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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This is a study of trends in the operational availability of shipboard equipment and factors underlying these trends. Using 3-M data, the study found decreasing operational availability for all three kinds of equipment analyzed. The main components of operational availability, reliability and mean downtime, were examined to determine which was responsible for the decrease. The finding that mean downtime was the main reason, for electronic and HM&E (hull, mechanical, and electrical) equipment, led to an investigation of the trends in deferred maintenance actions,

7 Participants: Peter Roane, Peter Stoloff

20 supply times, and administrative delay times.

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1. The state of readiness of the Fleet has been a source of increasing concern to the Navy. The CNO has directed that the causes of trends in readiness be investigated and that the problem of measuring readiness be addressed. The Material Support Study deals with material condition, one of the major components of readiness. In one of its earlier tasks, it analyzed CASREPT data to measure trends in the downtime of 14 types of warships. That analysis was published separately as CNA Research Contribution 310 (Revised). The present study report analyzes 3-M data to discover which factors were determining the trends in operational availability of various kinds of shipboard equipment in the early seventies. It examines 12,000 corrective maintenance actions performed on 60 items of problem equipment -- 34 electronic, 12 ordnance, and 14 hull, mechanical, and electrical (HM&E) -- on 91 cruisers and destroyers.

2. The principal finding is that different factors have been determining the material condition of different kinds of shipboard equipment. The level of operational availability of all three kinds of equipment fell during 1970-73, but the reasons for the decline differed by group. For electronic and HM&E equipment, an increase in downtime was the greater factor; for ordnance, it was a decrease in reliability. The main reason for the increase in downtime of electronic and HM&E equipment also differed. For electronic equipment, it was an increase in supply time; for HM&E equipment, it was an increase in off-ship assistance and in delays in obtaining this assistance.

3. Because of limitations in the scope of this study, these findings cannot be translated directly into specific recommendations on the material support budget. The analysis does not deal with the costs and benefits of individual programs, nor

does it consider the differing mission essentiality of various items of equipment. Finally, the findings for 1970-73 might no longer apply. For these reasons, the substantive findings of the study should be used only for general insight into why the material condition of the 3 major classes of equipment declined during 1970-73.

4. The study does, however, make a major contribution to our understanding of the biases and other problems in analyzing 3-M data. And it suggests ways to overcome these. The study thus shows that, although uncertainties remain, 3-M data can be used to measure trends in material condition and determine what major factors were responsible. There is independent reason for confidence in using 3-M data: as the present report documents, the findings of the earlier CASREPT analysis is in general agreement with the results shown here.

Donald C. DAVIS
Director
Navy Program Planning

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SUMMARY

A major concern among Navy planners has been whether readiness of ships has fallen in recent years. Readiness depends, among other factors, on whether equipment is being kept in working order (material condition), and on whether there are enough trained people on board ships to get the most out of the equipment.

In this study, we are concerned solely with the equipment side of the equation. If material condition has declined, there is interest in understanding why, so that appropriate remedial action can be undertaken. A related question is whether the contributing factors are largely the same for different types of equipment, or whether there are major differences. At the aggregate level, possible reasons for a downtrend in operational availability include deteriorations in reliability, increases in supply delays, and more problems with repair.

This analysis tries to answer these questions. By examining 3-M reports of corrective maintenance actions performed on 60 items of problem equipment on destroyers, we found that material condition as measured by operational availability did indeed fall during the early 1970s. There were no substantial differences between the three kinds of equipment -- electronics, ordnance, and HM&E (hull, mechanical and electrical) -- all of which fell by 1.6 percentage points yearly.

The <u>reasons</u> for declining material condition, however, varied substantially across equipment types. Electronic items suffered somewhat from deteriorations in reliability (by 13 percent yearly), and large increases in mean downtime (20 percent yearly) caused primarily by worsening supply. By comparison, ordnance equipments suffered much larger downtrends in reliability (32 percent), and lesser increases in mean downtime (six percent) caused equally by supply and needs for off-ship repair. Finally, we found little problem with reliability for HM&E equipment, and the sizable increases in mean downtime (14 percent) were due mostly to rising needs for off-ship repair.

For all types of equipment, the problems with supply and off-ship repair showed up principally in increases in the percentage of all actions that were deferred for these reasons.

Actions to reduce deferrals for parts, of prime importance for electronics, and high importance for ordnance equipment, would include stocking more parts aboard ships, and buying more parts no matter where they are stocked to avoid the need for new ordering to satisfy Fleet demands. Improvements in ships' ability to make repairs would lower deferrals for off-ship repair assistance, of importance for both ordnance and HM&E equipment.

Major problems we (and others) have had in analyzing the 3-M maintenance data could be greatly relieved by modifying the reporting system. It would be valuable to

have information on the echelon which supported each maintenance action requiring off-ship repair or supply, and also on the associated waiting times between request and satisfaction.

INTRODUCTION

It is a truism that Navy ships cannot perform their missions without equipment in working order. Maintaining material condition[1] depends, in turn, on knowing what factors most influence it. The Material Support Study has carried out several analytical tasks to help provide this understanding.

Ultimately, of course, the goal of analysis in this area is to make the connection between material condition and specific programs in the support budget. Our achievements are more modest. In the three tasks completed earlier in this study, which are reported in references 1, 2, and 3, we have: (1) measured overall trends in the material condition of warships using CASREPT data; (2) measured trends in aggregate support funding to see whether these help to explain the trends in material condition; and (3) suggested a way to restructure the support budget along functional lines to ease future efforts to relate the budget to material condition.

The final task of the study, reported here, takes a less aggregate approach. We have looked at many specific items of shipboard equipment, measured trends in their material condition, and tried to account for these trends by shifts in reliability, supply delays, and repair times.

This research responds to a specific request by the Chief of Naval Material. In an earlier analysis of six items of equipment, we found considerable variation in how material condition depended on reliability, supply, and repair. In particular, supply did not appear to be the universal problem, as some believed.

The CNM asked us for more evidence of this variability, and this volume reports our findings. The number of equipments has been increased to 60, and the analysis has been carried out in greater detail.

As in the initial analysis of six items, material condition is measured by operational availability (A_o), the fraction of time an equipment is available for service. Trends in A_o are first related to shifts in reliability (how often things fail) and how long it takes to correct failures when they occur (mean downtime). Trends in mean downtime are then related to such factors as increases in the waiting time for parts and the need for off-ship repair assistance.

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[1]Material condition is a component along with such variables as the availability of trained maintenance and supply personnel of material readiness. Overall readiness is an even more inclusive measure. It depends also on factors such as command, training, communications, etc.

The data for this study consists of 3-M reports of corrective maintenance actions performed during 1970-73 on 60 items of problem equipment on destroyer-type ships.

Our findings are that for those years, A_o (operational availability) declined yearly by 1.6 percentage points for each major class of equipment: electronics, ordnance, and HM&E (hull, mechanical and electrical).

The reasons, however, varied substantially among the different types of equipment. Electronic items suffered somewhat from deteriorations in reliability (13 percent annually) and large increases in mean downtime (20 percent annually), with problems in supply being the major cause of the increase in MDT (mean downtime).

By comparison, ordnance items suffered much larger downtrends in reliability (32 percent annually) and lesser increases in MDT (6 percent annually) which were due to both supply and needs for off-ship repair. Finally, we found that HM&E equipments were troubled little by worsening reliability, and the sizable increases in MDT (14 percent annually) were due principally to rising needs for off-ship repair. The problems with supply and off-ship repair showed up principally in increases in the percentage of all actions that were deferred for these reasons.

Note that these findings, while informative in a general way, provide little help in choosing between line items of the support budget. Programs in the area of supply, for example, deal with such specifics as procurement of various parts, stockage levels at each echelon, reorder policies, and manning levels of supply billets. The supply variables dealt with in our study, on the other hand (e.g., overall delay times), are aggregate measures, each affected by many programs. A heavy application of inventory theory is needed to bridge the gap between program outputs and overall measures.

A similar situation exists with regard to repair and reliability.

In addition, tradeoffs between line items of the support budget cannot be carried off without consideration of costs -- not just the current budgets of each line item, but the incremental costs of different output levels.

Then, too, money should be spent first on those equipments which are most critical to the missions of the ships. We used no criterion of essentiality in choosing which equipments to analyze.

Finally, budget recommendations should be based on more recent data than the 1970-73 figures available for our analysis.

For these reasons, dealing with the level of aggregation, costs, essentiality, and timeliness, the main contribution of our study is limited to showing that trends in reliability, supply, and repair had different shares of responsibility for changes in the material condition of different kinds of equipment during 1970-73.

A secondary contribution of our study concerns the 3-M reporting system itself. There is current dispute about this system. The collection costs the system imposes on the shipboard and shoreside support establishment are apparent, but the benefits are harder to assess. The quantity of the information is too little to make hard judgments about individual programs, and the quality of the information is degraded by reporting biases.

Nor is the way analysts handle the data always up to par. Some have calculated operational availability without including delays associated with off-ship supply and repair. At least one publication quotes an incorrect formula for calculating operational availability. Then, too, some studies of supply ignore the effects of reliability and repair, and thus cannot discover which factor is relatively most responsible for poor material condition, and thus in greatest need of attention.

In responding to the confusion, some Naval officers feel that the 3-M reporting system should be scrapped. Others take the more optimistic view that the system is worthwhile, but needs change. At least one Navy group, Op-04M, is continually reviewing improvements to the 3-M reporting system.

To help with these problems we will describe some of the biases we have found in the data, estimate their importance, and show how their effects can be minimized. We show how the effects of reliability, supply, and repair can be jointly measured, and discuss the conceptually correct way of doing this.

Finally, we will point to those data which, if incorporated in the 3-M system, would make it more useful. Most, if not all, of these data may already exist in other reporting systems. Time precluded our collecting them and integrating them into the analysis. Even so, there would have been problems of compatibility. There is some reason to suggest, that therefore, the Navy consider setting up a single system for reporting reliability, maintenance, and supply data.

Despite its problems, 3-M data can be used to gain insight into the Fleet's material condition. From this analysis, we have obtained these general policy implications. For electronics and ordnance equipments, actions to reduce the deferrals for parts (e.g., increasing stockage of parts aboard ships, buying more parts no matter where they are stocked to avoid the need for new ordering, etc.) would greatly reduce mean downtime and thus increase operational availability (A_o). Improvements in ships' ability to make repairs, thus lowering deferrals for repair, would increase A_o for ordnance and HM&E equipments.

Of course, those factors that lowered material condition in the past might not be the factors whose improvement would most efficiently increase it in the future. Nevertheless, they are likely places to look.

DATA

GENERAL

From the Fleet Material Support Office in Mechanicsburg, Pennsylvania (FMSO), we obtained all reports by the 3-M system for corrective maintenance actions that occurred on 91 destroyers during the five years from 1970 through 1974. The ships (appendix A) include DDs, DDGs, DEs, DEGs, and DLGs (old designations).

By using 3-M data rather than CASREPT reports, we obtain more information: 3-M actions are described as non-deferred, deferred for work backlog aboard ship, deferred for parts, or deferred for off-ship repair. In addition, the two systems do not report exactly the same actions: the 3-M system reports on a very wide range of actions while the CASREPT system deals only with mission degradation. We will note any differences between these two populations of actions by comparing our 3-M findings with those of the CASREPT analysis carried out in reference 1.

For analysis, we chose 60 individual items of equipment at the APL level[1] (appendix B): 34 electronics (E) APLs, 12 ordnance (O), and 14 hull, mechanical and electrical (HM&E).

We chose to analyze APLs, rather than more highly aggregated EICs, in order to measure variations with type of equipment: mechanical systems may contain electronic components, etc.[2] Moreover, our data on equipment populations (obtained from FMSO's Weapon System Master File) specifies the number of units installed aboard individual ships only at the APL level. (See appendix C for this data.) Population is a necessary

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[1]In general, items with APL (Allowance Parts List) numbers are components of larger systems categorized by an EIC (Equipment Identification Code). For example, APL 916150582 (not included in our sample) is an HM&E item -- a 125 PSI, 900 gallon-per-minute centrifugal pump -- that is, found in fire mains represented by EIC T801. APLs are generally not specific to EICs: the centrifugal pump is also in main propulsion high pressure turbines, EIC F801.

[2]Because APLs are not specific to EICs (a given APL might be found in a variety of EICs), it would be difficult to draw out the implications of our analysis for equipment at the EIC level, much less for complete systems such as radars, boilers, etc.

input to calculations of operational availability: a large number of actions distributed over an even larger number of units yields few actions per unit.[1]

We selected troublesome APLs by choosing them from a FMSO list of the 300 APLs having the most corrective actions Navy-wide during 1975 (reference 4).[2] These are not necessarily the APLs with the highest failure rates (yearly failures per item). A one-of-a-kind APL, for example, can have a high failure rate but few total failures on a fleet-wide basis, and therefore not appear in our sample.[3]

Our selection procedure ignores relevant factors such as mean downtime per action, redundancy of APLs within EICs and EICs within total systems, and also the criticality of the systems to ultimate mission performance.

VARIABLES REPORTED UNDER THE 3-M SYSTEM

Under the 3-M system, corrective actions are reported by the Maintenance Data Collection Subsystem (MDCS). Our analysis is confined to corrective actions only, which are recorded by the Fleet on 4790-2K ("2-Kilo") forms. For our time period of interest, 1970-73, MDCS 3 was the version in use, and the reported variables are listed in appendix D.[4] FMSO supplied us these data for the 91 ships in our sample.

Because reporting under MDCS 3 started with actions discovered (initiated) on 1 January 1970, we lack any record of prior actions that were still in progress during the

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[1]Not knowing population by EIC impeded analysis even at the APL level. The reliability of a given APL may vary with its "application." Centrifugal pumps, for example, are driven harder (used more hours per week) in main propulsion systems than in fire mains. Because we lack APL populations by EIC, our estimates of A_o are averages with unknown weights) over all EICs in which they are found.

[2]We did not choose the highest 60 in the FMSO report. Some of the "worst" APLs were not installed on the ships we examined, judging from the fact that not a single action was reported over the entire 5-year period. Moreover, we had to dip far into the list to obtain an adequate sample of ordnance and HM&E APLs (12 and 14). Nevertheless, the 60 APLs in our sample were responsible for 44 percent of the total number of actions in the FMSO listing. We included 23 of the first 25, and 36 of the first 50.

[3]This may be one reason why ordnance and HM&E equipments appear toward the end of the FMSO list.

[4]Some descriptive statistics on these variables are included in the appendix.

period of analysis. The data terminate with actions initiated in the early part of 1975. The biases resulting from these "end effects" are discussed in the next section.

To calculate supply delays, we needed the dates on which parts were issued to shipboard repairmen. These data, which are recorded by the Fleet on "1250" forms, were also supplied to us by FMSO.

We have limited our analysis to actions where the equipment was "non-operational;" we'll call these "failures," for short. This category has a less ambiguous meaning than the other possibilities, and is less subject to variations in coding criteria used by different shipboard repairmen. Moreover, "failure" is more closely linked with degraded material condition than is "reduced capability," say. (A similar consideration underlies the preferential attention given to C3 and C4 CASREPTs.)

BIASES IN 3-M DATA

We are aware of concerns about the validity of analysis based on 3-M data because of reporting errors and other difficulties. We will discuss the problems listed below and mention our attempts to minimize their effects:

- Random reporting errors;
- Under-reporting by ships;
- "End effects" in the data tape;
- Population data for 1975 only;
- Incomplete and incorrect records;
- Simultaneous actions;
- Errors in reporting completion dates.

