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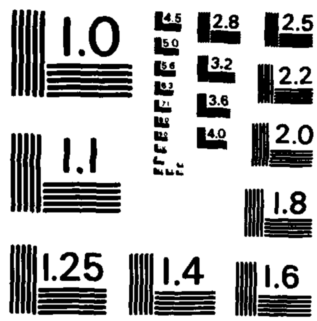

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Working Note AF301-4

October 1984

Christopher H. Hanks

Prepared pursuant to Department of Defense Contract MDA903-81-C-0166 (Task AF301).

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SUMMARY

In fiscal year 1984, the Air Force will spend more than $2 billion for initial and replenishment stockage in the Systems Support Division (SSD) of the Air Force stock fund. As in the other Services, the Air Force's stock fund is a self-supporting enterprise that "sells" items of supply to Department of Defense "customers." The SSD is the division of the stock fund in which the Air Force acts as its own manager and wholesaler of consumable repair parts.

Because of the resources involved and the continuing commitment to develop weapon-system-oriented methods for sizing inventories of secondary items, the Air Force is actively interested in relating the levels of SSD support to aircraft availability rates by weapon system. The following results represent a first step in quantifying that relationship by providing bounds on the effects that changes in SSD safety levels would have on availability rates. Safety levels are the stocks carried to provide coverage for fluctuations in demand.

Given a reduction in SSD safety levels leading to a drop in wholesale fill rates of 5 points, from 85 to 80 percent, expected SSD wholesale backorders to retail customers would increase about 70 percent, and aircraft availability rates would fall from 1 to 3 points, depending on aircraft type (and assuming no increase in funding for recoverable spares). The corresponding increases in the number of "lost" aircraft (those that would otherwise have been available) total over 150 aircraft Air Force-wide. The reduction in safety level represents about 30 percent of the "55 days' worth of demand" target values now used to size wholesale safety levels.

These estimates are bounds on availability effects, not predictions of what would actually occur in the field. The many factors that affect the readiness levels of weapon systems, coupled with the flexibility afforded stock fund managers, make such predictions difficult.

The results show that stock fund operations can have a noticeable effect on aircraft availability and that these effects can be estimated within a useful range of accuracy. The results do not necessarily mean that the Air Force's next supply dollar should be spent on stock fund items rather than recoverables. For acceptable levels of end-item support, the Air Force needs both consumable and recoverable spares.

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1. BACKGROUND

STOCK FUNDS IN THE DoD

The Department of Defense (DoD) has five stock funds: one in the Defense Logistics Agency (DLA) and one in each of the four Services. The funds are set up to operate as self-supporting enterprises that sell various commodities and items of supply to DoD customers and, from the receipts of those sales, obtain the cash to replenish their stocks and continue operations. Customers of the stock funds pay for their purchases out of their operations and maintenance appropriations and industrial fund accounts.

For normal peacetime requirements, the funds operate with obligational authority provided by, and administered within, the DoD, without recourse to Congressional appropriations. All the funds maintain revolving capital accounts to provide working cash for continuing operations.

The funds are subject to the Congressional appropriations process for the purchase of war reserve stocks and materials and for items in the relatively new category of inventory augmentation. Under this category, which was established in 1982, new or additional stocks are purchased to support force growth and modernization, modification programs, and readiness and sustainability initiatives.

Management of the funds is overseen by the Assistant Secretary of Defense (Comptroller) and the Assistant Secretary of Defense (Manpower, Installations, and Logistics), as well as various logistics, supply, and financial organizations within the Services themselves.

All the stock funds employ standard reorder point and economic order quantity (EOQ) methods for inventory management, in line with DoD

Instructions (DoDI) 4140.39 and 4140.45. These instructions outline the policies, procedures, and models to be used for secondary-item management at the Inventory Control Point (wholesale) and the intermediate and consumer (retail) levels. With the exception of the DLA stock fund, which operates at wholesale only, all the stock funds maintain inventories at both wholesale (for example, depot) and retail (base) echelons of supply. The financial and accounting relationships between echelons and the associated stock transfer and sales relationships, however, vary from Service to Service.

The stock funds manage a wide range of commodities and items, ranging from fuels, clothing, commissary items, and medical and dental supplies to hardware repair parts and spares. The hardware category includes both consumable items and intermediate- and field-level reparables. The Navy's stock fund includes depot-level reparables as well. All told, over 3.5 million line items are managed in the stock funds, with a grand total of more than $50 billion in obligational authority requested for fiscal year 1984 (FY84) across all commodities. Of that total, approximately $15 billion is for hardware items.

THE AIR FORCE STOCK FUND

This study focuses on the Systems Support Division (SSD), one of six divisions in the Air Force stock fund: (1) the SSD, (2) the General Support Division (GSD), (3) Fuels, (4) Medical and Dental, (5) Commissary, and (6) the U.S. Air Force Academy Bookstore.

The SSD and GSD are the two divisions concerned with hardware items, with Budget Codes of 1 and 9, respectively, for financial and accounting purposes. Both the SSD and GSD manage items used in the repair and maintenance of aircraft and aircraft components. In the GSD, items are requisitioned or procured at the base or retail level from outside wholesalers, such as DLA, the

General Services Administration, other Services, and commercial vendors. In the SSD, the Air Force acts as its own manager and wholesaler, with Inventory Control Points (ICPs) at each of the five Air Logistics Centers (ALCs) within the Air Force Logistics Command (AFLC), and a sixth ICP, the Cryptollogical Support Center, at Kelly Air Force Base (AFB), Texas.

The SSD, founded in 1968, now manages about 500,000 different line items, with an average procurement leadtime (administrative plus production leadtime) of more than 13 months for active items in the inventory. Expendability, Recoverability, and Repairability Category (ERRC) designators for SSD items are of two types. XB3 items, not subject to repair, that is, non-recoverable, are generally consumed in use. Examples are such things as fasteners and gaskets. XF3 items, repairable at the base and intermediate levels, cannot be repaired economically above those levels. The lower levels have the choice of repairing them or not, as they see fit.

SSD items are used primarily as spares and repair parts in Air Force base and depot maintenance operations. The volume of sales to depot maintenance activities is roughly 1½ times that to bases and intermediate-level activities. In addition, more than 10 percent of SSD sales are made to other Services or in support of Foreign Military Sales (FMS) programs.

The SSD received FY84 obligational authority for $1.8 billion to replenish wholesale stocks. This amount does not include the value of retail "ordering authority" required to replenish base-level stocks. The SSD is a vertically integrated system in which transfers, rather than actual sales, are made to retail supply points from the wholesale level. In addition to the $1.8 billion in obligational authority, the Air Force received appropriations of $942 million for inventory augmentation in FY84 and $75 million for war reserve purchases.

Wholesale requirements for the SSD are computed by the EOQ Requirements System (DØ62) documented in AFLC Regulation 57-6, "Requirements Procedures for Economic Order Quantity Items," May 1982. Part One of the regulation explains how gross stock level requirements are computed. Part Two covers the Central Secondary Item Stratification (CSIS) computation system for stratifying non-recoverable item requirements and assets in line with DoD guidance (DoDI 4140.24).

Air Force supply systems that provide data on SSD operations and performance are the DØ32 and DØ33 Stock Control and Distribution Systems and the M-32 base supply reporting system. The DØ32 system covers wholesale operations overall, while the DØ33 covers retail operations at the AFLC depots. The M-32 system describes retail supply performance at Air Force bases around the world. The Air Force Data Systems Design Office at Gunter AFB, Alabama, assembles worldwide summaries of the monthly M-32 reports and releases microfiche copies quarterly.

MOTIVATION FOR THE STUDY

In FY82 and FY83, the Air Force stock fund (and DoD stock funds in general) simultaneously experienced (1) increases in projected obligational authority requirements (driven by cash shortages caused by inflation and demand heightened by force growth and modernization) and (2) changes in approved financial management procedures (driven by Congressionally mandated requirements to seek appropriations for inventory augmentation and new rules constraining interfund cash transfers). The confluence of these events led, as might be expected, to both real and perceived cuts by both the Office of the Secretary of Defense and Congress in the funding and obligational authority provided to the Air Force for stock fund operations in FY82 and FY83.

The main reason for this study is the Air Force's interest in the potential effects that similar cuts in the future might have on end-item readiness.

Also motivating the study is the continuing commitment within the Air Force to develop and apply weapon-system-oriented, availability-based methods for sizing secondary-item inventories, as called for in the Defense Guidances of the past four years.

2. OBJECTIVE AND APPROACH

A TWO-PART PROBLEM

Assessing the effect of SSD funding constraints on end-item readiness is a two-part problem. In the SSD, as in any supply system, stock levels are a key determinant of the system's ability to meet customer demands and support operations. When SSD stock levels change for any reason, support and response to customers vary and aircraft availability can suffer. Therefore, part of the problem is to understand how changes in SSD stock levels can affect aircraft availability -- a matter of supply performance. The other part of the problem is to determine how budget-level funding decisions can cause SSD stock levels to change in the first place -- a matter of management analysis.

This work is an analysis of the supply performance aspect of the problem, namely, how availabilities change with stock levels, but not how and why the stock levels themselves change. Consequently, this study is only a first step toward enabling Air Force planners to assess the effects of SSD budget decisions on end-item readiness. The financial and management response mechanisms that lead to changes in stock levels in reaction to SSD budget decisions are the subjects of continuing research at Logistics Management Institute (LMI).

OBJECTIVE

The object is to determine the effect of variations in SSD safety levels on aircraft availability. Stock levels in the SSD are the sum of a pipeline level and a safety level. The pipeline level is the portion of the total stock level designed to cover mean (also called "average" or "expected") demand over the course of a resupply or procurement leadtime. The safety level portion consists of the stocks needed to cover the variation in demand that occurs about its expected value. When stocks are maintained at a level that will not meet expected demand in a resupply time, then the safety level is said to be negative. Because SSD policy does not allow negative safety levels -- that is, computed stock levels must always be at least equal to expected demand in a resupply time -- changes in SSD stock levels amount to changes in safety levels. The object of this study is, therefore, stated in terms of changing safety levels rather than stock levels.

Because the long-term goal of this analysis is to understand how SSD funding decisions affect end-item readiness, the presumption is that budget-level funding decisions will ultimately affect safety levels. Though this premise is reasonable and in line with how the DØ62 system works conceptually, the safety levels for weapon-system-support items, in fact, rarely bear the entire brunt of funding fluctuations. Other management options are available. For example, additive programs may be cut or delayed, non-demand-based stockage levels may be altered, priority schemes may be employed, and order quantities may be adjusted. Any or all of these methods can be and are adopted to preserve safety levels for high-priority, weapon-system-support items. Investigation of these kinds of management response options is continuing. In this work, however, the object is to size the effect on aircraft availability rates if, in fact, SSD safety levels do change.

TECHNICAL APPROACH

The aspects of the approach described here serve as background for the results presented in Chapter 3. Additional details about technical methods and data findings are given in Chapter 4.

Overview of the Aircraft Availability Model (AAM)

Aircraft availability rates for a given aircraft type (MD - Mission/Design) refer to the portion of the fleet that is not waiting for a recoverable, line-removable unit, that is, an LRU (ERRC designator XD) to be either repaired or received in a shipment. As computed by the multi-indenture, multi-echelon AAM, these rates are a function of the number of recoverable components (both LRUs and shop-removable units, SRUs) in the resupply pipelines (namely, the depot and base repair, order and ship, and procurement pipelines), the projected asset positions for these components, and the resulting number of expected backorders (EBOs) in place for aircraft LRUs.[1] The key point is that the AAM specifically includes the base and depot repair pipelines for SRU and LRU recoverables. The main way in which SSD items affect end-item availabilities is in their effect on these pipelines.

