the resupply system for CONUS-filled requisitions to increase its response time significantly beyond the results discussed above.

Other less important conclusions follow:

- For requisitions filled in CONUS, submission time accounts for a tremendous proportion of the total resupply time: 46.7 percent of the mean "logistics resupply" time for the Pacific and 43.6 percent of this time for the Atlantic.

- Almost 98 percent of the requisitions filled overseas are for consumables. This result, derived from the 7-equation availability model, indicates that while some repairables are certainly fixed overseas, almost all of them are simultaneously ordered from CONUS. This statement is supported by the observation that the ratio of 1-R to 2-R requisitions from both oceans is about the same for both issue groups. The incentives for this action are understandable, since carriers are not charged for repairables, but the cost to the system is huge, as the average cost of a repairable is $2810.

- The availability of parts requisitioned by carriers overseas is significantly lower than is generally acknowledged. We found that only about 50 percent of CONUS-filled IG-1 parts were ready-for-issue when the requisition was processed by ASO. This indicates a severe problem in the range and depth of spares purchased as ASO.

- For parts that are not immediately available, the expected waiting time is about 33 days (although the median waiting time is less). There is virtually no chance that this 50 percent of requisitions will be filled within the UMMIPS standard for IG-1 of 7 days. Even if a part is ready-for-issue, the probability of completion by day 7 is only .12 to .15.

- The time delays for requisitions issued by a 2nd-line stock point, representing 25 percent of all requisitions for spares, are significantly greater than for items issued by a 1st-line activity. For issue group one, the difference averages 2 1/2 days (3 days for a 2nd-line activity versus 1/2 day for 1st line). In view of the estimated costs of transferring the majority of 2nd-line off-section issues to the 1st-line activities, this is a strong recommendation for improvement.

- Although it is difficult to estimate from our data the time delays incurred by the bounceback of requisitions to ASO from stock points, it is clear that this is putting an undue strain on the system and is another point in favor of reducing the use of 2nd-line stock points for off-station issues.

- It is clear that the easiest way to reduce CONUS transportation time is to have parts issued by the stock point closest to the MAC/MSTS port of embarkation. This is being done in a surprisingly small proportion of the cases, especially for parts destined for the Atlantic. Since the placement of spares was beyond the scope of this study, this issue is not pressed further. But to the extent that ASO has a choice between two potential issues of an item, its future movements should be anticipated and the appropriate issuing activity selected.

- While only about 1 percent of IG-1 items were sent overseas by ship, these were subjected to long delay time, especially in the Atlantic Ocean. The estimated cost of shipping these parts by air is low enough that this improvement is recommended.

- The conclusions cited above highlight the importance of spares positioning in this system. This issue is relevant not only with regard to parts stocked overseas rather than in CONUS, but also with regard to specific locations within CONUS. The importance of the NARF as a significant bottleneck is also highlighted.

We recommend that the question of positioning be investigated in light of the evidence presented on CONUS resupply in this study.

- While the MILSTEP system has tremendous potential for Navy support activities, it is weakened by the small percentage of aviation material issues reporting to the system. When this is improved, MILSTEP should be used to monitor the performance of each sub-process in the resupply system. Flags should be programmed into the system to indicate trouble areas and efforts directed toward their improvement. (Some of these are discussed in the appendix). In short, the system will be an excellent tool, but only if it is used in the proper manner by people with sufficient authority to change the system.

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(c) John Sullivan, CNA Cost Analysis Division, memo 28 Apr 1970

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(e) Lester P. Silverman, "Resource Allocation in a Sequential Flow Process," CNA Professional Paper 21, 5 Mar 1970, to appear in Operations Research

(f) Warren G. Rogers and Lester P. Silverman, "Estimation of Completion Times in a Multi-Stage Process," CNA Working Paper in preparation

APPENDIX A

APPENDIX A

THE MILSTEP SYSTEM

The primary source of data for the analysis of the resupply system was the Military Supply and Transportation Evaluation Procedures (MILSTEP) maintained by the Fleet Material Support Office (FMSO) in Mechanicsburg, Pennsylvania. MILSTEP files contain the requisition date and subsequent important dates in the history of a supply system requisition.

To obtain the history of requisitions from overseas carriers it was necessary for us to merge two data files, the Requisition History/Status File (RH/ST) and Intransit Data Card (IDC) files. We matched the appropriate records on each file by GBL/TCN for each of 12 months (February, 1969 through January, 1970 inclusive).

Table A-1 shows the data elements which were used, the columns of either the RH/SF or IDC tapes where it was located, and the location of the element on our output record. Table A-2 shows how the data on the output tape was used to construct the 8 time-frames used in the study.

In constructing these time-frames, the following assumptions were made:

1. Date received at the ICP was assumed to be the requisition date plus the submission time.

2. When the beginning date of an interval was greater than the ending date and the calendar year of the requisition was 8, we added 366 to the time-frame to compensate for a change in calendar year.