Incorrect recording of the APL number is a random reporting error. Because it occurs, the maintenance actions reported for a given APL will lack some that belong, and include some that don't. The number of errors of omission and commission could be about the same in our large sample, so that estimates of reliability (which depend on the number of actions) are likely to be unaffected. Other biases could still remain, however; if a given APL has a lower mean downtime than that of the population as a whole, an equal number of omissions and commissions will lead to an overestimate of mean downtime.

Under-reporting creates problems for our study because it changed in extent during 1970-73, and thus affected our estimates of trends. The major change came in late 1970, at the end of the first year of analysis, when selected reporting was instituted by Admiral

Zumwalt (then CNO). The initial message (Z-46, a Zumwalt "Z-gram") and the implementing instructions are discussed in detail in appendix E. Of most importance for our study are the provisions that reduce the number of actions reported, and reduce the non-deferred ones more than the deferred ones. The resulting biases in our findings will be discussed as they come up.

The "end effects" occur because we looked at only an historical slice of data. Even though some actions starting before 1970 were still in progress during 1970 (with a few lasting until 1971), we avoided bias in measuring trends in reliability by using the number of actions starting each year. Mean downtime for each year was similarly calculated only for those actions starting during the year.

(A problem would have arisen if we had based our calculations for each year on the number of actions in progress, and the total amount of downtime. The number of actions in progress during 1970, recorded on our tape, underestimates the actual number in progress, and the error decreases with time.)

This way of calculating mean downtime, however, creates problems at the end of the period. Many actions starting in 1974 were still going on at our data cutoff in early 1975, and others were completed but delayed in transmission from the Fleet. Thus, only the shorter actions starting in 1974 were completed in time for inclusion on our tape, and mean downtime for this year would be seriously biased. (The distribution of action downtimes has a long "tail," and a sizable number starting in late 1974 were not completed by early 1975.) It was to minimize this problem that we eliminated 1974 and chose 1970-73 as our period of analysis.

The Weapon System Master File is not an historical record, so that our population figures -- number of units of each APL on each ship -- are correct only for late 1975, when we obtained them from FMSO.[1] Because some units then in place were probably installed during the period of analysis, some of our trend estimates may be biased: in the earlier years before all units were installed, our population figures would be too high; measures of reliability and A_o would thus be too high, so that a downward trend, for example, would appear worse than it really is.

The size of the bias might not be large: analysts at FMSO estimate that only 5 to 10 percent of the APLs change during a typical overhaul, and that changes between overhauls are even fewer. Moreover, our aggregation over ships, and APLs within classes, may help.

[1] Gathering similar information for 1970-73 from other sources, such as past Ships Characteristics Cards, would have been laborious, if not impossible.

The reverse problem is that the Master File shows no populations for some APL-ship combinations for which actions were reported. Because population data are needed to calculate operational availability, these combinations were deleted from analysis. Also deleted were records that are obviously incorrect (deferral date preceding discovery date), or incomplete (no completion date; two forms initiating the same action; a form closing out a deferred action unaccompanied by a form initiating it). Table 1 shows that we have analyzed only about 60 percent of the actions for which there is any information at all on the data tapes. Our estimates of reliability and A_o are thus high, but trends could be unaffected.

Another problem on the list is that several maintenance actions can occur on the same equipment at the same time. Because of this "overlap," the formula we use to calculate A_o -- and that other analysts use as well -- provides an underestimate. This technical problem is not academic. Appendix K shows that overlap is a common occurrence, and it has a sizable effect on estimates of A_o for all actions taken together. By analyzing only failures, which are less frequent and have less overlap, the bias is minimized.

Finally, we suspect that biases in the reporting of completion dates for maintenance actions may be partly responsible for the long mean downtimes indicated by our data. We will discuss this possibility in appendix J.

TABLE 1

ACTIONS DELETED FROM ANALYSIS

	Number of JCNs[a] on original tape	Deletions			Final number of JCNs analyzed
		Improper record sequence	Incomplete or illogical[b] data	No population data	
Electronics	52,073	7,799	1,062	9,064	34,148 (65.6%)
Ordnance	13,212	3,125	267	958	8,862 (67.1%)
HM&E	11,243	4,214	428	1,332	5,269 (46.9%)
Total	76,528	15,138	1,757	11,354	48,279 (63.1%)

[a]Job control numbers.

[b]E.g., completion dates occurring before discovery dates.

TRENDS IN A_o

Using the data just described, we first measured operational availability, the fraction of time an equipment is "up" when needed:

$$A_o = \frac{\text{up time}}{\text{total time}} = \frac{\text{total time less downtime}}{\text{total time}}$$

There's a problem in interpretation here. Saying an equipment is "not down" doesn't mean that it is really up. It could have already failed and not been detected. Electronic equipments that are not solid-state, for example, can fail when they are turned off because of surges in voltage that occur at those times. The failure would not be detected until the next time someone tries to use it. There is no way to account for this using 3-M corrective maintenance data,[1] and our measures of A_o are thus biased upward. We have no a priori reason to expect that the amount of overstatement varies over time, however, so our measures of trends in A_o should be unaffected. For convenience, we will continue to use the term "up" to mean "not down."

Another point is that historical data tells us only the fraction of time equipments were "up" in the past. These values of A_o are reliable estimates of future availability only if operating patterns do not change.

A more common expression for A_o is obtained by dividing each term in the formula above by the number of actions:

$$A_o = \frac{\text{MTBCMA} - \text{MDT}}{\text{MTBCMA}}$$

MTBCMA is the mean time between corrective maintenance actions,[2] estimated by dividing total "equipment time" during a given year (shipboard population times 365) by the number of actions started during that year. Mean downtime (MDT) is the average duration of all actions that started during the year.

Using this formula, we obtained values of A_o for each ship, year, and APL. The values of A_o and MDT aggregated over ships are shown in appendix F.

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[1] In other words, we are measuring durations in "calendar time," rather than "operating time."

[2] That is, the mean time between discovery of one action and discovery of the next one.

These values of A_o may be larger than figures seen elsewhere because we deleted some actions from analysis (mentioned earlier), and have confined attention to failures, which occur less often than all actions taken together. Note, too, that we are analyzing APLs, not EICs, as do many other analyses. Because all component APLs must work for a larger EIC to be "up" (neglecting redundancy), EICs typically have smaller values of A_o than those for APLs, derived here.

We used statistical regression techniques to estimate the time trend in A_o. We first took all 60 APLs together, and fitted the regression equation shown at the top of table 2. "T" stands for time (1970 = 0, 1971 = 1, etc.), and its coefficient β_T is the estimated change in A_o per year. By using dummy variables (D_{APL}),[1] the trend line for each APL can have a different height (corresponding to the absolute size of A_o), but all must have the same slope β_T.[2] We found a yearly decrease in A_o of 1.61 percentage points (top line), an estimate which is statistically significant at the 10 percent level.[3]

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[1]Because a constant is included in the regression equation, the number of dummy variables is one less than the number of APLs.

[2]Although fitting a regression line to only four points for each APL may seem like "overkill," this technique is better than, say, fitting a line to the endpoints alone.

Another point is that adding the dummy variables to "hold equipment constant" takes away statistical degrees of freedom, but fitting a single trend line to the entire data would be worse yet. This would be justified only if all equipments were samples from the same population -- an unwarranted assumption.

[3]The linear model estimated in table 2 implies that equipments with high and low values of A_o will show the same yearly decreases in A_o measured in percentage points. An alternative suggestion was that equipments with higher values of A_o would decrease by less. We tried a model with this behavior, in which A_o is replaced by the logarithm of $(1 - A_o)$. Estimating this model for all 60 APLs grouped together produced a yearly decrease almost identical to the pooled estimate in table 2.

TABLE 2

TIME TREND OF A_o

(failures, 1970-73)

$$A_o = \beta_o + \sum_{APL} \beta_{APL} D_{APL} + \beta_T T$$

Regression	APL type	Average value of A_o (1970-73)	Yearly decrease β_T	Yearly decrease t-statistic
1	All	.86	-.0161	-1.94[a]
2	Electronics	.89	-.0162	-1.89[a]
3	Ordnance	.81	-.0160	-.77
4	HM&E	.82	-.0164	-1.01

[a]Significant at ten percent level.

In separate regressions for each type of equipment, shown next in table 2, we found remarkable uniformity in the yearly decreases.[1]

These estimates of trends in A_o may be biased for several reasons. First, the MDCS-3 system was instituted at the start of 1970, and it probably took some time for the new reporting to become standard practice in the Fleet. We have no data to judge the effect on our measurements. If there was under-reporting until the system "took effect," this could help explain the measured downtrend in A_o. Reliability and thus A_o would be too high at first, relative to later years. Even if this were the direction the bias took we doubt that it could explain the entire downtrend, however: we will shortly point to other biases in the opposite direction that would tend to cancel this one; and CASREPT data independently shows a decline in material condition.

[1]For electronics, however, almost all of the decreasing downtrend in A_o was due to 2 APLs; and these APLs, moreover, had low populations. The 2 APLs were numbers 3 and 10. Table F-1 shows that A_o for these 2 electronic equipments suffered a uniquely large dropoff in 1973. According to table C-1 (column 5), the population of these APLs (10) was only .2 percent of the population of all APLs in our sample (about 4,000).

When these "outliers" are removed, the time trend in A_o for electronic equipments still shows a downtrend, but the yearly decrease is only .3 percentage points, and this estimate lacks statistical significance.

The second source of bias is the change to selected reporting that occurred in October 1970 (appendix E). Appendix G discusses the direction of bias. Briefly, because the change brought about a reduction in the fraction of actions reported after 1970, reliability appears better (higher) in later years; but the reduction was less for deferred actions, which have longer downtime, so that mean downtime appears worse (higher). The net effect is an overestimate of A_o for later years, and thus an underestimate of its downtrend.

The third source of bias is related to the fact that some ships went into overhaul during the period of analysis. During overhaul, 3-M maintenance reports slack off (see figures J-1 and J-3; note that the fall-off occurs only during the first half of the overhaul period). Fewer actions means larger MTBCMA, and (holding MDT constant) larger A_o. For this reason, ships will have artificially high values of A_o for those years when they spend time in overhaul.

This bias in the trend of A_o for a single ship should not affect our measures of A_o, which are averages over all ships which carry the equipment, provided that there was no systematic trend toward more overhaul time during 1970-73.

In fact, we found a trend. In a sample of 50 of the 91 ships, total overhaul time rose fairly steadily from 66 to 87 ship-months from 1970 to 1973. Providing that MDT is the same for actions in and out of overhaul,[1] we conclude that A_o declined by more than we measured.

The decline in A_o for 3-M actions is consistent with the findings of the CASREPT analysis reported in reference 1. For all warships taken together, total downtime for all CASREPTS rose by 10.8 percent yearly during 1970-74, and the more serious C3/C4 CASREPTs rose by 17.6 percent.[2]

In order to explain these declines in shipboard material condition, one might look first for reductions in spending. The analysis in reference 2, however, failed to find reductions in two aggregate measures of ship support. Expenditures on direct support of conventional ships adjusted for inflation and changing force structure stayed fairly

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[1] Figures J-1 and J-3 show that for one ship chosen at random, the rate of both discoveries and completions fell during overhaul; but mean downtimes could have stayed the same.

[2] Even though A_o and total CASREPT downtimes are each a function of frequency of occurrence (reliability) and mean downtime for repair, changes in these 2 measures cannot be compared numerically.

constant during 1966-73 and increased sharply from 1973-75. And general logistics support relative to the direct support part of the OM&N budget increased sharply during 1966-67, with little trend thereafter.[1]

Having found no general decrease in support spending to explain the observed reductions in material condition that took place during 1970-73, there is more reason to look at particular equipments, or classes of equipment, as we do in this analysis.

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[1] We have not looked into whether there were decreases in support funds prior to 1966, which could possibly have had a lagged effect on readiness during 1970-73.

CAUSE OF DOWNTRENDS IN A_0: DECREASING RELIABILITY OR INCREASING MEAN DOWNTIME?

Operational availability can fall because of decreases in reliability and increases in the times to fix equipments when they fail (longer mean downtime, or MDT). This section estimates the time trends in these 2 factors in order to help understand why A_0 fell during 1970-73.

Reliability can be defined in more than one way. Some texts on maintenance theory define it as the probability an item lasts at least a given time before failing (higher probability means higher reliability); and other sources define it as the expected time an item will last before failing (higher expected time, higher reliability). The latter form is more easily measured using 3-M data, and we will use it here. Other Navy analyses of equipment condition use it as well.

There are some other confusions, however, with regard to what reliability means. Although some texts in maintenance theory do not make the point explicitly, "reliability" generally refers to how long a system performs once it has been brought "up" from a previous failure.

In figure 1, which illustrates the "up" and "down" history of an item of equipment, this duration is represented by MTBF, the "mean time between failure."

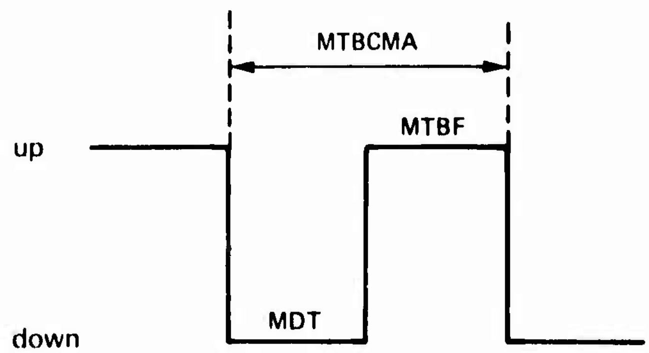

FIG. 1: DEFINITIONS OF TERMS

MDT is the mean downtime to correct the problem. The sum of MTBF and MDT is the average time between successive "downs." It is what we referred to in the last section as the "mean time between corrective maintenance actions," MTBCMA. Using the fact that MTBCMA = MTBF + MDT, the previous formula for A_0 can be written:

$$A_0 = \frac{MTBF}{MTBF + MDT} \;.$$

The terminology here is confusing. Thinking just about the words themselves, "mean time between failure" and "mean time between corrective maintenance actions," both seem to refer to the average time between one failure and the next one. But we use "mean time between failure" (MTBF) for the average time from when an equipment is brought "up" from its last failure to when it fails again. This time, which is a subset of the entire time between successive failures is the appropriate measure of "pure reliability," the tendency of an equipment to fail. The entire duration MTBCMA is a function of both the tendency to fail (MTBF) and how long it takes to fix a failure (MDT). Even though the "mean time between failure" is misleading, we use it this way because it is common practice in other Navy analyses of operational availability. At least one textbook uses it this way (reference 4).

To illustrate the importance of keeping these concepts straight, consider this example. A radar is found to fail once every ten years. Does this mean it is reliable? Not necessarily. It might be that the item always fails the moment it is turned on, and then takes 10 years to fix. Reliability (MTBF) would be zero. It failed only once a decade because it was always in the shop, and never had a chance to fail.

On the other hand, the item might typically last for 10 years before failure, and take only a second to fix. Here, reliability would be high (MTBF equals 10 years).

To summarize, MTBCMA is a function of 2 largely independent sets of factors: those which make an equipment fail (reliability), and those which bring it back up (MDT).[1] To measure reliability, we must take the difference between MDT and MTBCMA, both of which can be found directly from the data. Using the values of MTBCMA and MDT mentioned earlier in the calculation of A_o, we obtained the values of MTBF listed in appendix F.

TRENDS IN RELIABILITY

The time trend in these values, obtained by regression analysis, is shown in table 3. Electronic and ordnance APLs both showed substantial decreases in reliability during the period.[2] HM&E APLs showed improvement, but of minor extent and negligible significance.

Because of the late-1970 reporting changes, the reliability of electronic and ordnance equipments declined by more than these estimates, and the measured increase in reliability for HM&E may not be real.