Where SSD Comes In

As recoverable components move through base and depot repair, they generate demand for SSD repair parts and spares. (At bases, aircraft on the flight line can also generate direct demand for SSD items.) In addition, these components will also generate demand for GSD items and for other repair parts that may themselves be non-stock-funded, repair-cycle items. When these demands are not met, recoverable items (and occasionally aircraft) "go AWP" (that is, enter "awaiting parts" status), aircraft wait that much longer for missing parts, and availability rates fall.

Fill rates are a standard indicator of supply performance used to measure the degree to which demands for parts are being met. They represent the percentage of requisitions immediately filled by the supply system and not placed on backorder. Because the SSD is a two-echelon system, a distinction must be drawn between wholesale and retail fill rates. Though it is entirely possible for both wholesale and retail stock levels to be adjusted in response

[1]See: T. J. O'Malley, The Aircraft Availability Model: Conceptual Framework and Mathematics, Task AF201 (Washington, D.C.: Logistics Management Institute, June 1983), for a complete description of the methodology and outputs of the AAM.

to an SSD budgetary constraint, we assume in this report that such a constraint would be managed at the wholesale level and that retail stock levels would not be intentionally changed. (This is, in fact, what was done to accommodate the funding constraints in FY82 and FY83. Managers at the wholesale SSD level adopted procedures to operate under the constrained funding and told their ordering bases and retail supply points to continue business as usual.)

Other terms for fill rate are "issue effectiveness," "stockage effectiveness," and "supply availability." The last two reflect the fill rate for stocked items only, not all items. At the wholesale level, where it is reasonable to assume that a level exists for virtually every item, the terms are essentially interchangeable.

We therefore pose the following main question:

> What is the effect on aircraft availability rates if SSD wholesale safety levels fall to the extent that wholesale fill rates drop 5 points, from an 85-percent level to an 80-percent level?

The 85-percent fill rate level is an appropriate place to start because the official SSD goal through FY83 was to maintain an average fill rate of 85 percent system-wide. Examining a five-point drop is appropriate because system-wide wholesale fill rates tend to be stable, even under relatively adverse conditions. Despite the funding limitations in FY82 and FY83, for example, the wholesale SSD fill rate fell by only 4 points, from 86.3 percent in FY82 to 82.1 percent in FY83.

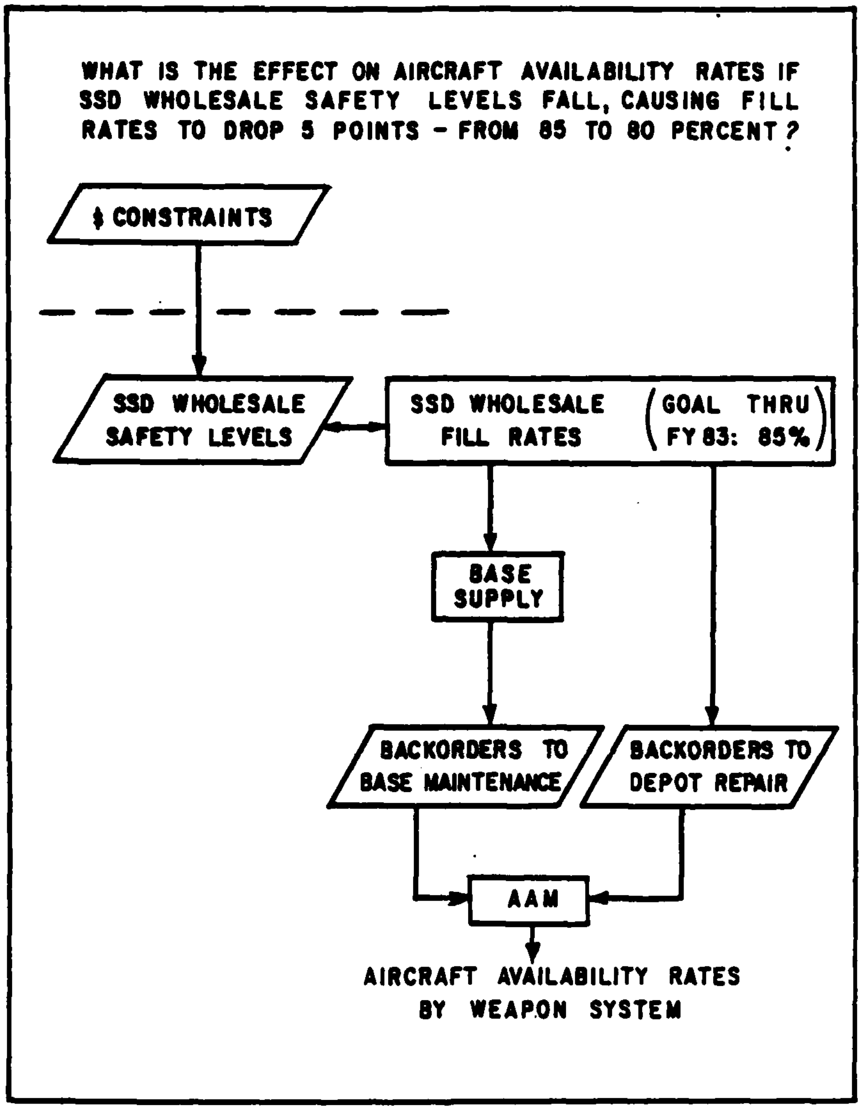
Basic Analytic Approach

To answer the main question, we first estimate the increases in depot and base repair times for recoverables that a five-point drop in the SSD wholesale fill rate would produce. Once these increases are known, they can be added to existing (baseline) repair times as recorded in the DØ41 recoverable item data bank, which serves as a main input to the AAM. To calculate new depot and base repair pipelines, we take the (known) rates at which recoverables enter base and depot repair and multiply them by the increased repair times. The AAM can then be run twice to see the effect of these SSD-driven pipeline increases.

The first run is a baseline run with no increases in repair times or pipelines. The second run is done with the increased pipelines. The differences between the cost-availability curves generated in the two runs can then be examined for each weapon system. This process gives us (1) the drop in availability rates that occurs with no change in recoverables investment and (2) the increase in recoverables investment required to maintain availability rates at the baseline levels they were at when there was no degradation in SSD support. Figure 2-1 shows the logical flow of this approach, including the fact that retail supply inventories at bases serve to buffer retail customers from fluctuations in support at the wholesale level.

Because baseline repair times in the DØ41 data base do not, by policy, include any AWP time, the approach outlined above will tend to overstate the relative increase in repair pipelines to a certain degree. This is not a serious problem, since the AWP increases involved are relatively small to start with, in comparison with the baseline DØ41 repair times. In any case, by ignoring any AWP time already present, we get worst-case results. In general when error-inducing assumptions such as this were made in the analysis, the choice was always made to err on the pessimistic side, so that the results would provide an upper bound on the effects on availability.

FIGURE 2-1. APPROACH



A second aspect of the approach worth noting is that the increases in the repair times and pipelines for recoverables in depot and base repair are computed without knowing which SSD items apply to which recoverables. Again, this is deliberate. For many of the half-million-plus items in the SSD, there are no accurate application files showing which SRUs, LRUs, and MDs use which SSD items. For this reason, and because the intent was to do a scoping study rather than an item-specific analysis, the estimated increase in repair times is spread uniformly across all the DØ41 recoverable items processed by the AAM in a model run. Evidence exists that this uniform spraying of SSD AWP time increases also yields worst-case results, at least in the aggregate across all aircraft types, but further analysis is needed to verify this hypothesis. In the real world, of course, the effects of a drop in the SSD fill rate would not be felt uniformly across all recoverables or all aircraft types. The results should, therefore, be viewed as scoping estimates of availability effects, rather than precise predictions of what would actually occur in the field.

The AFLC EOQ-METRIC Study

It should be noted that, besides this work performed under Air Staff sponsorship, another study of EOQ items and availability is underway, in this case sponsored by AFLC. The two studies differ in approach but are complementary in the views they provide on how EOQ items may affect availability. The AFLC EOQ-METRIC study is computing the differences in EOQ item levels and system availabilities that result when EOQ item requirements are computed with two models: an item-specific, multi-indenture availability model, using complete application data, versus a DØ62-like model that does not take indenture relations into account.

The EOQ-METRIC methodology is based on work by Muckstadt of Cornell University, showing how optimum EOQ levels to support system availability can be computed and incorporated into existing DØ62 computational machinery.[2] The EOQ-METRIC study is testing a small subset of the SSD data base by looking at

[2]Professor John A. Muckstadt, "A Multi-Echelon Model for Indentured Consumable Items," Technical Report No. 548 (Ithaca, New York: School of Operations Research and Industrial Engineering, College of Engineering, Cornell University, June 1982).

the parts and indenture files for ten selected LRUs. It is an item-specific comparative study of two different ways to compute EOQ levels. The LMI study, on the other hand, assumes no change in SSD operating procedures or computational methods and develops system-wide estimates of availability effects based on a uniform distribution of backorder increases, without regard to actual applications.

3. RESULTS AND CONCLUSIONS

PIPELINE EFFECTS - INCREASES IN AWP TIMES

For the repair lines at bases and depots, a 5-point drop in the wholesale SSD fill rate from 85 to 80 percent would cause AWP times to increase approximately 0.20 to 0.25 days at the bases and 1.3 to 3.3 days at the depots. These estimates represent the increase in AWP time averaged across all BP-1500 recoverable components with non-zero base or depot repair pipelines. The top values of these estimates, 0.25 and 3.3 days, respectively, were the ones used to compute effects on aircraft availability.

As noted, these are the effects if increases in AWP time are spread uniformly across all SRUs and LRUs with non-zero pipelines in the recoverables data base. In the real world, of course, SSD-driven AWP time increases would not be felt uniformly. Some items would suffer more and others less, depending on the particular SSD items involved and the repair cycle items to which they applied. Corresponding effects on aircraft availability would also vary from aircraft type to aircraft type. Nevertheless, these average effects provide a basis for comparing SSD effects on repair pipelines with other possible influences (e.g., across-the-board administrative leadtime increases). Also, for a given availability level, since uniform item pipelines tend to require greater support overall than non-uniform pipelines totaling the same amount, it is reasonable to expect that applying average AWP time increases gives worst-case results in the sense of most-expensive-to-correct. If all AWP time increases were concentrated on parts for a small number of aircraft types, the availability rates for those aircraft would indeed plummet, but the fix for this situation would be less expensive than when the AWP increases are spread across all repair parts.

AIRCRAFT AVAILABILITY EFFECTS - AIRCRAFT "LOST"

On the basis of the assumption that AWP times would increase by 0.25 days at bases and 3.3 days at depots for the average recoverable component, the 5-point wholesale SSD fill rate drop would cause aircraft availability rates to fall as shown in Table 3-1, which assumes a "going-in" availability level of 75 percent across all MDs, and no increase in funding for recoverable spares. The data in the table on fleet sizes are based on PA85-2 Aerospace Vehicles and Flying Hours Program files for primary aircraft inventory (PAI). The third column shows the drop in percentage points from the 75-percent level for each MD. The last column shows the total number of aircraft "lost" by MD and the total "lost" in the category. "Lost" aircraft are those that would otherwise have been available if the SSD fill rate had not fallen. Note that the total number of "lost" aircraft exceeds 150 Air Force-wide.