3. If the calendar year was 9 and the computed value for the time-frame was less than zero, the value was omitted from our calculations except when this occurred for the CONUS transportation. In this case examination of the end points revealed that the date shipped exceeded the date received at the POE and was obviously in error compared to other dates for that requisition. This occurred frequently enough in the data to require special consideration. For these instances the date shipped was assumed to be the date offered and the CONUS hold-time was set equal to zero.

4. Requisitions with calendar year date other than 8 or 9 were omitted.

5. If a data point was equal to zero blank, the related time intervals were omitted from our computation.

TABLE A-1

DATA FORMAT OF OUTPUT RECORD

Output tape column	Field	Source	Column
1-3	Document identifier	RH/SF	4-6
4-6	Routing identifier	RH/SF	7-9
7-21	Stock number - TSMC	RH/SF	11-25
22-36	Document number	RH/SF	33-47
37-39	Project code	RH/SF	60-62
40-41	Priority	RH/SF	63-64
42-44	Routing identifier from	RH/SF	70-72
45-49	Date received at stock point	RH/SF	84-88
50-51	COG	RH/SF	89-90
52-54	Supply action date	RH/SF	93-95
55-59	Shipped date	RH/SF	96-100
60	Mode	RH/SF	101
61-62	Submission time	RH/SF	102-103
63	Record type	RH/SF	104
64	Hold-code	RH/SF	105
65-69	Date offered	RH/SF	106-110
70-86	GBL or TCN	RH/SF	111-127
87-89	POE	RH/SF	128-130
90-95	Consignor	RH/SF	148-153
96-101	Consignee	RH/SF	154-159
102-104	Date received at consignee (if in CONUS)	IDC	15-17
105-107	Date received at overseas POE	IDC	18-20
108-110	POE location	IDC	21-23
111-113	Date shipped from POE	IDC	24-26
114	Mode	IDC	27
115-117	Date received at APOD	IDC	63-65
118-120	APOD identification code	IDC	66-68
121-123	Date forwarded to consignee	IDC	69-71
124-128	Weight	IDC	72-76
129-131	Consignor area, state and country code	IDC	112-114
132-134	Consignee area, state and country code	IDC	115-117

TABLE A-2

CALCULATION OF TIME-FRAMES

Time frame	Calculation*
Submission time	Given in columns 61-62
ICP processing time	Date received at stock point (columns 45-47) minus requisition date (columns 29-31) plus submission time (columns 61-62)
Stock control processing time	Supply action date (columns 52-54) minus date received at stock point (columns 15-17)
Warehouse processing time	Date offered (columns 65-67) minus supply action date (columns 52-54)
CONUS hold-time	Date shipped (columns 55-57) minus date offered (columns 65-67)
CONUS transportation	Date received at overseas POE (columns 105-107) minus date shipped from stock point (columns 55-57)
Overseas hold-time	Date shipped from POE (columns 111-113) minus date received at POE (columns 105-107)
Overseas transportation	Date received at APOD (columns 118-120) minus date shipped from POE (columns 111-113)

*Column numbers refer to the output tape constructed from the merged RH/SF and IDC tapes.

We encountered several problems with the MILSTEP system. The major problems were:

1. The most significant problem was the biased sample of requisitions reported on the system. For the data on ASO COG items, MILSTEP only contains the history of requisitions filled by 3 major jet bases or the Naval Supply Center. Further, only requisitions which are transported by military facilities rather than parcel post are picked up.

2. The IDC data file only collects data on a requisition until it leaves the forward supply point (APOD) and does not follow it back to the requisitioner. Moreover the great majority of records were not completed beyond the date shipped from the POE. The overseas facilities handling this material only rarely entered the date of arrival.

3. The submission time field on the RH/SF tape, being only two digits, was not large enough to handle approximately 5-10 percent of the IG-1 and IG-2 requisitions which took over 99 days to be submitted.

4. The date received at the ICP and/or first point of entry into the supply system was not explicit and had to be inferred from the submission time and the date of the requisition.

5. Dates were often out of chronological sequence, i. e., the date shipped from a stock point was greater than the date received at the CONUS destination.

6. There is confusion about the definition of the "mode" codes on the RH/SF and IDC files. The appearance of 2 mode codes would seem to allow for indication of CONUS transportation and overseas transportation modes respectively. However, we discovered a percentage of the first mode code being either MAC or MSTS and the second being QuickTrans or LogAir, which violates the above hypothesis.

Once the problems isolated above are resolved, we suggest greater utilization of MILSTEP for monitoring the performance of the resupply system. MILSTEP is the only data system in the Navy which gives detailed information about each aspect of the supply system. To this date, FMSO has used MILSTEP to indicate the glaring problems in submission time which resulted in a NavSup investigation. Other such analyses can be performed. In addition, the performance of each stock point, inventory control point, and transportation coordinating office can be monitored for trends and aberrations.