[1] The independence is not complete. A poorly trained mechanic might tend to find trouble where there is none (thus lowering measured reliability), and take a long time to "fix" it (increasing MDT).

[2] The 32 percent annual decrease for ordnance equipments seems too high, but we cannot dismiss it on grounds of statistical insignificance.

TABLE 3

TIME TREND OF MTBF
(Failures)

$$MTBF = \beta_0 + \sum_{APL} \beta_{APL} D_{APL} + \beta_T T$$

APL type	Average value of MTBF (1970-73)	Yearly change β_T	t-statistic
E	1403 days	-185 days (-13%)	-1.25
O	682	-221 (-32%)	-2.74[a]
HM&E	939	43 (+ 5%)	.38

[a]Significant at 1% level.

Deteriorations in reliability were found also by reference 1, in that the more serious CASREPTs (C3/C4s) rose in frequency by 6 percent annually during 1970-73. It may be more fitting, however, to compare 3-M failures with all CASREPTs, inasmuch as even C2 CASREPTs generally involve outright failures of equipment. Here, the 3-M decreases in reliability for electronics and ordnance (but not HM&E) far exceed the 0.8 percent increase in frequency of all CASREPTs.[1]

TRENDS IN MEAN DOWNTIME

Increasing time to make repairs also contributed to the decline in A_0 during the early 1970s. Table 4 shows that MDT (mean downtime) increased for both electronic and HM&E APLs. The increase for ordnance APLs is less certain.

Because a larger fraction of actions reported after October 1970 were deferred, rather than (shorter) non-deferred actions, the figures in table 4 overstate the increase in MDT. We expect, however, that the actual changes were indeed increases, because CASREPTs showed annual increases in MDT - 9.6 percent for all, and 10.0 percent for the more serious. The actual values of MDT were smaller (36 and 27 days, respectively),

[1]We cannot aggregate the 3-M results over equipment classes in order to simplify comparison with CASREPT findings. Our sample of APLs may not mirror the relative population of electronic, ordnance and HM&E equipments in the Fleet, and these classes may be represented differently in 3-M and CASREPT actions.

possibly because CASREPTs are a more pointed call for help by the Fleet: even C2s involve some degradation of capability in a primary mission area. (CASREPT mean downtimes could have turned out longer than 3-M times if they were much more serious in the technical sense.)

We have not looked further into why reliability for 3-M actions fell during 1970-73. The remainder of this report is an attempt to understand the rise in mean downtimes.

TABLE 4

TIME TREND OF MDT
(Failures)

$$MDT = \beta_o + \sum_{APL} \beta_{APL} D_{APL} + \beta_T T$$

APL type	Average value of MDT (1970-73)	Yearly change: β_T		Yearly change: t-statistic
E	46 days	8.7 days	(20%)	3.61[a]
O	64	4.3	(6%)	.56
HM&E	85	12.4	(14%)	2.00[b]

[a]Significant at 1% level.

[b]Significant at 10% level.

CAUSES OF THE INCREASING TREND IN MDT

To search for underlying causes for the increase in mean downtime, we looked at various kinds of actions and calculated their contributions to the trend in overall MDT. Suppose, for example, that actions needing parts had to wait longer and longer for them, and that this led to a large rise in overall MDT. We would know that increasing parts' waiting times were more of a factor in declining A_o than other changes which contributed less to the trend in overall MDT. (A large rise in waiting times would not necessarily lead to a large rise in overall MDT; few actions might need parts.)

Overall MDT can rise also from shifts in the percentage of actions of different types. An example might be more and more actions deferred because parts were unavailable.[1] If this were responsible for an increase in overall MDT, we could infer that decreasing parts stockage onboard ships and other likely causes of the shift toward deferral were having important consequences.

We will first describe the various kinds of actions to be considered, which are defined by deferral category and whether parts were used in the repair. The next task is to say how supply times and total downtimes were measured. Finally, we turn to the results: the contributions to the trend in overall MDT of trends in the percentage of actions of each type, and trends in their delay times.

DEFERRAL CATEGORIES

There are 4 deferral categories: non-deferred, deferral for backlog, deferral for parts, and deferral for repair. Deferral for backlog implies a queue in the ship's workload: the needed physical repair capability exists onboard and parts are quickly available, but repair shops or maintenance people are tied up with other tasks (other maintenance actions, operations, etc.).

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[1] To be more exact, it is the percentage of actions deferred, not the number of them that affects MDT. The 2 measures need not move together. For example, a gentle rise in the percentage of actions deferred would mean a fall in the number of deferrals if coupled with a strong downward trend in the total number of actions. Our 3-M data do, in fact, show a large drop in total failures between 1970 and 1971, but much of this may be due to changing reporting instructions to the Fleet. If the total number of actions, both reported and unreported, did not fall over time, increases over time in the percentage of actions deferred would mean increases in the number of deferrals.

Deferral for parts means that some of the parts needed in the repair are neither onboard, nor available from other echelons with "acceptable" delay. The criterion of "acceptable" in actual use is uncertain. Some analysts at FMSO suspect that shipboard work centers usually do not defer actions for parts unless at least one part must come up from a shore-based stock point or inventory control point (ICP). According to calculations by the 1971 S^4 study (reference 6) which are shown in our appendix H, the mean waiting time from these echelons is 14-32 days for a stock point (depending on the "cog code" for the part), 23-40 days for existing stock at an ICP, and 33-225 days if the ICP must spot buy or backorder the part.

Deferral for repair indicates a need for off-ship repair assistance by "tech reps," tenders, other intermediate maintenance activities, or depot-level activities such as shipyards.

These terms indicating the reason for deferral -- backlog, parts, and repair -- obviously do not tell the whole story. Actions needing parts also require hands-on repair; tenders may themselves have to wait for parts to fix combatants; tech reps may be used to get parts quickly rather than to provide specialized repair techniques; etc.

Moreover, the deferral entry on the "2-Kilo" forms may not indicate even the major reason for delay. Shipboard mechanics may get to backlog actions sooner than expected, but then find that needed parts are unavailable without a long delay. The "2-Kilo" forms describing maintenance actions are not usually updated as more information becomes available.

We have found no way to handle 3-M data which avoid these problems in interpretation.

NEED FOR PARTS

The 3-M "2-Kilo" forms indicate (under "Completed action taken") whether parts were actually used in a repair. This information is largely redundant for actions deferred for parts: as expected, almost all actions deferred for parts actually need parts. A deferral for backlog and off-ship repair, of course, may or may not need parts.

Not all actions are coded "Repaired with parts" or "Repaired without parts." Other possibilities include "Overhauled" and "Cancelled" (see appendix D for others). We have neglected these actions in this report. In other words, if 100 actions are repaired with parts, 200 are repaired without parts, and 20 are coded otherwise, we will say that 33 percent of all actions need parts. Few actions are ignored by this procedure: 6 percent, 10 percent, and 11 percent for electronic, ordnance, and HM&E, respectively.

DELAY TIMES

In general, mean downtime for any kind of action can be separated into several components:

$$MDT = MTTR + MSRT + MADT$$

where MTTR is the mean hands-on time to repair, MSRT is the mean supply response time, and MADT is the residual mean administrative delay time. There is no point in making this separation for actions not needing parts: MSRT is zero, and MTTR for all actions is a negligible part of MDT. For actions needing parts, we will show MSRT and the difference between it and MDT, which we will call MADT (MTTR is small). The remainder of this section will document the fact that MTTR is small, and describe how we calculated MSRT. MDT for all actions is simply the average time between discovery and completion.

For each action, we made a high estimate of the "repair duration:" we divided the number of repair man-hours reported on the "2-Kilo" forms by an assumed repair crew level of (only) one man, and an assumed workday of (only) eight hours. Using these factors, eight man-hours converts to a duration of one day. By averaging these repair durations over all actions, we obtained the estimates of MTTR shown in table 5.

TABLE 5

MEAN TIME TO REPAIR (MTTR)

	Average value (% of MDT)	Yearly increase
Electronics	1.1 days (2.4%)	-.1 days
Ordnance	1.7 days (2.7%)	0 days
HM&E	3.0 days (3.5%)	.2 days

Despite the expected bias to the small crew-level and workday factors used in the calculation, MTTR is less than 4 percent of MDT. It increased but little during the period.

It occurred to us that hands-on repair times might be associated with other delays that did make a sizable contribution to MDT. Suppose, for example, that a repairman spent a short time each day on a certain job because of other duties.[1] Small increases in the repair duration could then add significantly to the total calendar time for the repair, and perhaps total downtime. If this pattern were typical (due, say, to a general work backlog on the ship), efforts to reduce small hands-on repair times even further might be useful in reducing MDT (through lowering MADT).

We can test for this indirect effect of MTTR by measuring its correlation coefficient with MDT. The coefficient proved positive for each type of equipment, but the values -- .22, .43, and .55 for electronics, ordnance, and HM&E -- had statistical significance for HM&E alone.

Although these calculations suggest that MTTR may not measure the full effect of hands-on repair, further work is needed to pin this down. In any case, MTTR can be neglected as a component of MDT and, more important, of trends in MDT.

We turn now to mean supply response time (MSRT), which we have calculated for those types of actions in which parts were actually used.[2] MSRT is defined in this study by the average time between discovery date of an action, given on "2-Kilo" forms, and issue of the last part, given on "1250" forms. (This is not the average delay per <u>part</u>.) Issue means from the stockroom to the repairman.

We encountered several problems in this area. First, we wanted to measure supply time from when parts <u>were requested</u> from the stockroom aboard ship, rather than from when the action was <u>first initiated</u>. But these request dates, although recorded on shipboard "1250" forms, are not included in 3-M data sent to Mechanicsburg. We had to use discovery date instead.[3]

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[1] These delays associated with the intervening tasks would be "picked up" by the residual MADT.

[2] In analyses which reduce MDT for <u>all</u> actions into components, MSRT for actions needing parts is multiplied by the <u>fraction</u> of total actions needing parts.

[3] It could be argued that for deferred actions, the date of deferral provides a better estimate of when the part was ordered than does the discovery date. However, the average difference between discovery and deferral is small: 4.6, 3.3, and 2.1 days for the 3 classes of equipment.

Along with actual waiting times, our measure of MSRT includes the time to diagnose the failure and order the first part, plus additional delays when the initial diagnosis proved faulty. It may take several rounds of "order, test, and reorder" to find the right parts.

The times for initial diagnosis and "sequential ordering" are not due to the supply system. If they are constant in time, however, the trend in MSRT as we have defined it should mirror the trend in actual parts waiting time.

Note that our measure of supply time includes any hands-on repair time that occurs between discovery of the action and issue of the last part. We didn't take the trouble to measure and subtract this component from supply time because MTTR is so small.

Another problem in estimating MSRT is that we were able to match "1250" and "2-Kilo" forms for only a small sample of actions that needed parts. Many of the maintenance actions coded "Repaired with parts" under "Completed action taken" (on "2-Kilos") had no parts issue records ("1250s") with matching Job Control Number (JCN). Conversely, some parts records had JCNs with no matching maintenance action.[1] We found "matches" for only 37 percent, 20 percent, and 15 percent of all electronics, ordnance, and HM&E actions, although 91 percent, 83 percent and 67 percent of all actions were coded "Repaired with parts."[2]

We believe that the higher figures are better estimates of the percentage of actions needing parts, and we will use these in the analysis to come.

[1]This was not always due to bad reporting; in many cases the associated maintenance action was not supposed to be reported. After Z-46 came out in October 1970, CinCLantFlt and CinCPacFlt issued implementing instructions to enter "Z000" in the JCN field of "1250" forms associated with maintenance actions that were not to be reported under the selected equipment and selected ship rules. (Note that ordering for stock is not an explanation for a "missing" maintenance action; non-automated ships use "1348s," not "1250s" to requisition parts.)

[2]As another check, we made the same comparison with the sub-population of actions that were coded "Deferred for parts." Even though 94 percent, 83 percent, and 89 percent of these actions were coded "Repaired with parts, ± only 52 percent, 36 percent, and 30 percent had parts issue records.

ANALYSIS FOR ELECTRONICS

Having described the kinds of actions to be considered (defined by deferral category and the need for parts), and the variables used to describe them (percentage of total actions of each type, and delay times), we turn now to what the trends in these actions tell us about why overall mean downtime rose during 1970-1973. The analysis for electronics is presented first, with results for the other equipment types to follow. We will gain insight by looking at the average values of the variables (tables 6A and 6B) and the trends in these variables (tables 6C and 6D) before measuring the contributions of these trends to changes in MDT (tables 6E and 6F).

Table 6A shows that almost all actions needed parts (94.1 percent), and the unavailability of these parts appeared to be enough of a problem for 18 percent of these (16.9 percent divided by 94.1 percent) to lead to deferral.[1] Deferrals for other reasons were much fewer in number.

TABLE 6A

AVERAGE VALUES OF PERCENTAGES OF ACTIONS: ELECTRONICS (percent)

	Parts	No parts	Total
Non-deferred	74.0	3.8	77.8
Deferred, backlog	.9	.4	1.3
Parts	16.9	.5	17.4
Repair	2.3	1.2	3.5
Total	94.1	5.9	100.0

TABLE 6B

AVERAGE VALUE OF DELAY TIMES: ELECTRONICS (days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	3.5	6.3	7.6
Deferred, backlog	41.9	72.1	130.6
Parts	42.2	48.4	105.1
Repair	45.5	78.3	84.0

The striking point from table 6B is the huge times for deferrals of all types, relative to times for non-deferred actions. Deferrals for parts, for example, took over 90 days to complete: 42.2 days waiting time (mean supply response time, or MSRT), plus an additional 48.4 days between delivery of the last part and completion of the action (which we call "mean administrative delay time," or MADT).

Table 6C shows the trends in the figures in table 6A. The percentage of actions that were non-deferred declined by 2.8 percentage points yearly (1.7 percent plus 1.1 percent), with deferrals for parts taking up almost all of the slack (2.4 percent).[2]

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[1] Note that a few actions were deferred for parts but did not need them (.5 percent in table 6A, and similarly small percentages for the other classes of equipment). Deferral in this case was likely due to faulty diagnosis, and we will ignore these actions in discussing the role of supply.

[2] Neglecting those due to faulty diagnosis.

TABLE 6C

TRENDS IN PERCENTAGES OF ACTIONS: ELECTRONICS
(Annual change in percentage points)

	Parts	No parts
Non-deferred	-1.7	-1.1
Deferred, backlog	.2	.1
Parts	2.4	.2
Repair	.1	-.1

TABLE 6D

TRENDS IN DELAY TIMES: ELECTRONICS
(Annual change in days)

	Parts		No Parts
	MSRT	MADT	MDT
Non-deferred	1.4	.8	.6
Deferred, backlog	-.8	17.3	.5
Parts	3.3	.4	4.4
Repair	11.9	-10.8	46.0

Some of the observed reduction in the percentage of actions that were not deferred could be due to the introduction of selected reporting in 1970.

The trends in delay times (table 6D) show a modest increase in downtime for parts deferrals: 3.7 days per year (3.3 plus .4), mostly attributable to waiting time for parts (MSRT). Deferrals for backlog that needed parts also increased markedly, and by much more than those not needing parts: why this added time did not show up in MSRT is strange. The increase in downtime for repair deferrals is huge, and the fact that this occurred for actions not needing parts could be due to a systematic breakdown of the reporting system: tech reps may bring parts with them and not fill out "1250" issue forms.

We come finally to the contributions which these trends make to the rise in overall mean downtime. To estimate these contributions, which are shown in tables 6E and 6F, 1) the trends in the percentages (table 6C) must be multiplied by the average values of the delays (table 6B); and 2) the trends in the delays (table 6D) must be multiplied by the average values of the percentages (table 6A).[1] Appendix I provides more explanation.