These results are bounding estimates only, not predictions of what would actually occur. The reason, again, is that increases in AWP time would not be distributed uniformly, and actual MD effects would vary accordingly. Also, the 75-percent availability level was chosen as a roughly appropriate level at which to examine the effects of an SSD fill rate drop, but not all aircraft currently operate at exactly that level in the field. Actual availability levels vary by MD, at least as reflected in current mission-capable (MC) rates. (Aircraft availability rates *per se* -- the percentage of aircraft not waiting for a recoverable part -- are not measured directly by any of the Air Force's supply or maintenance reporting systems.) These results are, therefore, not enough to justify a conclusion that the next Air Force supply dollar should necessarily be spent on the stock fund to improve readiness, as opposed to spending for recoverables, test equipment, or some other form of logistics support. What the results do show is that the SSD can have measurable effects

TABLE 3-1. AIRCRAFT "LOST"

AIRCRAFT TYPES WITH TOTAL FY85 FLEET SIZES		NUMBER OF AIRCRAFT AT 75% AVAILABILITY	DROP IN AVAILABILITY (% POINTS)	AIRCRAFT "LOST"
Attack				
A7	325	244	1.6	5
A10	583	437	2.6	15
A37	106	80	1.7	2
	1014	761		22
Bombers				
B52	241	181	3.8	9
B111	57	43	3.7	2
	298	224		11
Airlift				
C5	65	49	3.3	2
C130	696	522	2.0	14
C135	701	526	1.9	13
C141	254	191	3.4	9
	1716	1288		38
Fighters				
F4	1473	1105	2.0	29
F5	102	77	1.5	2
F15	612	459	3.4	21
F16	668	501	3.0	20
F106	97	73	1.0	1
F111	294	221	3.4	10
	3246	2436		83
Trainers				
T33	144	108	1.1	2
T38	803	602	2.5	20
T39	103	77	1.1	1
	1050	787		23
Helicopters				
H1	126	95	1.0	1
H3	75	56	1.0	1
H53	42	32	1.1	0
	243	183		2

on aircraft availability and that these effects can be estimated within a useful range.

INCREASED COSTS

A natural question to ask is this: How much more would have to be spent on recoverable spares to make up for the SSD-caused drop in availability rates? With the cost/availability curves generated by the AAM, we can answer this question.

The increase in recoverables investment needed to make up for the drop in SSD fill rate and maintain availability rates at 75 percent across the board is shown in Table 3-2. The dollar values in Table 3-2 are FY83 requirements based on an unscrubbed[1] March 1983 DØ41 data base, for the same set of MDs as in Table 3-1. The $114 million figure is the total increase in recoverables investment needed to maintain availability rates at 75 percent. This investment would be essentially one-time in nature, to boost pipeline and safety levels for recoverables to accommodate the increased size of the repair pipelines.

TABLE 3-2. INCREASED COSTS

AIRCRAFT CATEGORY	FY83 COSTS FOR 75% AVAILABILITY ($ in millions)	INCREASE IN REQUIREMENT ($ in millions)
Attack	$ 237	$ 7.0
Bombers	425	22.5
Airlift	542	28.5
Fighters	1065	53.0
Trainers	59	1.4
Helicopters	38	1.4
Total	$2400	$114

[1]An unscrubbed DØ41 data base does not reflect error corrections, scrubs, additive programs, and other adjustments to the item-specific data. Such adjustments would affect the total costs shown in Table 3-2, but would have very little effect on the changes in cost.

THE SAFETY LEVEL REDUCTION

The reduction in SSD wholesale safety levels that produces the 5-point drop in fill rate from 85 to 80 percent represents approximately 30 percent of the "55 days' worth of demand" dollar target that Headquarters AFLC uses to size the aggregate SSD wholesale safety level at each ICP. On the basis of a demand figure of approximately $1.6 billion in FY82, the dollar value of this reduction is on the order of $70 million. As was the case for the increase in the recoverables requirement, these "savings" are one-time in nature. They reflect a lowering of the average inventory position at the wholesale level by means of a reduction in reorder point levels.[2]

The fact that the $70 million in savings is outweighed by the $114 million increase in recoverables investment is not surprising (in the sense that repair parts generally cost less than the items they repair), but the figures must be interpreted carefully, nonetheless. The $114 million is the cost in recoverables investment to recoup the increase in expected backorders (EBOs) in place caused by the lack of SSD repair parts. If the increase in EBOs had been smaller (remember that the estimate of the EBO increase in this report is a worst-case possibility), the $114 million figure would have been smaller. In fact, if the increase in EBOs were small enough, the increase in recoverables investment to maintain existing availability rates would be less than $70 million. This would occur if the SSD effect on EBOs were so slight that large quantities of SSD parts were needed to obtain the same backorder reduction achieved by small quantities of recoverable spares.

[2]The effect is similar to what would happen if a driver decided to change policy and always fill his gas tank when there was one gallon left in the tank rather than two. With no change in his driving habits (demand), he would save only the cost of the one gallon not replaced at the transition fill-up, when he first applied the one-gallon rule.

The only way to examine these tradeoffs is with an item-specific, multi-indenture model with full application files for all classes of parts, both consumable and recoverable. The $70 and $114 million figures indicate that, in such a model run, stock fund items would often be the spares of choice, but an optimal solution would involve a mix of consumable and recoverable spares, based on the interplay among backorder reductions, availability improvements, and item costs.

One cannot conclude, therefore, from the comparison of the $70 million with the $114 million that the stock fund is either overfunded or underfunded in relation to recoverables. Both recoverables and consumable spares are needed to provide acceptable levels of end-item support.

4. DATA AND ANALYSIS

This chapter discusses in detail the data and analysis underlying the results of the study. The bulk of the work is in estimating the AWP time increases that result from the drop in the SSD fill rate. Once these increases are known, they are added to the baseline DØ41 repair times, and the AAM projects the effects on aircraft availability.

The estimates of increases in AWP time are derived from Air Force supply performance data. Standard methods from inventory theory are then applied and the data interpreted and converted into projections of AWP time increases. The data, drawn from supply performance reporting systems, both wholesale and retail, are of interest in their own right, given their implications about current supply performance in the Air Force.

The discussion begins with some basic points about the relation among backorders in place, fill rates, and AWP times. In view of the multi-echelon nature of the problem, the discussion then turns to the analysis of the wholesale/depot repair case, followed by the retail/base repair case. How the size of the safety level reduction is estimated is also covered. As the data are introduced, their sources are identified.

BASIC NOTIONS

The key idea here is that the relative increase in AWP time for a given repair process is equal to the relative increase in EBOs for the process. It is, therefore, possible to project AWP time increases by projecting the changes in EBO levels.

For a given repair process, depot or base, we are interested in the increase in AWP time that a 5-point drop in the wholesale SSD fill rate, from 85 to 80 percent, would produce.

Let PNP denote the percentage of items entering the repair process that generate demand for SSD parts, let NFR denote the non-fill rate at the supply point servicing the repair line (i.e., the percentage of requisitions not immediately filled), and let AWP denote the average awaiting parts time in the repair process (averaging across only items that enter AWP status in the first place).

Then,

$$\text{PNP} \times \text{NFR} \times \text{AWP} = \text{average awaiting parts time across } \underline{\text{all}} \text{ components in the repair process,} \tag{4-1}$$

and what we want is $(\text{PNP} \times \text{NFR} \times \text{AWP})_{80} - (\text{PNP} \times \text{NFR} \times \text{AWP})_{85}$, where the subscripts denote the wholesale fill rate. The quantity PNP x NFR x AWP may be thought of as a two-term weighted average, where the second term covers all components that experience zero AWP time, because they either did not need an SSD repair part or did need one and received an immediate fill from supply.

If we define:

$$\Delta = \frac{(\text{PNP} \times \text{NFR} \times \text{AWP})_{80}}{(\text{PNP} \times \text{NFR} \times \text{AWP})_{85}} - 1, \tag{4-2}$$

the increase in AWP time can be expressed as:

$$(\text{PNP} \times \text{NFR} \times \text{AWP})_{80} - (\text{PNP} \times \text{NFR} \times \text{AWP})_{85} = \Delta \times (\text{PNP} \times \text{NFR} \times \text{AWP})_{85}. \tag{4-3}$$

Assuming we can obtain the right value for Δ, this formulation allows us to go directly from empirical data on PNP, NFR, and AWP (at the 85-percent wholesale fill rate) to the value of the AWP time increase we want. The question, therefore, is how to determine Δ.

The value of Δ is a function of how EBO levels change. EBOs are defined as the average number of backordered requisitions (customer demands on the supply point serving the repair line) in place at any given time. The number of backordered customer requisitions at a supply point is a random variable that varies with time. The EBO quantity denotes its mean (expected) value.

Expected backorders are a function not only of demand and fill rate, but also of how long backorders last when they occur. If we let DDR denote the daily demand rate at the supply point, let NFR denote the non-fill rate as defined before, and let AVBOD denote the (mean) duration of a backorder (the time in days it takes to fill a backorder, measured from the time the requisition is placed and backordered, to the time it is filled and released), the average number of backorders in place at any time is given by:

$$\text{EBO} = \text{DDR} \times \text{NFR} \times \text{AVBOD}. \tag{4-4}$$

For example, if there are 10 demands per day, and 20 percent are not filled, and a backorder takes an average of 30 days to fill, there will be an average of 10 x 0.2 x 30 = 60 backorders in place on any given day. If equation (4-4) is viewed as applying to one item, AVBOD equals the average backorder duration over all backorders for that item. If equation (4-4) is applied to an entire system of items, AVBOD equals the average duration over all backorders for all items.

We assume that the average awaiting parts time in the repair process, AWP, is essentially equal to AVBOD, the average duration of a backorder (due-out), from supply to the repair process. In the data, these times may differ because of variations in measurement rules; conceptually, however, the two times are identical. We are, of course, also assuming that the average daily demand rate stays the same (steady state demand).

Let EBO_{80} and EBO_{85} denote expected backorder levels for SSD items corresponding to wholesale fill rates of 80 and 85 percent. The relation between EBOs and average AWP times can then be described as:

$$\frac{EBO_{80}}{EBO_{85}} = \frac{(DDR \times NFR \times AVBOD)_{80}}{(DDR \times NFR \times AVBOD)_{85}} = \frac{(PNP \times NFR \times AWP)_{80}}{(PNP \times NFR \times AWP)_{85}} . \qquad (4\text{-}5)$$

Note that both the DDR and PNP factors are independent of the wholesale fill rate and therefore cancel in (4-5).

It follows immediately from equations (4-2) and (4-5) that Δ, the percentage increase in AWP time in the repair process that occurs when the SSD fill rate drops from 85 to 80 percent, is equal to the percentage increase in expected backorders. This principle, that increases in AWP time can be measured by the increase in expected backorders, is central to the arguments that follow.

WHOLESALE/DEPOT REPAIR ANALYSIS

This section begins with an overview of the argument for the increase in depot AWP time caused by the drop in the wholesale fill rate. The subsections that follow define terms and give details about data and analysis.

Overview

The presumption is that funding or obligational authority constraints placed on the SSD would be accommodated by a lowering of the implied shortage factors ("control knobs") in the DØ62 system for computing wholesale stock level requirements. This would cause a decrease in safety level requirements, and wholesale reorder points would come down. In turn, wholesale fill rates would fall, and expected backorders to customers in depot repair lines would increase by some amount, say Δ percent. We assume a drop in funding that brings the wholesale fill rate down by 5 points, from 85 to

80 percent. Using the arguments of the preceding section, in particular equation (4-3), and data from Air Force supply performance reporting systems, we conclude that the average increase in depot repair AWP time is given by:

Fraction in depot repair needing SSD parts (PNP)	x	Non-fill rate to depot customers (NFR)	x	Average depot SSD AWP (AWP)	x	Increase in EBOs (Δ)	(4-6)
"		"		"		"	
0.3	x	(0.06 - 0.15)	x	102 (days)	x	0.72 = 1.3 to 3.3 days.	

Note that the non-fill rate to depot customers is estimated at 6 to 15 percent, with 15 percent as the upper bound, since we are assuming a going-in wholesale fill rate of 85 percent. The arguments for this estimate of the non-fill rate to depot maintenance customers, and for the PNP, AWP, and Δ factors shown, are presented in the following subsections.

<u>Depot Demand for SSD Items</u>

The DØ33 Middle Management Reports are the basis for the estimate that 30 percent of the items entering depot repair demand SSD parts (i.e., that PNP = 0.3). (The remaining demand, of course, is for GSD items or for parts that are themselves repair-cycle items.)