TABLE 6E

CHANGE IN OVERALL MDT DUE TO TRENDS IN PERCENTAGES OF ACTIONS: ELECTRONICS
(annual change in days)

	Parts	No parts
Non-deferred	-.16	-.08
Deferred, backlog	.23	.11
Parts	2.17	.21
Repair	.12	-.04

TABLE 6F

CHANGE IN OVERALL MDT DUE TO TRENDS IN DELAY TIMES: ELECTRONICS
(annual change in days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	1.04	.59	.02
Deferred, backlog	-.01	.15	.00
Parts	.56	.07	.02
Repair	.27	-.24	.56

[1]Consider, for example, the first entry in table 6E (-.16 days per year). This equals -1.7 percentage points (first entry in table 6C) times 9.8 days (sum of 3.5 and 6.3 days from table 6B). Results may not agree exactly with tables 6E and 6F because numbers shown in all 6 tables were rounded.

Looking over the results shown in tables 6E and 6F, we see that most of the rise in overall MDT for electronics actions was due to worsening supply. First, there is the 2.17 days (table 6E) associated with growing deferrals for parts. Keeping in mind that the increase in parts deferrals is accompanied by a roughly equal decrease of non-deferred[1] actions, the shift toward deferral for parts contributes a total of 1.93 days (2.17-.16-.08). This is 34 percent of the full trend in overall MDT of 5.6 days per year found by summing all entries in tables 6E and 6F.[2] The growth in MSRT was responsible for another 1.86 days (sum of all 4 entries), or 33 percent of the total. In other words, worsening supply was responsible for two-thirds (34 percent and 33 percent) of the increase in overall MDT for electronics.

There is a point to be made here about misinterpreting maintenance figures. Although backlog deferrals needing parts rose substantially in mean downtime (17.3 - .8, or 16.5 days annually, from table 6D), this trend contributed little to the rise in overall MDT (.14 days, from table 6F). The reason was that relatively few actions were of this type. The more gentle rise in mean downtime for non-deferred actions needing parts led, because of their greater number, to a much larger increase in overall MDT. Simply measuring trends can be misleading.

Note that we have ignored trends in the percentage of actions needing parts, and what these trends contributed to the rise in overall MDT. Overall MDT would rise if actions needing parts took longer to complete and rose as a percentage of total actions, or vice versa (actions needing parts took less time, and became less common). In actuality, we found little help here in explaining the rise in overall MDT. Table J-2 of appendix J shows that, holding other factors constant, actions with parts took longer to complete, but the estimated difference was negligible in both size (.3 days) and statistical significant ("t" statistic of .07). The percentage of electronics actions needing parts did increase during the period -- by 1.0 percentage point yearly -- and thus tended to increase overall MDT. Ordnance and HM&E equipments, to be analyzed next, also experienced increases in the percentage of actions needing parts (by 1.5 and .2 percentage points yearly); but here, too, the insignificant difference in mean downtime between actions needing, and not needing parts eliminates the importance of the shift in explaining changes in overall MDT.

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[1] Neglecting those due to faulty diagnosis.

[2] This increase differs from the 8.7 days estimated earlier (table 4) because of differences in analytical technique. In the present analysis, we did not use dummy variables to "hold APLs constant" (permit their trend lines to have different heights while holding their slopes constant).

ANALYSIS FOR ORDNANCE

Supply was a problem for ordnance as for electronics, but growing needs for off-ship repair contributed almost as much to the rise in mean downtime. These findings are developed in tables 7A-7F.

TABLE 7A

AVERAGE VALUES OF PERCENTAGES OF ACTIONS: ORDNANCE (percent)

	Parts	No parts	Total
Non-deferred	61.6	4.3	65.9
Deferred, backlog	1.5	1.1	2.6
Parts	22.8	1.2	24.0
Repair	5.3	2.2	7.5
Total	91.2	8.8	100.0

TABLE 7B

AVERAGE VALUES OF DELAY TIMES: ORDNANCE (days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	6.1	6.8	7.2
Deferred, backlog	90.0		45.3
Parts	50.0	65.8	95.8
Repair	41.2	83.5	132.4

As with electronics, over 90 percent of all actions needed parts (table 7A), and about 25 percent of these were deferred for parts. Deferrals again took much longer (table 7B).

In table 7C we see a shift from non-deferred actions to deferrals for both parts (a 2.6 percent annual rise), and repair (1.7 percent). Just as for electronics, parts deferrals rose in MDT (7.5 - 1.0, or 6.5 days from table 7D), but not due to growing MSRT for unexplained reasons. Repair deferrals not needing parts also increased in time, by 18.9 days yearly. The estimated decrease in MDT for backlog deferrals is uncertain, being based on only 15 data points.[1]

[1] The rises in MSRT for non-deferred ordnance actions during 1970-73 may have been related to increases in the number of parts per action needing parts, which rose by 17 percent yearly (average value of 2.0 parts per action during the period). Even if the time between discovery of the action and delivery of each part were governed by the same probability distribution, actions needing more parts would have larger expected delays until delivery of the last one (MSRT). In reality, sequential ordering, which is due to imperfect diagnosis, means that additional parts have larger times. For HM&E actions analyzed next, the number of parts per action rose even faster, by 37 percent yearly (average value of 3.9 parts per action). There was no upward trend for electronics actions (average of 2.2 parts per action).

TABLE 7C

TRENDS IN PERCENTAGES OF ACTIONS: ORDNANCE
(Annual change in percentage points)

	Parts	No parts
Non-deferred	-2.5	-1.6
Deferred, backlog	-.1	-.2
Parts	2.6	.3
Repair	1.5	.2

TABLE 7D

TRENDS IN DELAY TIMES: ORDNANCE
(Annual change in days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	4.5	-2.1	2.9
Deferred, backlog	-44.6		-2.4
Parts	-1.0	7.5	15.2
Repair	-43.0	41.3	18.9

The rising deferrals for parts and repair both made large contributions toward the yearly growth in overall MDT: 3.01 and 2.13 days, respectively (table 7E). Subtracting the .44-day reduction for non-deferred actions (split proportionally between parts and repair deferrals[1]), these shifts accounted for 2.75 and 1.95 days, or 35 and 25 percent of the 7.8-day rise in overall MDT.[2]

Supply had no further effect through increased waiting time: the sum of the MSRT entries in table 7F is negligible (positve or negative, depending on how much of the -.67 entry is MSRT, and how much MADT).

TABLE 7E

CHANGE IN OVERALL MDT DUE TO TRENDS IN PERCENTAGES OF ACTIONS: ORDNANCE
(annual change in days)

	Parts	No parts
Non-deferred	-.32	-.12
Deferred, backlog	-.06	-.09
Parts	3.01	.29
Repair	1.87	.26

TABLE 7F

CHANGE IN OVERALL MDT DUE TO TRENDS IN DELAY TIMES: ORDNANCE
(annual change in days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	2.8	-1.29	.12
Deferred, backlog	-.67		-.03
Parts	-.23	1.71	.18
Repair	-2.29	2.20	.42

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[1] Because the yearly trend in parts deferrals was 50 percent higher than the trend for repair deferrals, we divided the .44 days using the same ratio, obtaining .26 and .18 days.

[2] We will refer to repair deferrals in general terms as a repair problem, even though hands-on repair times aboard ships and tenders are negligible. Repair deferrals take long to complete because of such diverse factors as waiting for tenders or other off-ship assistance, parts delays experienced by the tender, and delayed close-out of the action by the ship's force due to work backlogs. No matter what the basic causes for repair deferrals are, they would not have contributed to increases in MDT during 1970-73 unless more actions were needing off-ship assistance, and this increase reflects a repair problem in that fewer actions can be repaired by the ship.

ANALYSIS FOR HM&E

Off-ship repair, which was a minor problem for electronics and a roughly equal partner with worsening supply for ordnance, is the major offender in the case of HM&E. Over 39 percent of these actions were deferred for off-ship repair (table 8A), compared with only 3.5 percent and 7.5 percent for the other kinds of equipment. The shift in actions (table 8C) is from non-deferred to repair deferrals almost exclusively, and these repairs are taking much longer each year (table 8D). (There is a large and unexplained rise in MDT for parts deferrals which did not need parts.)

TABLE 8A

AVERAGE VALUES OF PERCENTAGES OF ACTIONS: HM&E (percent)

	Parts	No parts	Total
Non-deferred	32.0	7.7	39.7
Deferred, backlog	1.9	1.9	3.8
Parts	16.7	.7	17.4
Repair	28.7	10.4	39.1
Total	79.3	20.7	100.0

TABLE 8B

AVERAGE VALUES OF DELAY TIMES HM&E (days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	4.0	13.8	8.0
Deferred, backlog	74.8		217.1
Parts	38.9	70.6	130.5
Repair	66.7	55.4	106.2

TABLE 8C

TRENDS IN PERCENTAGES OF ACTIONS: HM&E (annual change in percentage points)

	Parts	No parts
Non-deferred	-6.3	-3.4
Deferred, backlog	0.4	0.3
Parts	0.5	0.2
Repair	5.6	2.8

TABLE 8D

TRENDS IN DELAY TIMES: HM&E (annual change in days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	-1.3	13.9	7.0
Deferred, backlog	31.7		-66.0
Parts	1.7	-4.3	30.0
Repair	9.7	9.1	15.0

Approximately 40 percent of the 20.8-day annual rise in overall MDT (tables 8E and 8F) is due to shifts toward repair deferrals (6.83 + 2.97 - 1.12 - .27 days per year). Increasing downtimes for repair deferrals is responsible for another 20 percent (2.61 + 1.56 days). Only 15 percent of the total MDT increase is due to rising MSRT, and even this is probably high: the 2.78 days between discovery and last parts issue (MSRT) for repair deferrals might not really be a supply problem, but due to longer waits for tender availability.

TABLE 8E

CHANGE IN OVERALL MDT DUE TO TRENDS
PERCENTAGES OF ACTIONS: HM&E
(annual change in days)

	Parts	No parts
Non-deferred	-1.12	-.27
Deferred, backlog	.30	.65
Parts	.55	.26
Repair	6.83	2.97

TABLE 8F

CHANGE IN OVERALL MDT DUE TO TRENDS
IN DELAY TIMES: HM&E
(annual change in days)

	Parts		No parts
	MSRT	MADT	MDT
Non-deferred	-.41	4.45	.54
Deferred, backlog	.61		-1.26
Parts	.28	-.72	.22
Repair	2.78	2.61	1.56

POLICY IMPLICATIONS

There is clearly a problem with applying historical analysis to current times. The fact that reliability was a major problem for electronics equipment during 1970-73 does not necessarily mean that it remains so today. If reliability has improved markedly in the intervening years, further spending improvements might have relatively less effect.[1]

There is no way to avoid the "caveat" that the validity of the recommendations presented in this section depends on things not having changed much since 1973.

Before discussing the implications of our findings for allocation of the material support budget, we want to make 2 general observations based on our analysis. First, we have shown that it is possible to compare the relative contributions of reliability, repair, and supply to overall material condition in a single coherent analysis.[2] Although separate studies in the area of supply, for example, are the appropriate way to measure the relative merits of various programs to get parts to the Fleet, supply programs must ultimately be compared with improvements in reliability and repair if the Navy is to achieve the most improvement in material condition per dollar spent on support.

The second broad conclusion from our research is that no single factor was responsible for the 1970-73 reductions in material condition of all 3 types of equipment. Electronics equipment suffered from deteriorations in both reliability and supply (growth in deferrals for parts). Ordnance suffered much more from worsening reliability, and the smaller increases in MDT came from growing deferrals for both parts and repair. HM&E suffered little from declining reliability, and its moderate increases in MDT were due almost solely to growing problems with repair.

We turn now to more specific statements about the material support budget. As we mentioned in the Introduction, our analysis offers little help in choosing among individual line items: it is carried out at too high a level of aggregation, and lacks consideration of costs so necessary in comparing programs.

Our findings do, however, have some implications for broad apportionments between major areas of support, that are made during yearly budget preparation. Most of these decisions must be made, in today's world, without analytical support because detailed program comparisons based on cost and effectiveness are too few in number and limited in scope. Even with its limitations, our research may provide some "suggestions for emphasis."

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[1]If reliability, repair, and supply all improved at the same rate, material condition would be higher and thus less needful of change compared to other broad areas of total Navy capability, but the relative contributions of these factors to improved material condition might be unchanged.

[2]Note that although we have reported these calculations for broad classes of equipment, the analysis can be (and was) carried out for individual APLs.

For help in drawing out these implications, we need to view the budget as divided into the major functional areas we have studied: reliability, repair, and supply. An earlier task of the Material Support Study (reference 3) showed by example that the line items of the support budget could be re-grouped under the 7 functional categories shown in table 9. Each category contributes to one of the 3 major components of operational availability: reliability, repair, and supply.

TABLE 9

COMPONENTS OF MATERIAL CONDITION (A_0)

Reliability

1. Reliability improvement
2. Replace before failure

Repair

3. Repair probability
4. Repair time

Supply

5. Supply availability
6. Supply time
7. Resupply time

Reliability can be upgraded by basic improvements in design or by diagnosing imminent failures where possible. (Past study shows that periodic replacement of electronic equipment is generally counter-productive.) Repair capability is described by the percentages of failures that can be repaired at each echelon and the associated repair times. Supply variables are the fractions of parts available at each echelon, the associated waiting times for delivery to ships, and the time that the forward supply echelons themselves must wait for rework of repairables by depot-level facilities.[1]

Using this conceptual framework, we can translate our findings into "suggestions for emphasis" in apportioning the support budget.

ELECTRONICS

Programs that improve reliability are worthy of attention; our analysis provides no insight into the best ways of doing this.

[1]Resupply time is really an input to supply time.

Increased funding of supply programs that reduce the percentage of actions that are deferred for parts would also help significantly to improve material condition. Such programs occur in all 3 supply areas shown in table 9. Greater availability of parts onboard ship and at intermediate echelons of supply would reduce the need for supply from the Inventory Control Point, and thus avoid the longer waiting times associated with this echelon. Perhaps even more importantly, buying more parts, no matter where they are stocked, would reduce the need for placing new orders to fill the requests of ships, and thus avoid the procurement delays that can take the better part of a year to fill (see appendix H). Programs to reduce the waiting time for parts from rear echelons (e.g., second destination transportation) might also help to reduce the deferrals for parts. Finally, stocking more repairables at shipyards would avoid the need for ships to wait until failed parts can be reworked and returned.

Reducing the percentage of actions deferred for repair is less critical. Repair deferrals were relatively few, increased little in time, and hands-on repair times are small.

ORDNANCE

Programs to improve reliability are probably of major importance. Increasing the ability of ships to make their own repairs must be emphasized if long delays associated with repair deferrals are to be avoided. Improving the actual, hands-on times to make these repairs at the organizational and intermediate levels is probably much less important.

HM&E

Programs to increase shipboard ability to make repairs are critical.[1] Reducing the wait for tender availability would also help.

TRADEOFFS BETWEEN DIFFERENT CLASSES OF EQUIPMENT

Regarding budgetary allocations among electronics, ordnance, and HM&E, our finding that A_0 declined equally for each class implies no preference for any one.

[1]This could be a "lost cause" if the increased repair deferrals were due to installation of new equipment requiring extensive repair facilities available only at the depot level.

RECOMMENDED IMPROVEMENTS IN THE 3-M REPORTING SYSTEM

Throughout this paper we have mentioned our problems in using 3-M data -- more exactly, MDCS data on corrective maintenance -- to measure material condition. This section will discuss changes which might alleviate some of these problems. We will start with some general points before moving to specifics.

GENERAL

As with any reporting system, the 3-M system should be designed to generate information for making decisions. In thinking about ways to improve its usefulness, we should be clear on what kinds of decisions the information is to support, and what data is relevant. On the "source" side, there are the costs and incentives of reporting (gathering and transmitting) the needed data.

Overall, there is the guiding principle that if the reporting costs exceed the benefits realized through better decisions, we have gone too far (or in the wrong direction). Judging where to stop is not, of course, an easy task. The costs of collecting data can be measured with enough time and effort, but measuring the value of the information is more than anyone knows how to do at present.

Even so, some of the problems in using the 3-M system clearly occur because the needs of those who analyze the data have in some cases been forgotten.[1] Consider, for example, the ordering of parts. The "1348" requisition forms tell the supply system what parts to send to what ships. But to make yearly budgetary decisions on what parts to buy, where to stock them, and how much to spend on transportation of parts to the Fleet, analysts must be able to monitor past trends in parts availability at the various echelons of supply, and the associated waiting times between order and delivery.

However, the supply data to make these calculations are not reported under 3-M. Issue dates are included, but not order dates. And there is no information on where parts come from.

These supply data are, of course, kept by other reporting systems (e.g., ACCESS) but it is not easy to integrate them with maintenance data on an action-by-action basis.

For another example, take the need for off-ship repair assistance. To obtain the help of "tech reps," ships send the appropriate messages. But Washington-based budget analysts must decide every year how much to fund such activities; and the number of visits that "tech reps" make, the lengths of time they spend, and the parts they bring with them are not reported.

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[1] The difficulties we are discussing are present in the current versions of MDCS, as well as in the version in use during the early 1970s when our data was generated.

Some problems are due not to poor design of the reporting system, but to failure to provide enough incentives to make the system work. Because Navy people aboard ship are directly responsible for the material condition of their ship, they need no additional incentive to do the paper work to obtain parts or off-ship repair assistance. Data on "2-Kilo" forms, however, may have no effect on Fleet readiness for several years (and on somebody else's "watch"); there are long time lags between data submission, analysis, budget action, and resultant changes in parts stockage, repair facilities, maintenance personnel, etc. This situation must be a prime reason for the incomplete and incorrect data we found on 3-M records, which play no role in organizing repair and supply activity in "real" time.

But the problem is not hopeless. In the aircraft maintenance area, supply action is initiated by the 3-M forms themselves. There are enlisted men in the AZ rating whose principal job is to prepare status reports on material condition for the commanding officer. Officers assigned to the Aircraft Maintenance Department supervise the maintenance work and data collection. This system provides the Commanding Officer with continual feedback on how well aircraft repair and supply tasks are being performed.

The surface Navy might also benefit from having people aboard ship who are specifically dedicated to <u>providing information</u> on maintenance to the operational command. At present, center supervisors on ships are responsible for making sure that 3-M forms are filled out, as well as getting the work done; but the forms are not used by the ship to check on itself. They are more burden than benefit.

One problem area has to do with changes to reporting systems. In designing a new system, it is difficult to know beforehand the value of various kinds of data, and the burden of collecting them. Adopting an initial system and then modifying it as experience accumulates may provide a good system in the long run. But short term disruptions may result, and if changes continue to be made, the long run never arrives.

For example, the introduction of selected reporting in 1970 (see appendix E) probably arose out of a feeling that the 3-M reporting burden on the Fleet had grown unacceptably large. From then on, full reporting was to continue on only those equipments on a Selected Equipment List (SEL), for which more information was most needed. The list included old items in the worst shape, and new equipments for which operational data had not been established.

But the 1970 (and subsequent) changes also made it harder to compare maintenance statistics before and after the change.[1] Although we have estimated the direction of

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[1] They also contributed to a deterioration in the quality of the data by creating confusion among shipboard 3-M documentors as to what actions were to be reported; a NavMMACLANT study (reference 6) found that during 1973, only 30 percent of shipboard documentors were fully up-to-date on reporting guidance.

the biases which the changes created in our calculations, there is no way to determine precisely how much of the measured trends in MTBF, MDT, and A_o are due to reporting changes.

The 1970 changes illustrate another point, the value of a graduate reporting system. Equipments with growing problems as indicated by the limited information collected at one level, move to a higher level involving more intensive data collection. Under selected reporting, there was a need for some way of knowing when an equipment became "sick" enough to justify full reporting. The full reporting of parts issues ("1250" forms) and of all actions deferred for off-ship repair assistance may have been intended to provide this signal; when the number of parts or actions reached a certain point, the equipment could be included in the SEL. But growing deferrals for backlog and parts also mean increased needs for special attention. Full reporting for these types of actions may have been rejected in 1970 to minimize the reporting burden, but information was sacrificed in the process.

We have made these general observations for any help they may give to current efforts to redesign the 3-M system. We are not able to transform these observations into specific recommendations for major changes. First, this would require a systematic look at all information on reliability, repair, and supply that the Fleet generates. The data we have analyzed is not the totality of all such information.

Second, the 3-M data that we did examine might be useful for purposes other than carrying out the kind of analysis we have done. Shipboard data can be used in studies of: how many parts to buy and where to position them; how many tenders and other IMA (Intermediate Maintenance Activity) resources to buy, where to position them, and how to schedule them; what systems need design fixes to improve reliability.

However, these decisions all depend, to some extent, on the same general kinds of data; and because there are several systems that now provide this data (different "sources"), it is possible that a fresh, comprehensive "source-use" analysis would be profitable. We will, however, list here our major problems with using the data we had, to carry out the kind of analysis we attempted.

SPECIFICS

We have not been able to determine where actions deferred for off-ship repair assistance have been handled. The combatant lists requested availability (e.g., IMA, TSU,[1] depot) on the deferral form, but the place where the work was really done was filled out only for 30 percent of the actions. We have no idea where the remaining off-ship repair work was done.

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[1] Type Commander Support Unit.

There is another problem with repair deferrals: we know when the off-ship repair work was completed, but not how long it took thereafter for the ship's force to start the final work to complete the action. The time between completion by a tender and final close-out (a time we were able to measure), could be due to waiting for the end of tender availability, work backlog aboard the combatant, or even delivery of final parts.

We similarly could not determine from the data what supply echelon produced parts not found on the ship.[1] Equally important, our supply data lacked the dates on which these parts were ordered. For these reasons, we could not measure the extent to which reductions in spending for parts lengthened how far back in the system the ships had to go for parts, and the extra penalty they paid in increased waiting time.

To remedy these problems without changing the character of the 3-M system, 3-M forms could be expanded to state which echelons contribute repair and supply support for each action. A full accounting would include not only major echelon -- organizational, intermediate, and depot -- but also what physical agency was used: whether intermediate-level repair, for example, was provided by tech reps, tender, etc.; and whether off-ship supply parts were provided by an AFS, NSC, etc.

Supply data should include order dates for each part, along with issue dates.

Even if many of these data can be found in one place or another, it is costly to gather and integrate the large quantities needed to provide good statistical results;[2] and inconsistencies are common. Moreover, the diversity of sources cannot be completely justified on the grounds that different users have different requirements for data. Most analyses of reliability, repair, and supply have the same general goal: to monitor material condition and find out why it may have fallen in order to plan remedial action.

[1] Parts not onboard were responsible for more than the 17-22 percent of actions deferred for parts. Actions needing parts available from other ships and supply centers with "reasonable" delay (under 30 days, say) might not be deferred (at least for parts).

[2] For best results, different variables describing the same action should be brought together using Job Control Numbers.

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APPENDIX A

SHIP SAMPLE

TABLE A-1

SHIP SAMPLE

Ship type	Hull no.	UIC	Date of commissioning	Overhaul dates during period of analysis
DD	0714	04314	9/1945	7/1/71-10/1/71
DD	0715	04315	11/1945	9/8/71-12/8/71
DD	0716	04316	1/1946	8/25/71-11/15/71
DD	0717	04317	3/1946	5/15/72-9/15/72
DD	0719	04319	3/1949	4/24/72-9/8/72
DD	0724	043[illegible]4	2/1944	7/1/71-10/1/71
DD	0743	03843	12/1944	6/2/72-11/8/72
DD	0782	03882	3/1945	1/14/70-4/15/70; 4/1/74-7/16/73
DD	0783	03883	4/1945	10/24/69-1/23/70; 8/9/72-11/9/72
DD	0785	03885	8/1945	3/6/72-6/23/72
DD	0786	03886	10/1945	5/21/73-8/21/73
DD	0788	03888	3/1946	9/27/71-2/22/72
DD	0789	03889	7/1946	9/20/71-1/10/72
DD	0821	52121	10/1945	5/9/72-8/25/72
DD	0822	52122	10/1946	9/6/72-2/8/73
DD	0824	52124	7/1949	8/17/71-11/24/71
DD	0825	52125	12/1946	10/13/68-2/13/70; 9/15/72-1/31/73
DD	0826	52126	6/1946	7/25/72-12/15/72
DD	0841	52141	11/1945	7/3/72-10/18/72
DD	0842	52142	11/1945	3/15/62-7/14/72
DD	0843	52143	12/1945	9/15/71-1/17/72
DD	0844	52144	1/1946	7/1/71-11/8/71
DD	0845	52145	2/1946	6/25/73-9/25/73
DD	0846	52146	3/1946	9/20/71-1/17/72
DD	0853	52153	9/1946	7/1/71-10/8/71
DD	0864	52164	6/1946	11/3/69-3/2/70; 2/1/73-7/27/73
DD	0866	52166	8/1945	1/18/72-5/1/72
DD	0868	52168	11/1945	9/8/71-1/19/72
DD	0871	52171	4/1946	9/18/72-1/31/73
DD	0873	52173	2/1945	3/15/72-6/15/72
DD	0876	52176	3/1945	4/6/72-8/25/72
DD	0878	52178	4/1945	7/5/72-11/30/72
DD	0883	52183	7/1945	9/1/72-1/15/73
DD	0931	52191	11/1945	11/30/71-4/14/72
DD	0933	52193	8/1957	2/15/72-5/19/72
DD	0942	52201	11/1957	2/24/70-7/28/70; 6/29/73-4/4/74
DD	0944	52203	3/1958	1/15/73-8/31/73
DD	0945	04661	6/1958	4/24/70-11/24/70; 4/29/74-4/30/75
DD	0946	04662	11/1958	5/31/72-11/3/72
DD	0951	04667	8/1959	2/29/72-8/11/72
DDG	0004	04670	11/1960	9/7/71-7/6/72
DDG	0005	04671	2/1961	3/5/70-9/4/70; 4/1/74-12/24/74
DDG	0006	04672	5/1961	12/1/69-5/29/70; 4/19/74-2/28/75

TABLE A-1 (Cont'd)

Ship type	Hull no.	UIC	Date of commissioning	Overhaul dates during period of analysis
DDG	0007	04673	11/1960	7/8/70-12/18/70; 10/4/73-8/27/74
DDG	0008	04674	4/1961	9/19/69-3/19/70; 7/18/72-1/26/73
DDG	0009	04675	1/1961	2/20/70-7/10/70; 6/26/73-6/27/74
DDG	0010	04676	4/1961	1/4/72-5/4/72
DDG	0011	04677	9/1961	3/27/70-10/8/70; 6/27/74-5/13/75
DDG	0012	04678	8/1961	10/1/69-7/19/70; 3/14/73-1/11/74
DDG	0013	04679	12/1961	7/14/71-12/31/71
DDG	0015	04681	12/1962	1/11/73-11/1/73
DDG	0018	04684	12/1962	8/3/70-3/16/71; 1/17/74-12/17/74
DDG	0020	04686	11/1963	9/15/69-3/13/70; 3/4/74-3/20/75
DDG	0021	04687	3/1964	2/20/70-7/20/70; 6/4/73-3/8/74
DDG	0033	04665	11/1967	11/17/70-4/7/71; 6/28/74-3/5/75
DDG	0034	04663	2/1968	8/9/71-12/3/71
DDG	0035	52227	6/1968	10/3/69-4/1/70; 3/14/72-9/1/72
DDG	0036	52228	6/1969	6/15/70-9/22/70; 2/1/73-8/8/73
DE	1036	54034	3/1960	9/1/71-12/1/71
DE	1037	54035	6/1963	10/22/71-5/15/72
DE	1040	54037	12/1964	2/5/72-8/15/72
DE	1041	54038	4/1965	11/20/71-7/2/72
DE	1043	54039	2/1965	7/6/72-4/6/73
DE	1044	54040	8/1965	7/9/71-4/27/72
DE	1045	54041	12/1965	6/2/69-1/15/70; 3/15/73-12/9/73
DE	1049	54044	6/1967	8/18/70-12/23/70; 6/28/74-3/20/75
DE	1051	54046	7/1968	1/12/72-6/16/72
DE	1052	54047	4/1969	10/8/69-1/18/70; 6/8/72-11/28/72
DE	1053	54048	1/1970	11/14/69-1/31/70; 6/1/70-8/7/70; 3/25/74-10/18/74
DE	1054	54049	4/1970	9/14/70-11/8/70; 6/28/74-4/17/75
DE	1055	54050	7/1969	2/12/70-4/29/70; 3/5/73-10/5/73
DE	1056	54051	8/1969	6/8/70-7/20/70; 11/9/73-6/28/74
DE	1057	54052	6/1970	9/11/67-5/8/70; 11/23/70-1/15/71; 9/1/73-4/22/74
DE	1058	54053	2/1970	11/21/69-1/27/70; 7/6/70-9/10/70; 10/16/73-7/16/74
DE	1060	54055	6/1970	3/23/70-5/4/70; 10/1/70-12/8/70; 7/2/73-3/29/74
DEG	0001	04692	3/1966	8/20/70-2/19/71; 1/15/74-11/25/74
DEG	0002	04693	6/1967	7/6/70-3/8/71; 10/15/73-7/7/74
DEG	0003	04694	4/1968	1/15/70-3/2/70; 9/10/71-6/5/72
DEG	0004	04695	4/1967	2/15/73-12/20/73
DLG	0006	52231	4/1960	1/27/70-3/11/70; 10/5/70-3/15/71; 11/5/73-1/24/75
DLG	0015	52686	5/1960	6/26/70-7/1/70; 12/18/70-2/18/71; 6/24/74-4/25/75

TABLE A-1 (Cont'd)

Ship type	Hull no.	UIC	Date of commissioning	Overhaul dates during period of analysis
DLG	0016	52687	8/1962	11/7/72-5/9/73
DLG	0017	52688	12/1962	2/10/70-4/7/70; 4/8/74-4/10/75
DLG	0021	52692	1/1963	9/10/68-1/9/70; 1/12/70-2/24/70; 7/13/70-10/4/70; 2/1/73-11/21/73
DLG	0024	52699	2/1963	6/29/70-8/14-70; 1/22/71-3/22/71; 11/19/73-10/18/74
DLG	0026	52701	11/1964	3/27/72-11/13/72
DLG	0027	52702	5/1965	9/6/73-5/22/74
DLG	0028	52703	1/1966	8/18/69-2/16/70; 9/10/73-6/19/74
DLG	0031	52706	4/1967	10/15/70-3/23/71; 2/1/74-12/19/74
DLG	0032	52707	7/1966	11/20/79-5/20/70; 1/23/73-8/28/73
DLG	0033	52708	5/1966	12/4/73-10/31/74

APPENDIX B

APL SAMPLE

TABLE B-1

APL SAMPLE

	Electronic APLs	Predominant EIC*
1	49401930	MK 72 signal data converter
2	49402524	AN/SPG-51C radar
3	49402624	MK 56 gun director
4	49402955	AN/SPG-51C radar
5	56982411	AN/SPA-25A indicator group
6	56995305	AN/SPG-53A radar
7	56998500	AN/SPG-55B radar
8	56998750	AN/SPG-55B radar
9	57036630	AN/SPS-10F radar
10	57039650	AN/SPS-40A radar
11	57040405	AN/SPS-48A(V) radar
12	57091316	AN/SQS-23D detecting/tracking
13	57091613	AN/SQS-26CX detecting/ranging
14	57112000	AN/SRC-20 radio
15	57112100	AN/SRC-21 radio
16	58138242	AN/UGC-6K TTY page printer
17	58139025	AN/UGC-25A TTY page printer
18	58139029	AN/UGC-20A teletypewriter
19	58393723	AN/UPX-23 interrogator
20	58439716	AN/URC-9 receiver-transmitter
21	58614207	AN/USM-116C elect. multimeter
22	58614308	AN/USM-117C oscilloscope
23	58627081	AN/USM-281 oscilloscope
24	58841200	AN/VRC-46 radio
25	58981717	AN/WLR-1C receiving set
26	59010200	AN/WRT-2 transmitting set
27	78044353	AN/SYA data display group
28	78044355	AN/SYA data display group
29	78049081	AN/UYA data display group
30	81039001	R-390A/URR MF receiver
31	81095100	R-1051/URR radio receiver
32	81095102	R-1051B/URR radio receiver
33	92601290	TSEC/KWR-37 cryptographic equipment
34	92601500	TSEC/KW-7 cryptographic equipment

*That EIC (Equipment Identification Code) associated with the most failures of the APL on a Navy-wide basis during 1975, according to Fleet Material Support Office (FMSO) Navy Maintenance & Material Management Information System Report No. MSO 4790.S2711-01, Logistics High Failure Equipments, 8 Jan 76. None of the APLs in our sample are described by nomenclature in this reference.