The DØ33 system is the retail stock control and distribution system that serves customers at depots. In effect, the system is the "base supply" for customers at each of the Air Logistic Centers (ALCs). Every month, every ALC issues a Middle Management Report summarizing DØ33 supply performance.

The 30-percent figure is from the supply effectiveness section of the March 1983 Middle Management Report issued by the ALC in San Antonio, Texas. The supply effectiveness portion of the report shows the total of local issues and backorders during the month to maintenance customers at the ALC, along with backorder cancellations and releases. This information is broken out into the various categories of repair parts going to maintenance: "DØ41 computed" (reparables), "DØ62" (SSD), and "base computed" (GSD). Within these categories, the data are further broken out according to the priority group of the requisitions involved. Taking the number of issues and backorders for DØ62 items as the measure of maintenance customer demand for SSD items, we can divide by the total number of issues and backorders for all types of repair parts to obtain the PNP factor.

According to the data in the San Antonio ALC report, the 30-percent figure holds up as a close upper bound for PNP, whether one looks at priority group 1 and 2 requisitions only, or priority groups 1, 2, and 3, and also whether or not backorder releases and cancellations are counted in the monthly totals.

The Non-Fill Rate to Depot Customers

Since we are assuming a wholesale SSD fill rate of 85 percent, a reasonable figure to use for a bound on the non-fill rate to depot repair is 100 - 85 = 15 percent. The availability of "retail" stocks under DØ33 control, however, in addition to the wholesale stocks controlled by the DØ32 system, serves to increase the fill rate experienced by depot customers and can, therefore, make their actual non-fill rate something less than 15 percent. For computing the effects on availability, we used the worst-case figure of 15 percent.

The estimate that the non-fill rate factor may be less than 15 percent again is based on data from the March 1983 Middle Management Report from the San Antonio ALC. According to the report, the "off-the-shelf" DØ33 fill rate to maintenance customers for DØ62 (SSD) items is 60 percent. Taking this figure as representative and applying the 85-percent wholesale fill rate to the DØ33's 40-percent non-fill rate yields an estimate of 0.60 + (0.85)(0.40) = 0.94, or 94 percent, as an upper bound on the fill rate to depot maintenance customers, and, therefore, 6 percent as a lower bound on the non-fill rate. As before, this estimate is potentially biased because it is based entirely on data from the San Antonio ALC. From DØ32 summaries we know, for example, that at San Antonio in March 1983 the wholesale fill rate was on the order of 75 percent (an off-the-shelf rate of 76.5 percent), somewhat lower than the system-wide average for the month (82 percent). Thus, a true lower bound for the non-fill rate to depot customers may be more like 10 percent than 6 percent.

AWP Time in Depot Repair

When the wholesale SSD fill rate is 85 percent, the average AWP time for items in depot repair that go AWP for an SSD part is approximately 102 days. The arguments and data supporting this estimate follow.

The average wholesale SSD fill rate in FY82, based on summaries of DØ32 data, was 86.3 percent. This corresponds to a true wholesale fill rate of approximately 85 percent, because off-the-shelf (stockage effectiveness) rates will always be higher than true fill rates, but not by much at the wholesale level, since virtually every item is stocked. Therefore, FY82 is a good year to observe AWP times when the wholesale fill rate is 85 percent.

The FY84 and FY85 Budget Estimate Submissions for the Air Force stock fund, SSD, report that the average number of backorders in place at any given time in FY82 was approximately 110,000. This figure is based on "snapshots" of wholesale EOQ requisition backorders in place, taken at the end of each quarter of the year. (The data are: 111,800, 114,800, 111,900, and 106,300 backorders in place at the end of each quarter.)

Summaries of DØ32 performance data (prepared by Headquarters AFLC/MMLSC using DØ84 Supply Availability and Workload Analysis reports for "EOQ

Stocked Items") show that the average monthly demand in FY82 on the wholesale SSD was 220,500 demands, a daily demand rate of 7,230. (The average monthly rate of 220,500 is based on monthly demand data for FY82, where the highest figure for a month was 238,400 demands, and the lowest was 197,600 demands.)

Substituting these values for backorders in place, daily demand rate, and non-fill rate into equation (4-4):

$$110{,}000\ (\text{EBO}) = 7{,}230\ (\text{DDR}) \times 0.15\ (\text{NFR}) \times \text{AVBOD},$$

we can solve for AVBOD, the average duration of a wholesale SSD backorder, and get: AVBOD = 102 days. Treating customer AWP time as essentially equal to backorder duration, we get the estimate that average depot maintenance SSD AWP time is 102 days, when the wholesale SSD fill rate is 85 percent.

In applying equation (4-4) to get this estimate for AVBOD, we should be using backorder (EBO), demand (DDR), and non-fill rate (NFR) values that hold from the point of view of the customer (in this case, maintenance personnel at depots). The data we have used, however, all apply at the SSD "wholesale supply window." The problem is that not every depot customer demand/backorder is necessarily a wholesale demand/backorder; depot customers order from the "retail" DØ33 system, rather than directly from the wholesale DØ32 system. Also, not every wholesale backorder necessarily applies to a depot customer; many wholesale backorders are backordered replenishments to retail supply points or backorders to customers at bases rather than depots.

Let's look first at the situation in which there is a customer backorder but no backorder at the wholesale supply point. For this to happen, the DØ33 system at the customer's location must be out of stock, while stock is available in the DØ32 wholesale system. In this case, the customer's backorder will not last very long. The backorder will be filled by wholesale in the time it takes the DØ33 system to communicate (computer-to-computer) with the DØ32 system (usually within 48 hours). If, however, the DØ32 system is also out of stock, the customer's backorder <u>does</u> become a wholesale backorder, with essentially the same duration -- again, since the difference is the small amount of time it takes for the two systems to communicate. It is, therefore, reasonable to count as customer backorders only those backorders that become wholesale backorders.

For the second problem -- that not every wholesale backorder is a customer backorder -- we have to make two assumptions: (1) in the application of equation (4-4), depot customers experience the same non-fill rate as all customers; and (2) whatever percentage of total wholesale backorders (EBOs) applies to depot customers applies as well to demands (DDR).

Under these assumptions, the average duration of a depot backorder is the same as for all wholesale backorders. With data that distinguished demands and backorders between bases and depots and between replenishment backorders versus customer backorders, these assumptions would not be necessary. Unfortunately, these data are not readily available from the wholesale reporting system. It would probably be possible to estimate depot demand and backorders at wholesale by examining a set of DØ33 Middle Management Reports from all the ICPs over several months.[1]

Also, it is interesting to note that <u>financial</u> reporting systems for the stock fund do distinguish between depots and bases, showing that wholesale SSD sales to depots are roughly 1½ times those to bases. In any case, if depot customer backorders receive priority treatment, so that percentages or

[1]At the time of this study, these reports were not readily available. A study to collect the reports and perform the necessary analysis would be worthwhile.

fill rates do not match, the 102-day estimate is too high, though it is still useful as a worst-case bound.

Because the estimate that wholesale SSD backorders last an average of 102 days is one of the more controversial findings of the study (in terms of skeptical reactions produced), additional evidence to support the estimate may be of interest. Such evidence is available from two sources.

Referring first to the Supply Availability and Workload Analysis Report in the November 1983 MILSTEP (Military Supply and Transportation Evaluation Procedures) Highlight Tables, we see that the net demand (requisitions processed) for Air Force-managed stock-funded (SSD) items in FY82 was 2,645,932, making a DDR of 2,645,932/365 = 7,249 per day. From the same report, the material obligations outstanding (backordered requisitions in place) in 1982 were 105,730, and the fill rate for the year was approximately 85 percent (a supply effectiveness rate of 86.2 percent). Substituting these MILSTEP data (which are consistent with the DØ32 data used earlier), into equation (4-4) and solving for AVBOD gives a figure of 97 days. (The same table gives similar data for FY83: net demands of 2,464,183, a fill rate of approximately 81 percent, and backorders in place of 136,925, giving an AVBOD of 107 days.)[2]

A second and different kind of confirming evidence for the 102-day estimate comes from data about the <u>age</u> of existing backorders. At the end of

[2]These MILSTEP data support the 102-day estimate, but other data in the same MILSTEP report support a different view. In the Pipeline Performance Analysis report for FY82, the average number of days for ICP processing of delayed issues is shown as 50.6 days, and for FY83 the figure is 47.7 days. However, the annual demand figures cited in the Pipeline Performance reports are substantially different than those in the Supply Availability report (e.g., 1,665,265 vs. 2,645,932 for 1982), so the data are probably not comparable.

February 1984, there were 21,956[3] backordered SSD requisitions in place at the Oklahoma City ICP. The average age of these requisitions was 82.6 days. This implies an average duration of approximately twice that amount, or 165 days.[4] This indicates that the 102-day estimate is feasible and may even be conservative, although this data is for 1984 conditions (different from the 1982 conditions that underlie the 102-day estimate) and is biased in that it applies to the ICP at Oklahoma City only. In any case, the view of the supply manager at the Oklahoma City ICP was that the 102-day estimate seemed reasonable.

As a final note, it should be remembered that the average procurement leadtime for SSD items is longer than a year. When considered in this context, the estimate that wholesale backorders last an average of "only" 102 days is not unreasonable. It indicates that levels exist for virtually all items, reorder points are being reached, and safety levels are present and in use (though they may not be high enough for some items).

The Increase in EBOs to Depot Repair

In the previous subsection, we assumed that the percentage of demand on the wholesale SSD supply point is generated by depot repair also applies to wholesale EBOs. Here we will assume further that the percentage increase in

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[3] Mr. Al Horn, the supply manager (MMMR) at the SSD Inventory Control Point at the Oklahoma City ALC, provided these data.

[4] Let A_t denote the age of a backorder of duration t, assuming that backorder is observed at a random point in its existence. Then the random variable A_t is uniformly distributed over the interval [0,t] and has an average value of t/2. It follows that the average age, A, of a set of backorders of varying duration, observed at a random point in time, is given by:

$$A = \int_0^\infty \frac{t}{2} f(t)dt = \frac{\bar{t}}{2} ,$$

where f(t) is the pdf for the duration random variable t, and $\bar{t}$ is the average duration. Thus, $2A = \bar{t}$.

EBOs to depot repair (when the wholesale fill rate drops from 85 to 80 percent) is measured by, and equal to, the increase in total SSD wholesale EBOs. If, in fact, backorders to depot repair lines receive preferential treatment at the SSD wholesale supply window when fill rates drop, then our estimate will be too high but, again, useful as a worst-case upper bound.

The claim is that wholesale SSD EBOs increase on the order of 72 percent when the wholesale fill rate drops from 85 to 80 percent. This estimate is based on the results of an EOQ computational model run on an SSD demand "template" constructed from DØ62 data (Table 4-1).