TABLE B-1 (Cont'd)

	Ordnance APLs	System Associated With:*
1	004020001	Tartar launching equipment
2	004020006	Tartar launching equipment
3	004120004	Terrier launching equipment
4	005000001	ASROC fire control equipment
5	005000002	ASROC fire control equipment
6	005020002	ASROC launching equipment
7	005020017	ASROC launching equipment
8	005020021	ASROC launching equipment
9	006020038	Gun mounts, MK 108 rocket launcher
10	006020046	Gun mounts, MK 108 rocket launcher
11	006030015	Gun mount, 5"/54 MK 42 Mod 9
12	006320222	Torpedo tube submerged and A.W. launchers

	HM&E APLs	System Associated With:*
1	021200007	Boilers
2	021200008	Boilers
3	021200163	Boilers
4	021200167	Boilers
5	057800081	Turbines
6	057800174	Turbines
7	061900224	Compressors
8	061900264	Compressors
9	252360005	Gyro compass equipment
10	252360019	Gyro compass equipment
11	267000006	Projection equipment
12	666010147	Engines
13	667770002	Engines
14	910010118	Laundry equipment

*Ships Parts Control Center (SPCC) COSAL Introduction, appendix C.

APPENDIX C

POPULATION DATA

TABLE C-1

APL POPULATION DATA

	E				O				HMGE			
APL	No. of Ships With APL On Board[b]	Total No. of Units[b]	No. of Ships Reporting Actions[c]	Intersection (Ships/Units)[a]	No. of Ships With APL On Board[b]	Total No. of Units[b]	No. of Ships Reporting Actions[c]	Intersection (Ships/Units)[a]	No. of Ships With APL On Board[b]	Total No. of Units[b]	No. of Ships Reporting Actions[c]	Intersection (Ships/Units)[c]
1	4	6	12	3/5	10	10	10	9/9	17	34	26	17/34
2	18	29	22	18/29	4	4	4	4/4	17	34	23	17/34
3	6	6	21	6/6	4	10	4	4/10	1	4	2	1/4
4	8	18	9	2/6	18	18	26	18/18	3	12	5	3/12
5	26	81	21	20/69	50	51	53	48/49	25	200	33	25/200
6	24	24	28	24/24	15	60	40	15/60	7	21	8	7/21
7	2	12	11	2/12	36	37	39	33/33	9	18	9	9/18
8	11	27	8	8/19	36	147	36	33/131	9	20	10	9/20
9	26	33	31	26/33	14	40	13	9/30	26	26	32	25/25
10	3	4	10	3/4	8	14	10	7/13	22	39	24	21/37
11	11	16	9	8/12	7	7	9	7/7	31	80	28	22/65
12	28	42	38	28/42	71	144	81	69/140	38	47	39	34/41
13	8	11	11	8/11					59	60	47	40/40
14	84	347	91	84/347					59	62	57	33/36
15	82	232	88	80/228								
16	50	128	49	42/114								
17	77	464	74	68/425								
18	43	103	33	32/84								
19	38	130	13	13/57								
20	71	275	77	66/261								
21	58	281	62	51/262								
22	72	419	73	64/397								
23	53	123	68	44/109								
24	48	90	56	43/77								
25	14	20	39	12/17								
26	62	149	73	62/149								
27	7	57	7	7/57								
28	7	51	7	7/51								
29	5	68	5	5/68								
30	78	241	76	68/220								
31	63	364	76	60/355								
32	72	498	70	64/479								
33	83	219	83	78/208								
34	34	52	81	22/50								

[a] Number of ships reporting actions which have units on board; number of units on those ships.

[b] As of October 1975, according to Weapon System Master File.

[c] During period of analysis.

APPENDIX D

MDCS DATA

TABLE D-1

DATA REPORTED ON MDCS FORMS

General Characteristics of Action

- UIC (Unit Identification Code of ship or organization (e.g., tender, shore base providing off-ship repair assistance)
- EIC (Equipment Identification Code of equipment)
- APL (Allowance Parts List number of equipment)

Ship Status When Action Discovered (When discovered code)
- Starting up
- Operations
- PMS/SOT
- Inspection

Condition of Item When Action Discovered (When discovered code)
- Non-operational
- Reduced capability
- Operational
- No malfunction

Priority Assigned to Action
- Urgent
- Impaired
- Routine
- Convenience

Deferred Action Taken
- Non-deferred
- Deferred
  - Backlog
  - Parts
  - Repair

Repair Action Taken
- Repaired, no parts
- Repaired, parts
- Rejected
- Not completed
- Overhauled
- Cancelled
- Services
- Configuration change

Repair UIC
- AD
- AR
- Combatants
- Shore facilities
  - FMAG, San Diego
  - Other

Completed Action Taken
- Repaired, no parts
- Repaired, parts
- Cancelled
- Overhauled
- Bench repair
- Configuration change

Condition of Item When Action Completed (Completed status)
- Non-operational
- Reduced Capability
- Operational
- No malfunction

Time Characteristics

Duration and Hands-on Repair Time for All Phases

Non-Deferred
- Phase I: Discovery to completion

Deferred for Backlog or Parts
- Phase I: Discovery to deferral
- Phase II: Deferral to completion

Deferred for Repair
- Phase I: Discovery to deferral
- Phase II: Deferral to completion of off-ship assistance
- Phase III: Completion of off-ship work to close-out by ship

TABLE D-2

DESCRIPTIVE STATISTICS ON ACTION CHARACTERISTICS[a]

Variable	Electronics (43212 total actions) Number Reporting	Percent	Ordnance (9823 total actions) Number Reporting	Percent	HM&E (6601 total actions) Number Reporting	Percent
SHIP STATUS WHEN ACTION DISCOVERED	37887		8173		5555	
Starting up	3377	8.9	441	5.4	363	6.5
Operations	20737	54.7	2582	31.6	2396	43.1
PMS/SOT	7824	20.6	2436	29.8	728	13.1
Inspection	5949	15.7	2714	33.2	2068	37.2
CONDITION OF ITEM WHEN ACTION DISCOVERED	40265		8624		5822	
Non-operational	13521	33.6	1368	15.8	1398	24.0
Reduced capability	15816	39.2	3110	36.1	2404	41.3
Operational	9715	24.1	3706	42.9	1805	31.0
No malfunction	1213	3.0	440	5.1	215	3.7
PRIORITY ASSIGNED TO ACTION	15131		5483		4605	
Urgent	201	1.3	52	.9	162	3.5
Impaired	3265	21.6	863	15.7	2093	45.4
Routine	11261	74.4	4350	79.3	2254	48.9
Convenience	404	2.7	218	4.0	96	2.1
DEFERRAL ACTION TAKEN	43212		9823		6601	
Non-deferred	28134	65.1	4384	44.6	1967	30.0
Deferred	15078	34.9	5439	55.4	4634	70.0
Backlog deferrals	2602	17.3	928	17.1	698	15.1
Parts deferrals	7872	52.2	2765	50.8	645	13.9
Repair deferrals	4604	30.5	1746	32.1	3291	71.0
REPAIR ACTION TAKEN[b]	1506		421		944	
Repaired, no parts	646	42.9	209	49.6	314	33.3
Repaired, parts	562	37.3	88	20.9	447	47.3
Rejected	78	5.2	36	8.5	59	6.2
Not completed	44	2.9	3	.7	8	.8
Overhauled	62	4.1	7	1.7	29	3.1
Cancelled	83	5.5	33	7.8	58	6.1
Services	28	1.8	42	9.9	25	2.6
Configuration change	3	.2	3	.7	4	.4

TABLE D-2 (Cont'd)

REPAIR UIC	1519		602		856	
AD	1395	91.8	545	90.5	787	91.9
AR	22	1.4	12	1.9	18	2.1
Combatants	14	.9	13	2.2	20	2.3
Shore facilities						
FMAG, San Diego	82	5.4	27	4.5	27	3.2
Other[c]	6	.4	5	.8	4	.5
COMPLETED ACTION TAKEN	39282		8308		5414	
Repaired, no parts	3681	9.4	1181	14.2	1657	30.6
Repaired, parts	33204	84.5	6319	76.1	3161	58.4
Cancelled	925	2.3	603	7.2	165	3.0
Overhauled	1114	2.8	132	1.6	368	6.8
Bench repair	70	.2	24	.3	18	.3
Configuration change	288	.7	49	.6	45	.8
CONDITION OF ITEM WHEN ACTION COMPLETED	41033		8730		5898	
Non-operational	384	.9	81	.9	72	1.2
Reduced capability	453	1.1	188	2.1	119	2.0
Operational	40034	97.6	8412	96.3	5658	95.9
No malfunction	162	.4	49	.6	49	.8

[a] Data for all actions, including non-failures, and those actions without corresponding populations as shown in table 1 of the text.

[b] For off-ship repair assistance, if used.

[c] MOTU 13, NavShipRepFac Yokosuka, NavSeaCenLant, NavSubBase Pearl Harbor.

APPENDIX E

CHANGES IN 3-M REPORTING REQUIREMENTS

APPENDIX E

CHANGES IN 3-M REPORTING REQUIREMENTS

The 3-M[1] System contains an extensive amount of data. Analysis from the information derived from this system can be beneficial only if one is aware of the 3-M reporting requirements during the time frame for which the analysis is being done.

Policies and procedures for the management and reporting of ship maintenance for the operating force were implemented in March 1965 with the promulgation of OpNav 43P, Maintenance and Material Management (3-M) Manual. Since then, there have been major changes to the reporting policies. This appendix addresses these major changes, most of which pertain to selective reporting.

Prior to 1 January 1970 a maintenance action was defined as any corrective or preventive action taken to maintain equipment or material in a satisfactory condition. Thus, both preventive maintenance (PM) scheduled and completed at greater than weekly intervals and corrective maintenance (CM) were documented and reported to the processing center. After 1 January 1970 the ships were required to externally report only corrective maintenance and not preventive maintenance. PM documentation was now preserved only on the ship, possibly with a status report prepared for the Commanding Officer. The Equipment Identification Code (EIC) was changed from seven to four characters with very little if any connection between these two combinations.[2]

3-M documentation was placing a heavy administrative workload on the Fleet. In an effort to reduce this, the CNO appointed a review group to refine the management information system and enhance its overall effectiveness. The information was refined but whether the system became more effective is uncertain. The CNO put into effect the recommendation of the review group to the Fleet[3] in October 1970. Since implementation, this message, known as Z-gram 46, has stimulated the majority of changes in the 3-M reporting requirements which are described in the following paragraphs.

The Selected Equipment List identified by EIC certain items which were in most cases new or modified, for which reliability had not been established, or which were

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[1] Maintenance and Material Management

[2] For example, the EIC for a boiler was ZA08000 before 1 January 1970 and F101 after.

[3] CNO message 151927Z, Oct. 1970.

Note: This appendix was prepared by Cdr. Alan Sherman, USN.

proven unreliable. Corrective maintenance actions performed by ship's force on installed selected equipment would be exhaustively reported only by ships commissioned less than 20 years ago, by cruisers, and by other designated special case ships (hereafter referred to as SEL reporting ships). The non-SEL reporting ships included almost all FRAM I and FRAM II destroyers. In August 1973 Change Five to the Ships' 3-M Manual eliminated the requirement for reporting certain APLs for some of the EICs on the Selected Equipment List.

Non-Deferred Maintenance Actions performed on selected equipment by ship's force were reported routinely only by SEL reporting ships.[1] In addition the Fleet Commanders-in-Chief determined that all ships would report any maintenance action which was essential for inclusion in the material history. These actions were those which altered the design or operating characteristics of an equipment (installation of a field change, alteration, use of non-standard replacement parts, etc.).

Fleet Commanders-in-Chief further amplified the reporting requirements in Z-gram 46 to include deferred maintenance which when accomplished would modify the characteristics of an equipment or system and those which were essential to producing a comprehensive pre-InSurv package. Other maintenance defined for performance by ship's force was reported according to guidelines set down by the Type Commanders. For example, ComCruDesPac[2] did not require the reporting of maintenance which could be accomplished by ship's force within 30 days.

All maintenance deferred for performance by agencies external to the ship (IMAs, shipyards, etc.) continued to be reported by all ships.

Further variations in reporting requirements were also evident with InSurv discrepancies. ComCruDesPac required that all InSurv discrepancies (with an Insurv number) be documented; however, it was common practice with west coast ships not to report these discrepancies if they could be corrected within 30 days.[3] This was not the case for the east coast ships where sample checks were made on the status of their Insurv documentation.

Reduced 3-M reporting was not to affect submission of supply forms 1250 and 1348. In the case where reporting of maintenance actions was not required but reporting of associated material issues using form 1250 or 1348 was required, "Z000" was entered

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[1] Ships' 3-M Manual (OpNavInst 4790.4).

[2] ComCruDesPac Inst 4700.1A.

[3] The variation in InSurv reporting was recently discovered by the Board of Inspection and Survey from data provided by CNA.

in the job sequence number blocks and "GENERAL" entered in the EIC block to uniquely identify to the Maintenance Support Office those supply documents which were unaccompanied by a maintenance action report.

In May 1974 3-M reporting was further refined by designating selected ships to report on the selected equipments. The selected ships now included those older than 20 years which previously were not required to report selective equipments.

At a recent meeting on 3-M Project Intercept, it was agreed that the concept of full reporting of all maintenance for only selected equipment was still realistic; however, the sampling approach would be de-emphasized. Specific ships would no longer be designated to report on selective equipment. Rather, all ships would report all maintenance actions on those equipments that appear on the SEL. In addition, equipments would be allowed to remain on the SEL for at least three years.

In studies of corrective-maintenance-resource consumption which attempt to identify the main contributions to the corrective maintenance burden (manpower and cost), the analyst has to consider which items are on the SEL so as not to bias the man-hour and cost results.

APPENDIX F

A_o, MDT, AND MTBF BY APL

TABLE F-1

A_o BY APL
(Failures)

APL	Electronics 70	71	72	73
1				1.00
2	0	.73	.10	.41
3	.89	.81	.89	.36
4				1.00
5	1.00	.99	.99	.97
6	.62	.82	.72	.74
7		1.00	.87	.84
8			.88	.88
9	.94	.96	.95	.96
10	.91	.81	.44	.20
11			.92	.66
12	.85	.82	.80	.81
13	.89	.79	.63	.76
14	.89	.96	.89	.92
15	.94	.97	.91	.93
16	.99	.97	.94	.98
17	.98	.99	.96	.98
18	.99	.95	.91	.98
19	.99	1.00	.96	.91
20	.95	.95	.91	.94
21	.99	.99	.95	.97
22	.99	.98	.98	.98
23	.95	.89	.89	.90
24	.93	.97	.90	.94
25	.87	.97	.89	.80
26	.90	.94	.88	.93
27	.91	.99	.99	.98
28	.92	.99	1.00	.99
29	.87	.90	.96	.95
30	.94	.96	.97	.95
31	.96	.97	.95	.95
32	.99	.99	.96	.95
33	.95	.98	.96	.98
34	.88	1.00	1.00	.94

APL	Ordnance 70	71	72	73
1	.09	.86	.03	.25
2	.45	.64	.97	.73
3	.99	.94	.84	.98
4	.73	.87	.69	.69
5	.90	.98	.89	.90
6	.96		.95	.76
7	.81	.99	.51	.88
8	.97	.97	.88	.94
9	.99	.91	.98	.66
10	.99	1.00	.97	1.00
11	.99		.99	1.00
12	.91	.95	.78	.86

	HM&E 70	71	72	73
1	.65	.61	.45	.18
2	.75	.72	.79	.73
3	.05	.87	.44	.43
4	.49	.64	.95	.44
5	.97	.96	.96	.99
6	.94	.98	.99	.95
7	.99	.99	.84	.85
8	1.00	1.00	.68	1.00
9	.89	.85	.78	.92
10	.94	.94	.93	.96
11	.94	.99	.91	.89
12	.81	.93	.78	.80
13	.98	.94	.86	.85
14	.95	.99	.98	.95

TABLE F-2

MDT BY APL
(Failures; MDT in days)

	Electronics			
APL	70	71	72	73
1				1
2	35	16	33	44
3	21	49	21	147
4				1
5	1	27	12	33
6	12	13	20	24
7		2	20	20
8			97	54
9	5	9	11	14
10	65	28	32	53
11			28	54
12	10	24	25	49
13	12	29	62	40
14	25	18	26	30
15	17	26	32	33
16	14	44	67	126
17	32	35	37	53
18	11	53	64	52
19	187	9	69	97
20	18	27	52	34
21	54	53	241	145
22	59	105	107	98
23	99	222	159	142
24	60	68	53	73
25	27	15	20	56
26	24	49	45	35
27	11	2	2	7
28	11	3	1	5
29	36	48	35	97
30	37	67	50	102
31	31	34	56	44
32	29	51	62	70
33	32	24	55	35
34	77	7	6	66

	Ordnance			
APL	70	71	72	73
1	115	35	103	113
2	61	173	11	20
3	17	23	73	22
4	18	16	48	61
5	31	11	23	40
6	193		41	140
7	61	9	131	65
8	47	69	196	68
9	6	288	23	170
10	2	1	12	2
11	2		4	1
12	77	73	164	98

	HM&E			
	70	71	72	73
1	51	123	156	136
2	51	113	100	127
3	139	37	102	138
4	97	144	39	164
5	55	101	89	44
6	254	102	32	102
7	8	8	85	96
8	3	1	175	10
9	34	213	117	146
10	33	70	57	102
11	33	15	100	82
12	131	72	103	82
13	12	83	119	154
14	22	19	29	50

TABLE F-3

MTBF BY APL
(Failures; MTBF in Days)

Electronics

APL	70	71	72	73
1				607
2		44	4	31
3	181	211	181	181
4				22
5	4234	2325	1234	1026
6	19	60	52	66
7		4378	131	105
8			694	378
9	67	192	212	311
10	665	118	26	13
11			304	104
12	60	112	97	208
13	91	109	105	128
14	193	382	223	340
15	241	726	324	477
16	2040	1219	1028	8087
17	1871	2344	969	2824
18	1693	1082	617	2502
19	18428	9298	1623	937
20	375	534	5402	563
21	4326	7455	4538	4235
22	5346	4261	4259	4838
23	1748	1870	1268	1285
24	814	2378	478	1091
25	187	429	162	226
26	206	727	341	446
27	111	271	383	418
28	122	271	502	577
29	249	412	792	1676
30	604	1854	1609	1983
31	761	1213	968	888
32	3271	3698	1373	1250
33	626	1375	1438	1687
34	558	3424	1709	1006

Ordnance

APL	70	71	72	73
1	11	218	3	37
2	51	313	353	53
3	1549	342	383	890
4	47	113	105	138
5	280	460	189	344
6	4187		756	444
7	262	591	139	494
8	1397	2486	1464	1078
9	2366	2875	1031	330
10	248	263	383	525
11	424		229	254
12	808	1269	592	619

HM&E

	70	71	72	73
1	92	188	126	30
2	156	288	377	351
3	7	255	81	106
4	93	254	691	128
5	1712	2697	2309	3491
6	4126	4278	2157	2088
7	649	813	462	561
8	595	6569	372	2180
9	274	1247	414	1800
10	558	1171	719	2284
11	521	1132	1046	683
12	540	1023	367	329
13	463	1273	744	900
14	464	1233	1723	924

APPENDIX G

BIASES DUE TO CHANGES IN 3-M REPORTING DURING 1970-73

APPENDIX G

BIASES DUE TO CHANGES IN 3-M REPORTING DURING 1970-73

Appendix E describes the changes in 3-M reporting that occurred during our period of analysis, 1970-73. Because these changes affected the fraction of actions that were reported ("reporting ratio"), there are biases in our estimates of the trends in MDT, MTBF, and A_o. This appendix calculates the directions of the biases.

For simplicity, we will assume that there was full reporting before selective reporting was established by message Z-46 in October 1970. In other words, the reporting ratio was 100 percent prior to October 1970, and less than 100 percent afterwards. The lower percentage has probably remained about constant. Although which EICs were on the list has changed from time to time, their total number has remained at about 350. Unless there have been sizable changes in either the average number of failures per included EIC, or the total number of failures in all EICs, the reporting ratio stayed about constant after October 1970.

By assuming a reporting ratio of 100 percent for 1970 (actually, until October 1970), we need only calculate the bias in the <u>values</u> of MDT, MTBF, and A_o during 1971-73 in order to measure the bias in their <u>trends</u>. That is, if we overestimated MDT itself during 1971-73, we also overstated its upward trend.

<u>Bias in MDT</u>

Actual mean downtime is a weighted average of reported and not-reported downtimes.

$$MDT_A = at_r + (1 - a)t_n$$

where

MDT_A = actual mean downtime

a = fraction of actions reported

t_r = MDT for actions that are reported

t_n = MDT for actions that are not reported

$$MDT_M = t_r$$

where

MDT_M = measured mean downtime.

It can be shown (with some effort) that t_r exceeds t_n. The contributing factors are: 1) as shown in the text, deferred actions have longer mean downtimes than do non-deferred actions; 2) the 1970 changes mean that deferred actions have a higher reporting ratio than non-deferred ones, which implies that reported actions are more likely to be deferred than non-deferred. Therefore we overestimated mean downtime:

$$MDT_A = at_r + (1 - a)\,t_n < at_r + (1 - a)\,t_r = t_r = MDT_M \quad .$$

Because we overestimated MDT for 1971-73, MDT was not worsening as fast as we calculated in the text.

Bias in MTBF

We have measured reliability (MTBF) by the time between corrective maintenance actions (MTBA)[1] less mean downtime. Using the method for calculating MTBA given in the text:

$$MTBA_A = \frac{\text{Population x 365}}{N_A}$$

$$MTBA_M = \frac{\text{Population x 365}}{N_M}$$

$$MTBA_M = \frac{MTBA_A}{a} > MTBA_A$$

where

N = number of actions in a year (actual and measured)

a = fraction of actions reported.

Also

$$MTBF_M = MTBA_M - t_r \quad .$$

[1] MTBA corresponds to MTBCMA in the text.

Then

$$\begin{aligned}
MTBF_A &= MTBA_A - MDT_A \\
&= MTBA_A - at_r - (1 - a)\,t_n \\
&= aMTBA_M - at_r - (1 - a)\,t_n \\
&= a(MTBF_M) - (1 - a)\,t_n \le MTBF_M \quad .
\end{aligned}$$

We have thus overestimated mean time between failure for 1971-73, so that the reliability of electronic and ordnance equipments is deteriorating faster than shown by the time trend in the text, and the small increase in reliability for HM&E equipments is probably illusory.

Bias in A_o

Using the formulas for A_o in the text and the previous notation and results from this appendix:

$$A_M = \frac{MTBA_M - MDT_M}{MTBA_M} = \frac{\dfrac{MTBA_A - t_r}{a}}{\dfrac{MTBA_A}{a}}$$

$$= \frac{MTBA_A - at_r}{MTBA_A}$$

where

A_M = measured A_o

$$A_A = \frac{MTBA_A - MDT_A}{MTBA_A}$$

$$= \frac{MTBA_A - at_r - (1 - a)\,t_n}{MTBA_A} \le \frac{MTBA_A - at_r}{MTBA_A} = A_M$$

where

A_A = actual A_o .

By overestimating A_o for 1971-73, we have understated the decline in operational availability shown in the text.

In summary, if we were to change the results of the text in order to correct for the reporting bias, the added deterioration in reliability would more than make up for the lesser increase in mean downtime, so that A_o would fall by more than we initially estimated. There is an intuitive way to see that we must have overestimated operational availability during 1971-73:

$$A_o = \frac{\text{total time} - \text{total downtime}}{\text{total time}}$$

and if we are missing actions, total downtime is underestimated.

APPENDIX H

SUPPLY AVAILABILITIES AND RESPONSE TIMES BY ECHELON

APPENDIX H

SUPPLY AVAILABILITIES AND RESPONSE TIMES BY ECHELON

Table H-1 was obtained in its entirety from the S^4 study's analysis of Sixth Fleet supply data for the early 1970s.[1] The various columns give the availability of parts (a) and the response time (t) at each of the supply echelons. These figures vary by Cog Code (the first two characters of the National Stock Number) which specify the general type of material, the agency which manages its inventory, and the way it is funded.

For example, Cog Code 1A referred in 1973[2] to ordnance equipment and repair parts managed by the Ships Parts Control Center (SPCC) and funded out of a revolving stock fund (the Navy Stock Account, or NSA).

Reading across, a 1A part will be found onboard the ship with a probability (availability) of .508 and on the average is obtained in .125 days (1 hour). If unavailable onboard, which occurs with probability .492 (=1-.508), the part will be on an AFS with a conditional probability of .228, and obtainable in eight days (not eight days more than .125). In other words, a 1A part will be found on an AFS with an unconditional probability of .112 (.492 x .228).

This sequential scheme continues until the ICP echelon. Given that the part is not available at prior echelons, which occurs with probability .136 (.492 x .772 x .960 x .374), it will be obtained either by issue from existing stock, by waiting for delivery on an existing order from the manufacturer (backorder), or by placing a new order (spot buy). The probabilities are no longer sequential; for example, if a part must be obtained at the ICP, it will be filled by backorder with probability .126, not (1-.801) x .126.

The mean delays shown in the last column were obtained by multiplying together the accumulated availabilities and response times at each echelon and adding up the contributions.

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[1]The figures were obtained from a working paper of that study, and from a personal conversation with one of the analysts.

[2]The definitions change from time to time.

TABLE H-1

AVAILABILITY AND RESPONSE TIMES AT VARIOUS ECHELONS

Cog Code	Ship		MLSF[1]		Screen		Stock point		Inventory control point: Issue		Inventory control point: Backorder		Inventory control point: Spot buy		Mean delay
	a	t	a	t	a	t	a	t	a	t	a	t	a	t	
1 A	.508	.125	.228	8	.040	12	.626	25.39	.801	34.70	.126	178.70	.073	173.90	15.5
H	.462	.125	.514	8	.060	12	.552	26.10	.778	40.55	.119	154.25	.103	162.65	13.3
N	.473	.125	.474	8	.060	12	.753	31.70	.848	35.27	.142	103.85	.010	212.60	11.5
2 A	.699	.125	.170	8	.040	12	.451	26.20	.720	30.77	.229	132.17	.051	205.37	11.7
G	.533	.125	0	8	.060	12	.519	19.3	.620	23.19	.205	128.40	.175	113.55	
H	.275	.125	.238	8	.060	12	.391	16.80	.554	32.78	.311	147.08	.135	211.28	34.5
N	.476	.125	0	8	.060	12	.417	28.20	.567	47.13	.367	149.52	.066	225.60	33.9
U	.679	.125	0	8	.060	12	.319	22.40	.762	34.70	.132	132.20	.106	98.00	
4 A	.520	.125	0	8	.040	12	.659	14.25	.840	34.70	.117	92.90	.043	170.00	
G	.566	.125	.514	8	.060	12	.456	21.00	.654	34.14	.281	146.91	.065	180.96	12.0
N	.667	.125	.170	8	.060	12	.576	15.40	.768	40.09	.185	138.70	.047	156.04	10.1
9 C	.498	.125	.478	8	.050	12	.489	30.30	.791	37.90	.141	133.00	.068	82.39	11.8
G	.516	.125	.648	8	.020	12	.686	32.26	.867	37.94	.089	102.44	.044	63.74	8.6
N	.589	.125	.549	8	.060	12	.641	31.39	.933	35.39	.066	84.89	.001	59.09	7.9
Q	.350	.125	.822	8	.030	12	.701	29.56	.888	32.56	.041	33.56	.071	73.66	7.9
Z	.558	.125	.575	8	.030	12	.713	26.66	.941	31.89	.038	82.59	.021	55.29	7.4

[1]Mobile logistic supply force (i.e., AFSs).

APPENDIX I

AVERAGE DOWNTIME AS A FUNCTION OF TYPE OF ACTION AND COMPONENTS OF DOWNTIME

APPENDIX I

AVERAGE DOWNTIME AS A FUNCTION OF TYPE OF ACTION AND COMPONENTS OF DOWNTIME

The overall mean downtime for a maintenance action is total downtime divided by the number of actions. It is also the sum of the mean downtimes for various kinds of actions weighted by the relative number of each kind. Therefore it can be represented by a complete disjoint set of actions. We have expressed mean downtime in this way using the four deferral categories (non-deferred, backlog deferrals, parts deferrals, and repair deferrals) each subdivided into two "completed action taken" categories (repaired with parts and repaired without parts). For completeness, we have included all eight categories, although some have few actions (e.g., "deferred for parts - repaired without parts").

Downtime for each action is separated into components: supply time, hands-on-repair time and the residual which we call "administrative delay time." All components are not relevant to each category of action. For example, there is no supply time for actions repaired without parts. We also found that hands-on-repair time for an action is negligible when compared to the total downtime. Therefore, we did not decompose downtime for actions repaired without parts, and downtime for actions repaired with parts was separated only into supply time and a residual.