TABLE 4-1. DISTRIBUTION OF DØ62 LINE ITEMS BY UNIT COST AND TOTAL ANNUAL DOLLAR VALUE OF DEMAND

TOTAL ANNUAL DOLLAR VALUE OF DEMAND	UNIT COST $ 0.00 to 0.99	$ 1.00 to 4.99	$ 5.00 to 9.88	$10.00 to 24.99	$25.00 to 29.99	$50.00 to 99.99	$100.00 to 249.99	$250.00 to 499.99	$500.00 to 999.99	$1000.00 and Over	TOTAL ITEMS	TOTAL ($000)
.00	15,357	37,067	26,357	42,885	36,903	36,799	39,972	20,642	11,835	9,760	277,577	0
0.01 - 24.99	8,904	12,933	5,261	4,589	0	0	0	0	0	0	31,667	335
25 - 99.99	2,470	7,548	6,254	9,798	7,918	3,855	0	0	0	0	37,843	2,162
100 - 499.99	1,962	6,282	5,536	11,333	10,909	11,103	11,504	2,754	0	0	61,383	15,515
500 - 999.99	575	1,659	1,555	3,465	3,831	4,444	5,654	3,279	1,665	0	26,127	18,761
1,000 - 2,499.99	520	1,510	1,387	3,249	3,694	4,756	6,573	4,272	2,765	1,360	30,086	48,539
2,500 - 4,999.99	200	647	609	1,575	1,819	2,575	4,147	2,988	2,225	1,560	18,345	65,525
5,000 - 9,999.99	117	345	306	800	1,065	1,522	2,574	1,921	1,507	1,512	11,669	81,383
10,000 - 24,999.99	55	212	188	527	618	1;044	1,916	1,766	1,377	1,634	9,337	146,563
25,000 - 49,999.99	21	71	71	168	243	376	785	683	633	865	3,916	136,376
50,000 - 99,999.99	4	26	31	68	123	172	346	335	318	533	1,956	136,180
100,000 - 499,999.99	2	15	29	55	92	116	323	184	188	415	1,328	255,435
500,000 - 999,999.99	0	0	2	9	12	14	22	14	15	34	122	83,891
1,000,000 - 1,999,999.99	0	0	1	1	7	3	2	7	3	6	30	41,053
2,000,00 or more	0	0	0	1	0	1	2	2	2	3	11	36,242

SOURCE: DØ62.M91B Report, 31 March 1981.

From the data shown in the table, we can estimate the annual demand rates for 140 representative items in the SSD. Dividing the dollar totals for each row by the corresponding entry in the "Total Items" column identifies positions within the row and column intervals that can serve as point estimates of total annual demand and unit cost. Dividing the value of annual demand by unit cost gives estimated annual (unit) demand rates for each of the 140 representative items. For each item in turn, the computational model computes EBO levels (backordered units in place) when the item is supported to an 85-percent fill rate, and then to an 80-percent fill rate, assuming no change in the mean demand rate. Multiplying these EBO levels by the number of items in each cell and accumulating yields an estimate of total wholesale SSD unit backorders in place under the two fill rates. The results are that the average number of backorders in place at 80-percent fill rate is 758,297, in contrast to 439,559 at 85 percent, an increase of 72 percent.[5]

To explain how the computational model works and how it produced these results, we should first review how stock level requirements are computed and adjusted in the DØ62 system, the EOQ requirements system for wholesale SSD operations.

SSD Reorder Point/EOQ Machinery. In the computational model, we obtained varying fill rates for the items in the demand template by adjusting the reorder points for the items. Order quantities were not changed. To justify this approach, let us review how wholesale EOQ requirements are calculated in the DØ62 system.

In line with DoD instructions (DoDI 4140.39), the wholesale SSD (and all DoD stock funds for that matter), are set up to address the same basic inventory problem in their requirements systems: how much stock should be ordered, and when, to minimize total annual ordering and holding costs while

[5]There are several reasons for the difference between predicted system EBO totals at 85-percent fill rate from the model (439,559) and actual backorders in place in FY82 when the fill rate was 85 percent (111,000). The actual figure represents backordered requisitions, while the computed figure counts backordered units. Since the template includes demand generated by retail replenishment actions with requisitions for EOQ quantities, this would tend to make unit backorders larger than requisition backorders. Real-world management actions also serve to reduce actual EBO levels. Also, the computational model computes item by item, rather than by minimizing system-wide SSD backorders. A system-wide model would predict fewer total EBOs for a system-wide average 85-percent fill rate. This last point is discussed further in a later subsection on the EOQ computational model.

meeting minimum performance objectives, expressed in terms of maximum acceptable EBO levels. Reference [1] includes the basic inventory theory that underlies the DØ62 computational machinery. Annex A of reference [2], a study of DoD stockage policy, includes a thorough description of specific characteristics of the DØ62 system. Reference [3] presents the basic analytical framework and methods upon which the system is built.

To summarize, the system addresses the following problem: For each item at an ICP, determine an inventory position[6] reorder point R, $R = \mu + k\sigma$, and an economic order quantity, Q, that will (over all items) minimize total annual ordering and holding costs, subject to a constraint on total backorders (total EBOs $\leq \beta$), where μ = mean demand and σ = standard deviation of demand in a procurement leadtime. The variable k is the factor for safety level that determines how much safety level is to be established above μ. Following reference [3], the DØ62 system assumes a Laplace probability density function (pdf) for demand in a leadtime. As a standard, constrained-optimization problem, the problem can be solved with the Lagrange multiplier method of calculus. The value of the Lagrange multiplier, λ (for any given EBO constraint β), is the "implied shortage factor"[7] referred to in both DoDI 4140.39 and the DØ62 system manual (AFLC Regulation 57-6, May 1982). The value of the factor k for safety level is an increasing function of λ, as one would expect. (The higher the implied cost of a backorder, the higher the safety level

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[6] The inventory position is the amount of stock on hand plus stock on order, minus outstanding backorders.

[7] As described on pages 217-218 and 435-436 of reference [1], the value of λ may be interpreted as either the implied cost of a backorder in the sense of a cost to be minimized or the "shadow price" of a backorder in terms of the reduction in total cost achieved if an additional backorder is allowed above the constraint β. The reciprocal, $1/\lambda$, represents the cost involved in reducing backorders by one. DoDI 4140.39 calls for use of cost minimization models where backorder costs are included.

required.) For the order quantity, Q, the Air Force uses the Wilson lot size (see references [1], [2], and [3] for definitions and discussion), subject to the bounds that Q must be at least equal to mean demand in six months (changing in FY84 to one year for stable design/demand items), but no more than three years' worth of demand.

Finally, as described in references [2] and [3], the implied shortage factor, λ, is a "control knob" by means of which levels can be adjusted to accommodate budgetary constraints. By adjusting λ downward (which is equivalent to increasing the EBO constraint β and "accepting" a greater backorder level in the system), safety level requirements will go down, and less money will be required to operate (i.e., maintain levels in) the supply system.

The key point, therefore, is this: As implied shortage factors are lowered in the DØ62 system to accommodate a funding constraint, safety level requirements would come down and reorder points would decrease. (No explicit provision is made in the DØ62 system to make any change in order quantities to accommodate budget limits.) This, then, is the basis for adjusting only reorder points in the computational model runs, without making any changes in order quantities, to get to the 85- and 80-percent levels of fill rate.

<u>The EOQ Computational Model</u>. The computational model is a one-item-at-a-time EOQ calculator developed by Dr. Craig Sherbrooke, programmed in BASIC, and designed to run on an IBM PC operating under any standard IBM Disk Operating System (PC-DOS 1.1, 2.0, or later versions). Source code for the version of the model used to evaluate the 140-item DØ62 demand template is included in the Appendix. The model provides the user with considerable flexibility in determining optimal reorder points and order quantities in the standard inventory problem. It also allows the user to set performance targets (e.g., fill rates) and obtain the optimal Rs and Qs that meet those

targets. This option of the model was used to evaluate the 140-item demand template. An important characteristic of the model is that it assumes a normal pdf for demand in a leadtime (as opposed to a Laplace pdf). The model also takes variation in leadtimes into account, rather than treat them as constant.

For application to the SSD template, the model was run under the assumption of a 12-month mean procurement leadtime, with a standard deviation of 3 months. The ordering cost was set at a constant $350 for every item, and the holding cost rate was set at 20 percent of unit cost. Both figures are in line with the holding and ordering costs at the ALCs, as specified in the DØ62 manual, AFLC Regulation 57-6. The model computed a Q equal to the Wilson lot size, subject to the six-month minimum and three-year maximum in line with Air Force policy.

For each item in the template, the model was run to achieve an 85- and 80-percent fill rate, in each case by adjusting the reorder point (i.e., lowering the safety level). Order quantities (Qs) were not changed. A sample of model output is given in Table 4-2. The table shows the results for the items in the $2,500.00 to $4,999.99 annual demand row in the template. For some items, the desired fill rates of 85 and 80 percent could not be attained. (Table 4-2 shows some examples.) The reason is that for each item the computational model attempts to get as close to 85- and 80-percent fill rates as possible, given the demand rate for the item and the constraints placed on its order quantity. The R and Q values shown reflect the integer values that get closest to the desired 85- and 80-percent fill-rate targets; different Rs and Qs would put the fill rates even farther away. The Q values shown are the Wilson lot sizes, unless the constraints come into play. It is also interesting to note that, for virtually all the items in the template, the reorder points for 85-percent fill rate are lower than the mean demand in a leadtime, indicating negative safety levels for that target. This compares with the positive-safety-level rule in the wholesale SSD and the fact that actual system-wide SSD fill rates are in the 80s range, nonetheless. This inconsistency between model-calculated fill rates for given safety levels versus observed fill rates in the real-world system raises interesting questions about the fundamental applicability of the models.[8]

TABLE 4-2. EOQ COMPUTATIONAL MODEL OUTPUT SAMPLE

NUMBER OF ITEMS	Q/MEAN	MEAN DEMAND IN LEADTIME (12 months)	Q	REORDER POINT (1)	REORDER POINT (2)	FILL RATE (1)	FILL RATE (2)	EBO (1)	EBO (2)
200	0.99	8,930	8,839	7,604	7,162	0.85	0.80	19,980	35,447
647	0.99	1,374	1,360	1,170	1,102	0.85	0.80	10,204	17,896
609	0.99	510	505	435	410	0.85	0.80	3,723	6,369
1,575	0.99	223	221	191	180	0.85	0.80	4,496	7,457
1,819	0.99	102	101	88	82	0.86	0.80	2,670	4,534
2,575	1.00	51	51	44	42	0.85	0.82	2,434	3,293
4,147	0.99	22	22	20	19	0.85	0.82	2,166	2,849
2,988	0.98	10	10	10	9	0.86	0.80	844	1,342
2,225	0.98	5	5	6	5	0.90	0.81	287	610
1,560	1.12	2	2	3	3	0.93	0.93	64	64
18,345[a]						0.85[b]	0.80[b]		

[a]Total items in row of the template.
[b]Average fill rates for items in row, weighted by both demand and number of items.

It is important to note that the computational model does an item-by-item calculation on the 140 items in the demand template, setting the level for each item to that required for the given fill-rate target. It does not compute a simultaneous, system-wide solution for all 140 items, which would minimize total costs (summed over all items), subject to a constraint on the sum of all backorders. Such a system model -- the DØ62 model is of this type

[8]AFLC has also run into this problem in its attempts to construct an "EOQ simulator." (See reference [2], Annex A, Part 1, pp. 3-17.) Also, the AFLC model is based on the Laplace pdf for demand rather than the normal. The choice of demand distribution is not, therefore, the source of the problem. The question is an interesting and potentially important topic for further research.

for the system of items at each ICP -- would achieve an average system-wide fill rate of 85 percent, say, by having higher fill rates for high- and medium-demand, low-cost items and lower fill rates for low-demand, higher-cost items. Such a simultaneous model is being programmed to run on the 140-item template, to see how projected EBOs change under such a system when fill-rate targets are changed.

Also, recalling the discrepancy between actual wholesale SSD backorders in place (111,000 requisition backorders in place on average in FY82) versus the computational model's prediction (over 400,000 unit backorders on average in place at an 85-percent fill rate), a system model should produce a smaller value for total projected EBOs.

Laplace vs. Normal. As noted above, an important difference between the computational model and the DØ62 system model is in the choice of a demand distribution. The increase in EBOs when the fill rate drops from 85 to 80 percent, under the assumption of Laplace demand, is 33 1/3 percent (as opposed to 72 percent when the normal distribution is used, as it was in the computational model runs). This fact is a consequence of equations (8) and (10) on page 246 of reference (3), which imply that for Laplace demand, EBOs are directly proportional to the non-fill rate:

$$EBO = \frac{\sigma}{\sqrt{2}} \text{ NFR for each item,}$$

where σ denotes the standard deviation in demand in a leadtime.

Thus, under Laplace demand, a 33 1/3-percent increase in the non-fill rate, from 15 to 20 percent, would produce the same percentage increase in EBOs. Given the notion that EBO = DDR x NFR x AVBOD, a linear relation such as this between EBOs and the non-fill rate implies that under steady-state demand, average backorder duration is a constant, independent of the safety level set for the item. Though this may seem counterintuitive (generally, one expects changing stock levels to affect not just the fill rate, but also the average duration of backorders), it is true that demand pdf's with exponential tails (like the Laplace) do, in fact, have this property.

For the normal distribution, the computational model results indicate that EBOs vary more closely with the square of the non-fill rate:

$$\text{EBO} \cong c(1 - \text{fill rate})^2 \quad \text{where c is some constant,}$$

since under such a square law, EBOs should increase about 77 percent:

$$\frac{\text{EBO}_{80}}{\text{EBO}_{85}} \cong \frac{c(0.20)^2}{c(0.15)^2} = 1.77,$$

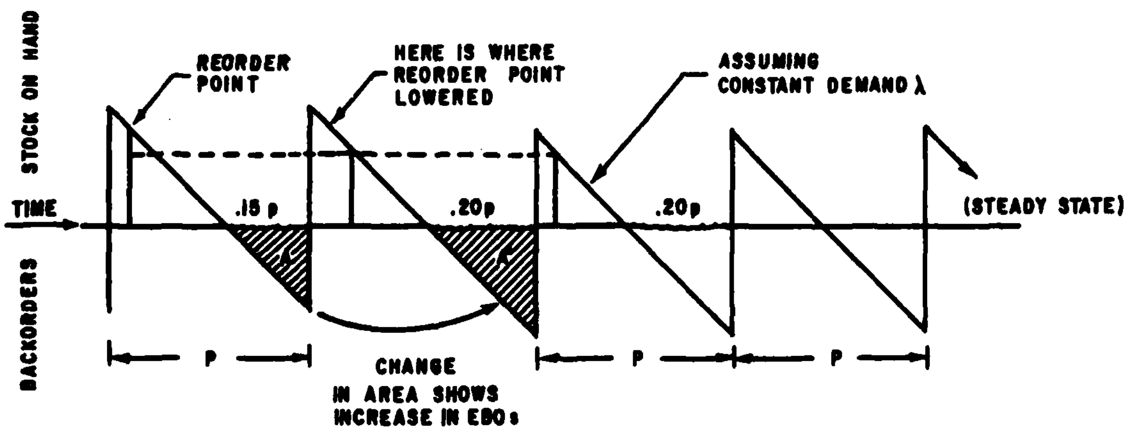
and this is in line with the 72-percent increase projected by the model.

In the case of constant demand, EBOs vary exactly as the square of the non-fill rate. The argument for this is illustrated in Figure 4-1, which shows how EBOs change in the deterministic case, when the fill rate moves from 85 to 80 percent, that is, when the non-fill rate rises from 15 to 20 percent. In the figure, λ denotes the constant daily demand rate (so that if there are d demands in each period p, $\lambda = d/p$). Let r denote the non-fill rate, and let b(t) denote the number of backorders on the books as a function of time in a given cycle. Then the average number of backorders that exist in a given period p (i.e., the EBO level) is given by:

$$\frac{\int_0^p b(t)dt}{p} = \frac{\int_0^{rp} \lambda t dt}{p} = \frac{\lambda r^2 p^2}{2p} = \frac{dr^2}{2} .$$

This shows both that EBOs are equal to the area of the shaded triangles and (equivalently) that EBOs are proportional to the square of the non-fill rate in the case of constant demand.

FIGURE 4-1. EBOs AND FILL RATES UNDER CONSTANT DEMAND



$$\frac{EBO_{80}}{EBO_{85}} = \frac{A'}{A} = \frac{(.20_p)^2}{(.15_p)^2} = 1.77$$

Since the increase in EBOs is greater for the normal distribution than the Laplace, the estimate of a 72-percent increase in EBOs serves as a worst-case upper bound on the value of EBO Δ factor used in equation (4-6). However, the substantial difference between the Laplace and the normal means that the estimated 3.3-day increase in depot repair AWP time may be too large by a factor of two, and the projected effects on availability, even though relatively modest, may also be overstated. Determining which demand distribution best fits the real world is a subject worth further research.[9]

This completes the wholesale, depot-repair analysis.

THE REDUCTION IN SAFETY LEVEL

Besides serving as the basis for the estimated increase in EBOs, the computational model and the demand template also serve as the source of the estimate that the reduction in safety level amounts to approximately 30 percent of the "55 days' worth of demand" figure used to size aggregate wholesale SSD safety levels at the ICPs.

As the computational model processed the template, it accumulated the value of the difference in reorder points, taking unit costs and item counts into account. The total for this difference over the entire SSD was \$45.9 million. The value of total annual demand from the template was \$1.069 billion. (This compares with an actual demand of \$1.2 billion in FY81.) It follows that \$161 million (55/365 x \$1,069 million = \$161 million) represents 55 days' worth of demand, and that the savings in safety levels represent approximately 30 percent of that amount (\$45.9/\$161 = 28.5 percent).

RETAIL/BASE REPAIR ANALYSIS

The retail/base repair problem is to determine the average increase in AWP times for items in base repair that would result from a drop in the wholesale SSD fill rate. The situation is different than that for depot repair

[9]The Supply Availability and Workload Analysis report of the November 1983 MILSTEP Highlight Tables records that, with approximately a 5-point drop in the wholesale SSD fill rate from 86 to 81 percent, average requisition backorders in place increased from 105,730 to 136,925, an increase of 29.5 percent. This is evidence favoring the Laplace distribution, especially since demand decreased slightly over the periods in question, so that with constant demand the increase would probably have been slightly greater. However, since this is for requisition backorders, rather than unit or item backorders as calculated by the computational model, the evidence is not conclusive.

because base supply operations represent a true second echelon that serves to buffer base-level customers from fluctuations at the wholesale level. Also, the available data on demands, fill rates, and backorders for base-level customers are retail-level data that must be handled differently than wholesale-level data. As before, we will start with an overview and follow with subsections giving definitions of terms and details about data and analysis.

Overview

To estimate the increase in average AWP time for items in base repair when the wholesale SSD fill rate drops from 85 to 80 percent, we again evaluate the expression, $(PNP \times NFR \times AWP)_{85} \times \Delta$, but with data that apply at the base level and from the base customer's point of view. That is, for the PNP factor we want the percentage of items in base repair that demand SSD repair parts; for NFR we want the non-fill rate experienced by base customers (base maintenance organizations) at the base supply window; and for AWP we need to know the average AWP time for items that go AWP in base repair for SSD parts, given that the wholesale supply point is running at an 85-percent fill rate, and base supply is doing whatever it does under those circumstances.

Based on worldwide summaries of monthly, base-level M-32 supply management reports for FY82 (when the wholesale fill rate was approximately 85 percent), the estimates for the PNP, NFR, and AWP factors are: 6 percent of the items entering base repair demand SSD parts (PNP = 0.06); the average base non-fill rate is 35 percent (NFR = 0.35); and the average awaiting-parts time for items that go AWP in base repair is 29 days (AWP = 29 days).

For the Δ factor, we need to estimate how base-level backorders increase when wholesale fill rates drop five points and wholesale backorders increase. Base fill rates and backorder levels will react in some way to this reduction in wholesale support, and it is this reaction that the Δ factor must reflect.

A way to characterize the effect is to consider the average depot delay for all SSD requisitions reaching the wholesale supply point, which from the earlier analysis is 15.3 days (0.15 x 102 days = 15.3 days). The effect of the fall-off in wholesale support would be to increase the average depot delay for all SSD requisitions from the bases. Assuming no change in base reorder points and order quantities, and a 72-percent increase in wholesale requisition backorders in place (EBOs), the increase in average depot delay is 11 days (0.15 x 102 days x 0.72 = 11 days). The resulting increase in base-level backorders (EBOs) to customers is in the range of 33 to 40 percent.

Putting these data together, we get the estimate that a 5-point drop in the wholesale SSD fill rate, from 85 to 80 percent, would increase AWP times for items in base repair an average of 0.20 to 0.25 days:

$$\text{PNP}(0.06) \times \text{NFR}(0.35) \times \text{AWP}(29 \text{ days}) \times \Delta(0.33\text{-}0.40) = 0.20 \text{ to } 0.25 \text{ days.}$$

The specific M-32 data and arguments supporting these estimates are presented in the following subsections.

<u>Base Non-Fill Rate to Base Customers</u>

When the wholesale fill rate is 85 percent, the retail non-fill rate to customers in base maintenance is approximately 35 percent. This estimate is based on data (shown in Table 4-3) taken directly from reports of customer support effectiveness in M-32 summaries for 11 months in 1982. The data reflect issue effectiveness rates for all types of requisitions, from high-priority to routine replenishment. An interesting aspect of the world-wide retail fill rate is its stability from month to month. Also, the fact that retail fill rates increased slightly from 1982 to 1983, when the overall wholesale fill rate dropped five points, is indicative of the buffering effect of retail supply.

TABLE 4-3. RETAIL SSD FILL RATES TO MAINTENANCE ORGANIZATIONS

1982			1983		
JAN	-	62.46%	JAN	-	64.98%
FEB	-	62.32	FEB	-	63.94
MAR	-	62.75	MAR	-	64.09
APR	-	63.85	APR	-	64.26
MAY	-	63.71	MAY	-	63.14
JUN	-	65.10	JUN	-	57.21
JUL	-	65.05	JUL	-	68.33
AUG	-	64.75	AUG	-	65.95
SEP	-	66.14	SEP	-	65.05
OCT	-	63.01	OCT	-	63.70
NOV	-	63.51	NOV	-	63.31
AVG	-	63.37%	AVG	-	63.99%

SOURCE: USAF Supply Management Reports for 1982, 1983 Air Force Data System Design Center, Gunter AFB, Alabama.

Base Demand for SSD Items

The estimate that 6 percent (PNP = 0.06) of the items entering base repair generate demand for SSD parts is based on data from two different reports in the 1982 M-32 summaries: the reports of Repair Cycle Asset Control Data and the Due-Out Schedules for Supplies.

For each of 11 months' worth of due-out schedules for 1982, SSD due-outs represent from 18 to 20 percent of the combined GSD, SSD, and non-stock fund due-outs (urgency of need codes A and B). This means that if a due-out exists at a base, the probability is 20 percent (worst-case) that it is for an SSD item. It is, therefore, reasonable to assume that 20 percent of the AWP items in base repair are awaiting SSD parts (as opposed to GSD or non-stock-funded parts), since every AWP incident should generate a due-out.

The reports for repair-cycle assets include monthly counts and totals of the number of units that were "repaired-this-station" (RTS), including a subtotal for the items that accumulated AWP time (RTS(INCL AWP)). These totals are for maintenance organizations operating under Air Force Regulation 66-1 and Air Force Manual 66-5 -- in other words, organizations performing aircraft maintenance.

If we let P denote the number of items entering base repair that demand an SSD part, the ratio P/TOTAL RTS is the PNP factor we want. With a retail SSD non-fill rate of 35 percent, 0.35P represents the number of items that go AWP for an SSD part. Combining this with the due-out data, we get the following expression, which can be solved for P:

$$0.20 \times \#\text{RTS(INCL AWP)} = 0.35P.$$

For each value of P, the desired PNP factor is P/TOTAL RTS. For the months of December 1981 through November 1982, this procedure gave PNP factors that varied from 5.6 to 6.7 percent, with an average value of 6 percent.[10]

AWP Time in Base Repair

We again turn to the M-32 Repair Cycle Asset Control Data and Due-Out Schedules for Supplies to obtain the estimate that average base AWP time for an SSD part is 29 days.

The reports for repair cycle assets in the M-32 summaries include the average AWP time for the RTS units that went AWP in the course of their repair. Each monthly report reflects the units whose repairs were completed that month. Since demand (i.e., units entering repair) is fairly stable from

[10] Strictly speaking, the expression for P should be evaluated with the individual monthly factors that apply, instead of 0.20 and 0.35, and the 12-month average for PNP should be demand-weighted. For our purposes, the 6-percent estimate is accurate enough, especially since the factors involved, including demand, do not show much month-to-month variance in any case.

month to month, the monthly AWP averages can themselves be averaged to obtain an indicator of overall average AWP time. Table 4-4 lists monthly data for December 1981 through October 1982.

TABLE 4-4. M-32 MONTHLY AVERAGE AWP TIMES, USAF BASES WORLDWIDE, IN 1982

MONTH			AVERAGE AWP (Days)
DEC	1981	-	35
JAN	1982	-	29
FEB	"	-	27
MAR	"	-	29
APR	"	-	28
MAY	"	-	27
JUN	"	-	27
JUL	"	-	29
AUG	"	-	29
SEP	"	-	28
OCT	"	-	34

These AWP data include AWP time for not only SSD parts, but also GSD parts, and non-stock-funded, repair-cycle repair parts as well. Since we want the average AWP time for SSD parts alone, additional data are needed to justify our estimate. The M-32 due-out schedules supply such data in the form of frequency distributions for GSD, SSD, and non-stock-fund parts showing how long due-outs have lasted. The durations are grouped by intervals: 1-30 days, 31-60 days, 61-180 days, 181-365 days, and over 365 days. With these distributions it is possible to estimate separate GSD, SSD, and non-stock-fund average due-out durations, to see if there is a bias toward any one set of parts.[11]

[11] These estimates require the choice of points within the time intervals; they are, therefore, not as reliable as the direct AWP-time averages recorded in the Repair Cycle Asset Control Data (Table 4-4).

An analysis of these averages for January, April, July, and October 1982, reveals no significant bias. In fact, the distributions are quite similar, regardless of parts type. The conclusion is that the average AWP time estimate of 29 days holds for the subset of AWP incidents caused by SSD parts.

The Increase in Base EBOs to Base Repair

The first step in quantifying the increase in the retail EBO level is to measure the increase in average depot delay for all SSD requisitions coming from the bases to wholesale supply points. We obtain this increase, 11 days, by multiplying the baseline depot delay figure of 15.3 days (0.15 x 102 days = 15.3 days) by the increase factor of 0.72 for EBOs.

Two assumptions are made in this calculation. First, it is assumed that wholesale SSD requisition EBOs will increase 72 percent. (The template result applies to unit backorders rather than requisition backorders, and it is conceivable that varying requisition sizes could change the percentage increase in requisition EBOs.)

The second assumption made for purposes of calculating the increase in average depot delay is that the bases do not change their reorder points or order quantities when wholesale support falls off. Though this is in line with actual Air Force response to the funding limitations of 1982 and 1983, and suits our purpose of measuring the effect of a drop in wholesale support, it is a simplifying assumption that does not always hold. As with any inventory system when its suppliers "shift gears," the retail Air Force system, running semiautonomously on Standard Base Supply System computers, would respond in some cases by adjusting reorder levels, order quantities, or both. To apply the EBO increase factor (0.72) to the baseline depot delay (0.15 x 102 days), however, we must assume that demand (the DDR factor in the equation EBO = DDR x NFR x AVBOD) is the same at the two different wholesale fill rates; otherwise, the demand factors do not cancel in the EBO_{80}/EBO_{85} ratio, and we cannot equate EBO_{80}/EBO_{85} with the ratio for depot delay: $(NFR \times AVBOD)_{80}/(NFR \times AVBOD)_{85}$.

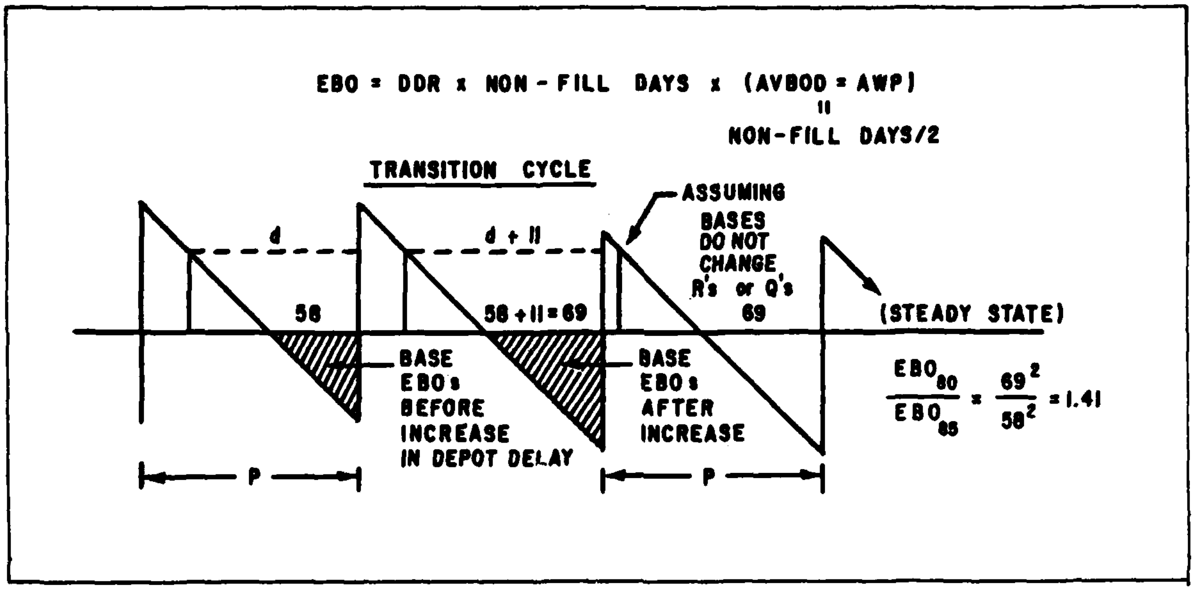
The second step in quantifying the increase in the retail EBO level is to estimate how an 11-day increase in the average depot delay across all SSD requisitions would affect base EBOs. The estimate is that EBOs would increase from 33 to 40 percent, depending on which of two methods is applied.

The 33-percent estimate is based on results from the EOQ computational model running on a modified version of the wholesale SSD demand template. To simulate the lower retail demand levels, demand in the template was reduced by a factor of 40 if annual demand exceeded 80,000 units, and by a factor of 20 otherwise. Further, if modified annual demand was no more than 10 units, no base level was set (i.e., the reorder point was set at zero). The order quantity Q was again set at the Wilson lot size (for the modified demand level), but this time subject to the <u>retail</u> policy in the Air Force that $1 \leq Q \leq$ annual demand. The cost-to-order was reduced from the wholesale figure of \$350 to \$100, and the holding cost factor was reduced from 20 percent of unit cost to 10 percent. Finally, the procurement leadtime (12 months, in the wholesale case) was replaced by an estimated average wholesale resupply time to bases of 45 days. This 45-day estimate is based on "status of due-ins" data in the worldwide M-32 summaries, showing age distribution for due-ins from AFLC by priority group. The standard deviation in resupply time was arbitrarily set at 0.3 days to reflect smaller variability in resupply time in the depot-to-base pipeline.

With these changes, the computational model was run twice, each time to a 65-percent fill-rate target: first, with a resupply time of 45 days and then with a resupply time of 56 days (45 + 11 = 56 days). Base-level EBOs increased 33 percent overall in response to the change. (Because some reorder points changed in this method, the original 11-day estimate is not fully applicable, for the reasons discussed earlier.)

The estimate that base EBOs could increase as much as 40 percent is based on an entirely different method, which looks at the effect of a change in depot resupply time in the deterministic, constant-demand case. Figure 4-2 illustrates the argument. To have a baseline average AWP time of 29 days, backorders must occur for the last 58 days of each cycle, as shown in the figure. If resupply time increases by 11 days, every backorder in the deterministic case will last 11 days longer. The effect on EBOs is that they increase by a factor of $69^2/58^2 = 1.41$, or approximately 40 percent.

FIGURE 4-2. CHANGE IN BASE EBOs WHEN DEPOT DELAY INCREASES FOR CONSTANT DEMAND



This completes the retail/base repair analysis.

BASE AND DEPOT REPAIR PIPELINES IN THE AAM

The repair pipelines in the AAM that are affected by the increase in AWP times are base repair pipelines and depot pipelines. There are two types of depot pipelines: repairs originating at bases and being sent to the depots and repairs originating within the depots themselves. The AWP time increases for the respective pipelines are multiplied by the underlying demand rates (i.e., the rates at which items enter the repair process). The resulting increases in pipeline quantities are then added to the existing pipelines.

As a multi-echelon model, the AAM performs the tradeoffs between spare reparables at bases versus spares at depots. Because DØ41 repair times do not include any AWP time, the effect of the increase in AWP times is, again, a worst-case estimate. If existing AWP times were included, the base against which the effect of the increase is measured would be larger, and relative effects on availability would not be as great.

REFERENCES FOR CHAPTER 4

[1] G. Hadley and T. M. Whitin, Analysis of Inventory Systems, Prentice-Hall Inc., 1963.

[2] Office of the Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics), Stockage Policy Analysis, Final Report of the Working Group on Secondary Item Stockage Policy Analysis, including Annex A, Part 1: Air Force Documentation of VSL/EOQ Implementation for Consumable Items, August 1980.

[3] Victor J. Presutti, Jr., and Richard C. Trepp, "More Ado About Economic Order Quantities (EOQ)," Naval Research Logistics Quarterly, June 1970, pp. 243-251. (Also appeared as: AFLC Operations Analysis Technical Memorandum No. 9, "More Ado About EOQ," January 1970.)

5 NEXT STEPS

The results and methods of this study are a first step in relating funding for the Air Force stock fund to aircraft availability rates. Throughout the report several topics for further research have been noted. Here we summarize the next steps.

THE RELATION BETWEEN FUNDING AND SAFETY LEVELS

A basic premise of the study is that constraints on the wholesale SSD obligational authority would be accommodated by a lowering of implied shortage factors at the ICPs. This is based on the premise that failure to receive obligational authority for a given level of requirements would inevitably result in an increase in backorder (EBO) levels, and that this fact would be dealt with by discounting the negative effect of backorders through the acceptance of lower implied backorder costs.[1] Given this approach, it is still necessary to determine precisely how much safety levels change when funding changes. The study avoids this question and simply shows what happens if safety levels change enough to make fill rates drop by five points.

In recent discussions with AFLC, however, it has been pointed out that implied shortage factors are rarely (if ever) changed to accommodate funding constraints. Instead, guidance on reducing order quantities is often issued, and other, temporary financial management controls are employed. Implied shortage factors are adjusted only as necessary (each quarter) to maintain "55 days' worth of demand" as the aggregate safety level value at each ICP.

[1] The argument here is that stated requirements theoretically represent optimal solutions, i.e., levels and order quantities that provide the minimum possible total backorders for the specified funding. Any reduction in funding, therefore, would necessarily entail an increase in backorders.

In the short term, these methods serve well enough, particularly if requirements do not fully materialize. In the longer term, however, these approaches amount to the use of non-optimal solutions in execution, overriding the optimal order quantities and reorder levels computed by the DØ62 system. Thus, the adherence to the "55 days" rule deprives AFLC of the use of safety levels as a tool to improve supply performance. The upshot is that the actual real-world relation between SSD funding and wholesale safety levels is significantly more complicated than that posited by the study, and further analysis of actual SSD execution procedures is needed before the relationship can be fully quantified.

TECHNICAL QUESTIONS

Several open technical questions have arisen and been noted in the report. For example, a simultaneous version of the EOQ computational model is needed to see how EBOs increase when a system-wide fill-rate target is used, rather than an item-by-item target. Also, the demand template should be updated with current DØ62 data.

Which of the two distributions, Laplace or normal, provides a better fit to real demand data needs further exploration, given the significant differences in the EBO/fill rate relationship implied by the two models. There is also the fundamental question of applicability of either model, given the substantial difference between computed (predicted) and observed fill rates in the SSD.

DATA QUESTIONS

In several areas, more (or different) data would be useful. Additional DØ33 Middle Management Reports from several ALCs for several months should be checked, for example, to see if the estimates for the wholesale PNP, NFR, and AWP factors hold up system-wide. It would also be worthwhile to examine maintenance data systems to see whether values for these factors are reported directly by such systems. Conceptually, since we are interested in EBOs, non-fill rates, and AWP times from the customer's point of view, maintenance records may well be where we should look (even though we are studying a supply system). Another area in this context, not addressed in the study, is the role of bench stock, which represents a third echelon of supply, but one controlled by maintenance.

Finally, though the study has examined the SSD, the AWP problem in Air Force repair lines is not, by any means, limited to SSD repair parts. In fact, studies for the Tactical Air Command and United States Air Force Europe (USAFE) have indicated that the most severe AWP problems are caused by repair-cycle repair parts rather than stock-fund items.[2] The USAFE study, for example, states that, at the time of the study (1978-79), 65 percent of USAFE's major problem repair parts were ERRC-designator XD2 investment items. (The study cites the failure to have retail levels for the items as the prime cause of the problem.) Thus, while SSD items may be a part of the AWP problem, repair cycle items contribute to it as well, and a balanced program of both consumable and recoverable spares and repair parts is needed to provide acceptable levels of end-item support.

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[2] See: Major William D. Arnold, HQ TAC, "The Impact on Combat Capability of Recoverables Awaiting Parts," paper presented at the 1982 Logistics Capability Symposium at the USAF Academy, Colorado Springs, Colorado, March 1982; and Captain Robert Moore, "USAFE Awaiting Parts (AWP) Analysis, July 1978 - March 1979," paper prepared for USAFE in 1979, copy to Headquarters USAF/LEY.

APPENDIX

THE EOQ COMPUTATIONAL MODEL

Below is a (BASIC) program listing for the EOQ computational model used in the study. The model was designed and programmed by Dr. Craig Sherbrooke. The model will run on an IBM PC operating under the Disk Operating System (PC-DOS 1.1, 2.0, or later).

The DATA statements reflect data from the DØ62 SSD demand template described in the report. The subroutine to calculate R, the reorder point, is based on the mathematics in Chapter 4 of Hadley and Whitin's <u>Analysis of Inventory Systems</u>. The Gaussian quadrature subroutine is used to evaluate areas under the normal pdf used for the demand distribution.

```
10 REM*****   stock fund program   'stfund'  12/05/83
20 DEFDBL Z:WIDTH "lpt1:",132
30 DIM ZDMD(14),COST(10),C(6),D(3),ZTFILL(2),ZTBACK(2),FILL(2),BACK(2)
40 A$="###,###                    $$#,###,###,###            ##.##  ##.##  #,###,###
  #,###,###"
50 B$="###,###  ##.##  ###,###  ###,###  ##,###  ##,###  ##.##  ##.##  #,###,###
  #,###,###"
55 C$="# ITEM  Q/MEAN     MEAN        Q       R1       R2   FR 1   FR 2     BACK 1
    BACK 2"
56 LPRINT DATE$:LPRINT:LPRINT C$
57 D$="$$###,###,###"
60 DEF FNPROB(X)=.398942*EXP(-(X^2)/2)
70 DATA 10.58,57.13,252.76,718.07,1613.34,3571.82,6974,15697,34825,69622,192345,
687631,1368433,3294727
80 DATA .40,2.60,7,16,35,70,160,350,700,2000
90 DATA 8904,12933,5241,4589,0,0,0,0,0,0
100 DATA 2470,7548,6254,9798,7918,3855,0,0,0,0
110 DATA 1962,6282,5536,11333,10909,11103,11504,2754,0,0
120 DATA 575,1659,1555,3465,3831,4444,5654,3279,1665,0
130 DATA 520,1510,1387,3249,3694,4756,6573,4272,2765,1360
140 DATA 200,647,609,1575,1819,2575,4147,2988,2225,1560
150 DATA 117,345,306,800,1065,1522,2574,1921,1507,1512
160 DATA 55,212,188,527,618,1044,1916,1766,1377,1634
170 DATA 21,71,71,168,243,376,785,683,633,865
180 DATA 4,26,31,68,123,172,346,355,318,533
190 DATA 2,15,29,55,92,116,232,184,188,415
200 DATA 0,0,2,9,12,14,22,14,15,34
210 DATA 0,0,1,1,7,3,2,7,3,6
220 DATA 0,0,0,1,0,1,2,2,2,3
230 IOPT=7:XVM=1:CORDER=350:CHOLD=.2:PLTIME=12:PLTSTD=3
240 ALPH=0:BETA=0:PIE=0:PIEHAT=0:PLT=PLTIME/12
250 FOR I=1 TO 14:READ ZDMD(I):NEXT I
260 FOR J=1 TO 10:READ COST(J):NEXT J
270 FOR M=1 TO 14
280 NN=0:FOR L=1 TO 10
```

```
290 READ NITEM:NN=NN+NITEM
300 IF NITEM=0 THEN 540
310 XMN=ZDMD(M)/COST(L)
320 XMU=PLT*XMN:PVM=((PLTSD/12)^2)/XMN:R=INT(XMU+.5)
330 SIG=SQR(PLT*XMN*(XVM+XMN*PVM))
340 CITEM=COST(L)
350 CI=CITEM*CHOLD
360 REM ***** IOPT=6 OR 7
370 Q=SQR(2*XMN*CORDER/CI)
380 IF Q<XMN/2 THEN Q=XMN/2                         'minimum Q=6 mos
390 IF Q>3*XMN THEN Q=3*XMN                         'maximum Q=3 yrs
400 Q=INT(Q+.5)
405 IF Q<XMN/2 THEN Q=Q+1
406 IF Q>3*XMN THEN Q=Q-1
410 FOR K=1 TO 2:IF K=1 THEN TFILL=85 ELSE TFILL=80
420 GOSUB 770                                      ' Calculate Deviate, Phi, R
430 IF R<0 THEN R=0
440 IF K=1 THEN RFIRST=R
450 IF K=2 AND R>RFIRST THEN R=RFIRST
460 DEVIATE=(R-XMU)/SIG:GOSUB 560                      ' Calculate PHI
470 ALPH=SIG*FNPROB(DEVIATE)-(R-XMU)*PHI
480 BETA=PHI*(SIG^2+(R-XMU)^2)/2-SIG*(R-XMU)*FNPROB(DEVIATE)/2
485 FILL(K)=1-ALPH/Q:BACK(K)=NITEM*BETA/Q
486 IF FILL(K)<TFILL/100 THEN R=R+1:GOTO 440
490 ZTFILL(K)=ZTFILL(K)+NITEM*XMN*FILL(K)
495 ZTBACK(K)=ZTBACK(K)+BACK(K)
500 ZTOTAL=ZTOTAL+R*CITEM*NITEM*(-1)^K
510 NEXT K
515 LPRINT USING B$;NITEM;Q/XMN;XMN;Q;RFIRST;R;FILL(1);FILL(2);BACK(1);BACK(2)
520 ZANN=ZANN+CITEM*NITEM*XMN
530 ZTDMD=ZTDMD+NITEM*XMN
540 NEXT L:LPRINT USING A$;NN;ZTOTAL;ZTFILL(1)/ZTDMD;ZTFILL(2)/ZTDMD;ZTBACK(1);Z
TBACK(2):LPRINT
550 NEXT M
555 LPRINT USING D$;ZANN
560 REM****Gaussian Quadrature ********************************************
570 C(1)=.238619:C(2)=-C(1):C(3)=.661209:C(4)=-C(3):C(5)=.9324699:C(6)=-C(5)
580 D(1)=.467914:D(2)=.360762:D(3)=.171324
590 R2=1:IF DEVIATE<0 THEN R2=-1:DEVIATE=ABS(DEVIATE)
600 J=0:FOR I=1 TO 6
610     X=(2/(1+C(I)))+DEVIATE-1
620     I1=INT((I+1)/2)
630     N=((4*D(I1))/(1+C(I))^2)*FNPROB(X)
640     J=J+N:GOTO 660
650     PRINT X,FNPROB(X),N
660     NEXT I
670 PHI=J/2:IF ABS(DEVIATE)<1 THEN PHI=PHI-.011696*(1-ABS(DEVIATE))^2
680 IF R2<0 THEN PHI=1-PHI:DEVIATE=-DEVIATE
690 RETURN
770 REM*****  Subroutine to Calculate R  ***********************************
780 RDIR=0:IDONE=0
790 IF RDIR=0 THEN DELTAO=99999!
800 IF IDONE=1 THEN R=RO
810 DEVIATE=(R-XMU)/SIG:GOSUB 560                      ' Calculate PHI
820 IF IOPT=1 OR IOPT=2 THEN 1000                              'R was input
830 ALPH=SIG*FNPROB(DEVIATE)-(R-XMU)*PHI
840 BETA=PHI*(SIG^2+(R-XMU)^2)/2-SIG*(R-XMU)*FNPROB(DEVIATE)/2
850 IF IDONE=1 THEN RETURN
860 IF IOPT=6 THEN RETURN                                     ' R was input
870 IF IOPT<=3 THEN DELTA=(PIE*XMN-(PIEHAT+CI)*(R-XMU))*PHI+(PIEHAT+CI)*SIG*FNPR
OB(DEVIATE)-Q*CI
880 IF IOPT=4 AND ICONST=1 THEN DELTA=BETA-Q*TBACK
890 IF IOPT=4 AND ICONST=2 THEN DELTA=100*ALPH-Q*(100-TFILL)
900 IF IOPT=7 THEN DELTA=100*ALPH-Q*(100-TFILL)
910 IF IPRNT=1 THEN PRINT " R=";R,"DELTA=";DELTA,"DELTA2=";DELTA2
920 IF RDIR<>0 AND ABS(DELTA)<DELTAO THEN DELTAO=ABS(DELTA):RO=R
930 IF RDIR=0 AND DELTA>0 THEN R=R+1:RDIR=1:GOTO 790
940 IF RDIR=0 AND DELTA<0 THEN R=R-1:RDIR=-1:GOTO 790
950 IF RDIR>0 AND DELTA>0 THEN R=R+1:RDIR=1:GOTO 790
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960 IF RDIR<0 AND DELTA<0 THEN R=R-1:RDIR=-1:GOTO 790
970 IF RDIR>0 AND DELTA<0 THEN IDONE=1:GOTO 800
980 IF RDIR<0 AND DELTA>0 THEN IDONE=1:GOTO 800
990 IF IOPT>=4 THEN RETURN
1000 ALPH=SIG*FNPROB(DEVIATE)-(R-XMU)*PHI
1010 BETA=PHI*(SIG^2+(R-XMU)^2)/2-SIG*(R-XMU)*FNPROB(DEVIATE)/2
1020 IF IPRNT=1 THEN PRINT " NOR.DEV=";DEVIATE,"PHI=";PHI,"ALPH=";ALPH,"BETA=";B
ETA
1030 RETURN
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The methods and results of this work represent a first step in quantifying the relation between consumable parts and end-item readiness. This working note addresses the effect on aircraft availability rates if safety levels in the wholesale Air Force stock fund were to change. (Safety levels are the stock levels maintained to cover variations in demand.) The results are that as many as 150 additional aircraft, Air Force-wide, could become unavailable due to parts, if safety levels fell to the extent that wholesale fill rates dropped

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20. ABSTRACT (Continued)

85 % to 80 %.

5 points, from ~~85 percent to 80 percent.~~ Areas for further research are also addressed.

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