These statements are summed up in the following equation:

$$\text{(1)}\quad \text{Overall mean downtime} = \sum_{i=1}^{4} \sum_{j=1}^{2} f_{ij}\, MDT_{ij}$$

$$= \sum_{i=1}^{4} \left[f_{i1}\,(MSRT_{i1} + MADT_{i1}) + f_{i2}\, MDT_{i2} \right]$$

where

i = index for deferral category (1 = non-deferred; 2 = backlog deferrals; etc.)

j = index for repair action taken (1 = repair with parts; 2 = repair without parts)

f_{ij} = proportion of actions in deferral category i and repair category j

MSRT = mean supply response time (time from discovery date to issue of last part)

MADT = mean administrative delay time (time from issue of the last part until date of completion of the action)

MDT = mean downtime.

From equation 1, it is obvious that changes in, for example, the mix of actions or supply time cause changes in the mean downtime. Furthermore, the breakdown into components allows us to estimate how much of the change in overall mean downtime was due to changes in the various factors:

$$\text{(2)} \quad \Delta\text{mean downtime} = \sum_{i=1}^{4} \left[f_{i1} (\Delta MSRT_{i1} + \Delta MADT_{i1}) + \Delta f_{i1} (MSRT_{i1} + MADT_{i1}) + f_{i2}\, \Delta MDT_{i2} + \Delta f_{i2} MDT_{i2} \right]$$

where

Δx = change in variable x.

APPENDIX J

POSSIBLE REASONS FOR LARGE VALUES OF MDT

APPENDIX J

POSSIBLE REASONS FOR LARGE VALUES OF MDT

In the text we measured the contribution of various factors to trends in MDT but we did not discuss why the values for MDT in tables 6, 7 and 8 are so large. In this appendix we make several attempts to shed some light on this question. We first try to gain insight into why mean downtime is so large by comparing downtimes for various types of actions. We then discuss the role that personnel variables may play in long downtimes. Finally, we look at the possibility of misreporting.

MEAN DOWNTIME AS FUNCTION OF TYPE OF ACTION

Under the 3-M system, corrective maintenance actions are described by the variables listed in table D-1 of appendix D. We selected 4 for analysis:

- Deferred Action Taken: non-deferred, deferred for backlog, parts or repair
- Condition of Item when Action was Discovered; failure or other (reduced capability, operational, or no malfunction)
- Completed Action Taken: repaired with or without parts (we ignored actions with other codes, such as "cancelled")
- Priority (deferred actions only): urgent, impaired, routine, or convenience.

Although we have up to now considered only actions where the condition of the item was "failure," we'll look here at the other possibilities as well. Note that the need for parts enters into both Deferred Action Taken and Completed Action Taken, but in different ways: an action may be deferred for parts if the repairman <u>thinks</u> that parts will be needed and not readily available, but it will <u>actually</u> be repaired with parts only if he is proven correct. In other words, whether an action is repaired with or without parts depends primarily on the type of failure, but "deferred for parts" implies something about the supply system as well (i.e., that at least one part is not onboard, and a long wait is expected).

Table J-1 shows mean downtime for actions classified according to the first 3 categories above. The effect of priority will be measured separately. Most striking is the effect of deferral. Whereas non-deferred actions take 8-26 days depending on the values of the other variables, deferred actions range from 65-220 days, with 29 of the 36 entries above 100 days.

TABLE J-1

MDT FOR VARIOUS TYPES OF ACTIONS
(1970-74)

Condition of Item	Deferred action taken	Completed action taken	MDT (Days) E	MDT (Days) O	MDT (Days) HM&E	Number of actions E	Number of actions O	Number of actions HM&E
Failure	Non-deferred	Repaired, no parts	8	6	9	397	51	72
		Repaired, parts	10	12	17	7,864	691	293
	Deferred, backlog	Repaired, no parts	131	65	94	39	15	12
		Repaired, parts	111	85	74	101	17	17
	Parts	Repaired, no parts	112	89	130	47	13	6
		Repaired, parts	88	117	107	1,765	250	152
	Repair	Repaired, no parts	79	127	102	137	26	97
		Repaired, parts	119	128	118	241	60	284
Other	Non-deferred	Repaired, no parts	16	18	26	962	286	297
		Repaired, parts	10	15	18	11,229	2,405	721
	Deferred, backlog	Repaired, no parts	123	173	184	418	209	203
		Repaired, parts	160	218	133	426	176	87
	Parts	Repaired, no parts	169	187	143	146	70	33
		Repaired, parts	106	146	146	3,641	1,726	271
	Repair	Repaired, no parts	108	153	179	862	318	506
		Repaired, parts	175	220	174	593	353	801

Another consistent pattern is that failures are repaired quicker than other actions. It appears that maintenance people are wisely devoting more attention to those items in the worst shape. Even for non-deferred actions, with their already small downtimes, failures are repaired faster.

The effect of Completed Action Taken is difficult to interpret. There are cases where items needing parts take longer to fix, and the reverse. The variation with type of APL is similarly not consistent across all cases. In order to identify the predominant effect of these latter two variables, we carried out a statistical regression of mean downtime on all the factors shown in the table (multiple regression). This technique accomplishes what the eye cannot: it measures the effect of each variable holding the others constant. To gain more information, we applied the regression technique to the yearly data, rather than to the 1970-74 averages shown in the table.

The regression results in table J-2 confirm the earlier observations: with high statistical significance, deferral adds greatly to mean downtime, about 4 months for backlog and repair, and 3 months for parts; and failures take 20 days less than other actions.[1]

The regression shows also that holding other variables constant, including deferral status, those items repaired without parts took almost exactly the same time as those repaired with parts. Apparently the dependence of MDT on the need for parts is fully described by deferral status. This is confirmed by the fact that most actions deferred for parts actually needed them,[2] and that MDT for non-deferred actions are too small to show much variation with the need for parts.

Other results from the regressions are that ordnance and HM&E actions take about 12 days longer than electronics failures, and that MDT shows an uptrend.

Finally, we show in table J-3 that for electronics and HM&E, higher priority means much less downtime. There is no such relationship for ordnance actions, but this could be a statistical fluke in view of the small number of data points for the first and last categories.

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[1]This estimate is small compared to many of the differences noted in table J-1 because of the large number of non-deferred actions for which the "failure-other" differential is small.

[2]94 percent, 84 percent, and 89 percent, for electronics, ordnance, and HM&E equipments, respectively.

TABLE J-2

REGRESSION OF MEAN DOWNTIME ON VARIOUS FACTORS

	Coefficient	t-Statistic
Constant	10.0 days	1.96
Deferred action taken		
Backlog	114.6	13.97***
Parts	97.9	17.63***
Repair	120.4	19.19***
Condition of item		
Failure	-19.8	-4.47***
Completed action taken		
Repaired with parts	.3	.07
APL type		
O	12.5	2.21**
HM&E	11.8	2.03**
Time	6.0	3.10***

$R^2 = .79$

$F(8,183) = 85.3$***

**Significant at 5 percent level.

***Significant at 1 percent level.

TABLE J-3

MDT OF DEFERRED ACTIONS AS A FUNCTION OF URGENCY[a]
(Failures)

	MDT (Days)			Number of Actions		
	E	O	HM&E	E	O	HM&E
Urgent	59	134	101	118	17	80
Impaired	89	121	111	1182	211	502
Routine	107	136	125	1845	293	296
Convenience	120	121	159	46	4	26
All	99	130	116	3191	525	904

[a]Includes actions for which no population is reported, as noted in table 5 of the text.

Why does it take 3 or 4 months to complete a deferred action? The stated reason for deferral indicates one cause of the delay--a wait for manpower, parts or tender--but not necessarily the major one. Consider, for example, the long final delay after all parts have been issued, which occurs for actions deferred for parts (tables 6B, 7B, 8B). Our data does not give us specific reasons for these long delays. Two factors which could be responsible are personnel shortages and misreporting.[1] If MDT is long for the first reason, it could be shortened by upgrading the quantity or quality of maintenance people. This should also help reduce misreporting.

PERSONNEL FACTORS

A shortage of enough trained maintenance and supply people aboard ships may be a significant contributor to long downtimes.[2] Although maintenance actions typically require

[1]Delays may also occur because ships might have to be in an underway status before final checks on repaired equipment can be made. This is especially true for off-ship repaired items. (The ship does not consider the action completed until the equipment is working properly.)

[2]See CNA's Manpower Personnel Effectiveness Study (CNS 1090) for an analysis of how CASREPT downtime is affected by personnel variables.

only a day of hands-on repair, the calendar time could be much longer if shipboard mechanics are overloaded and can spend only a little time each day on each job. For actions repaired with parts, this mechanism might help to explain the long (3-1/2 to 7 week) times we measured between delivery of the last part and completion of the action (MADT), during which the part is installed and final adjustments are made. This is also true for MDT for those actions which have no supply time, and is particularly true for actions deferred for backlog or off-ship repair reasons.

By definition, actions were deferred for backlog because there was a work backlog and the ship's personnel could not get to the action immediately. Personnel is a definite factor here.

Actions deferred for off-ship repair which were eventually repaired by a tender have long downtimes which might also be explainable in large part by personnel problems, and we will discuss these in some detail.

MDT for actions repaired by a tender are quite long--about 4 months. Hands-on repair time aboard combatants and tenders, plus waiting for tender availability, hardly explains these delays.[1] To measure hands-on repair durations by ship's force and tenders, we divided repair manhours by an assumed repair crew level of one man, and an assumed work day of 8 hours. Eight manhours of repair thus converts to a duration of one day.[2] Averaging durations over all actions produces the estimates for mean time to repair (MTTR) shown in table J-4.

TABLE J-4

MTTR FOR DEFERRALS FOR ASSISTANCE BY A TENDER
(failures)

	Combatant	Tender	Combatant	Total
E	.5 days	1.5 days	1.1 days	3.1 days
O	.9	3.4	1.9	6.2
HM&E	.5	2.5	.8	3.8

[1]Only 1/3 of all deferrals for off-ship assistance go to tenders, but our data contains hands-on repair time for these alone.

[2]The duration for a single action can be many days if a repairman divides his time among many maintenance actions. But we are calculating average hands-on repair time over all actions, which is the continuous repair duration if jobs, once started, are carried to completion. Repair may, of course, be interrupted for tasks other than different maintenance jobs.

In the first phase, the combatant ship's force devotes an average of .5 days (electronic APLs) of hands-on repair time between discovery (initiation) of the action and the date of deferral. Then, between the deferral date and completion of the off-ship assistance, the tender spends 1.5 days on hands-on repair. The final 1.1 days occurs during the final phase, between completion by the tender and final close-out of the action, when the ship's force is finishing the repair.

Despite our use of minimum crew level and workday factors, which tend to bias hands-on repair time upward, the average values of MTTR shown in table J-4 amount to only several percent of the 4-month mean downtime for repair deferrals shown in table J-5.

TABLE J-5

MDT FOR DEFERRALS FOR ASSISTANCE BY A TENDER
(failures)

	Combatant	Tender	Combatant	Total
E	7.1 days	34.0 days	73.2 days	114.3 days
O	2.6	32.9	80.3	115.8
HM&E	.8	28.9	112.3	152.0

We also found that repair time is poorly correlated with downtime from action to action, indicating that repair time does not add importantly to total delay through its effect on "eating and sleeping," and other delays that might be linearly related to repair time.

Because about 30 percent of our off-ship repair actions are handled by a tender, we were interested in whether the mean downtime for these actions could be explained by waiting for tender availability.

Once the decision is made to defer the action for tender assistance, there is a one-month delay (column 2 of table J-5) until completion of off-ship assistance. The wait for tender availability can account for this almost exactly. Suppose that ships typically get one 3-week availability per quarter. The average wait for availability would be about a month, and this would constitute the full delay until completion by the tender if failures are given first attention once the ship is alongside. The one-month mean downtime for the off-ship phase in table J-5 might therefore be due solely to waiting for tender availability.

However, once the tender completes its work, there is another long delay during which the combatant ship's force is closing out the action.[1] We can't explain this time, other than by speculating that personnel may play a role.

Although the statement that personnel problems might be a major factor behind large MDT is only a speculation which cannot be precisely shown by our data, the CNA Maintenance Personnel Effectiveness Study (reference 8), has found that personnel variables such as number, seniority, and training have large effects on CASREPT downtimes. We would expect that these actions, which are reported when there is a reduction in the capability to perform a mission, would be handled at least as efficiently as actions reported only under the 3-M system, and that the relationships found between personnel and CASREPT downtimes hold also for 3-M downtimes.

Personnel factors may also be related to another possible reason for long downtimes. Long downtimes could be due to misreporting of completion dates or parts issue dates. This could explain long MDT for actions not needing parts, and MADT for actions needing parts.

POSSIBLE EFFECT OF REPORTING BIAS ON LONG MDT

In measuring the contribution of MTTR and MSRT to MDT in tables 6B, 7B and 8B, we found long, unexplained residuals (mean administrative delay time).

Several Naval officers have suggested that these delays might not be real, but due rather to errors in reporting. The possibility most often mentioned is that "2-kilo" forms may often be filled out long after actions are completed,and when the actual completion dates have been forgotten. If there is a persistent tendency to understate how long ago the action was closed out, our estimates of MDT are too high. And if reported parts issue dates (i.e., MSRT) are not equally affected by late reporting, there would be smaller values of MADT to explain.

It is plausible that parts issue dates are reported more exactly than completion dates. Receiving a part from the stockroom happens at a discrete point in time, and the forms are close at hand. Finishing some repairs could drag on (installation, adjustments, checking, more adjustments), and the 3-M forms might be far from the site.

---

[1] Because of the way we handled the data, about 5 percent of the actions described by table J-5 were fixed at a shipyard, rather than by tenders. Some of the large delays in the trend column could therefore be due to the ship's force waiting until the ship left the yard to check out the repair and close out the action. But even if this delay were 90 days, the fact that it occurs in only 5 percent of the cases results in an addition of only 5 days to the average downtime.

We have carried out several sensitivity checks to determine how much of an effect misreporting could have on mean downtime. First, suppose that many "2-kilo" forms are not completed immediately, but lie around until a "clean-up" period during a relative lull in the workload. If 3-M documentors then write in the current date rather than try to remember the past, reported completion dates would cluster around these "clean-up" times.

To see whether this was occurring, we graphed the number of completion dates reported each week for 10 of the 91 ships in our sample. Each of the graphs looked about the same as the one for the DDG shown in figure J-1. (The time axis starts on 1 January 1970, and overhaul is shown by large x's.)

There is substantial variation from week to week and some clustering, but no obvious pattern that would help to explain, say, the 4-month downtimes associated with deferred actions.[1]

We also fail to notice patterns in the "1250" parts issue dates (figure J-2), "2-kilo" discovery dates (figure J-3), or all discovery, issue, and completion dates taken together (figure J-4).

These observations do not, of course, lay to rest the question of whether MDT is upward biased due to poor reporting. It could be that documentors try to remember actual completion times in filling out forms after the fact, but that they tend to underestimate how long ago the completion actually took place. We can estimate the resulting bias if we know the percentage of actions in which backdating occurs, and assume reasonable errors of memory.

Data on the extent of backdating is contained in the NAVMMACLANT Study mentioned earlier (reference 6). Based on a sample of 2116 3-M forms, the study found that the "shipboard delay" between the reported completion date[2] of an action and transmittal of the form off the ship had the distribution shown in table J-6 below. In a separate analysis of 200 3-M documents, backdating was found to be the cause of the shipboard delay in 35 percent of the cases.

---

[1] Many of the upswings and downswings in the figure last for 2 weeks each, which could indicate a 4-week cycle. Completion dates would be reported from 0 to 4 weeks too late, with an average of 2 weeks.

[2] Some of the documents described deferral actions, and the shipboard delay was between deferral date and transmittal. However, we can use both completions and deferrals as a source of data on the extent of backdating, even though we will use the data to estimate biases in completion dates only.

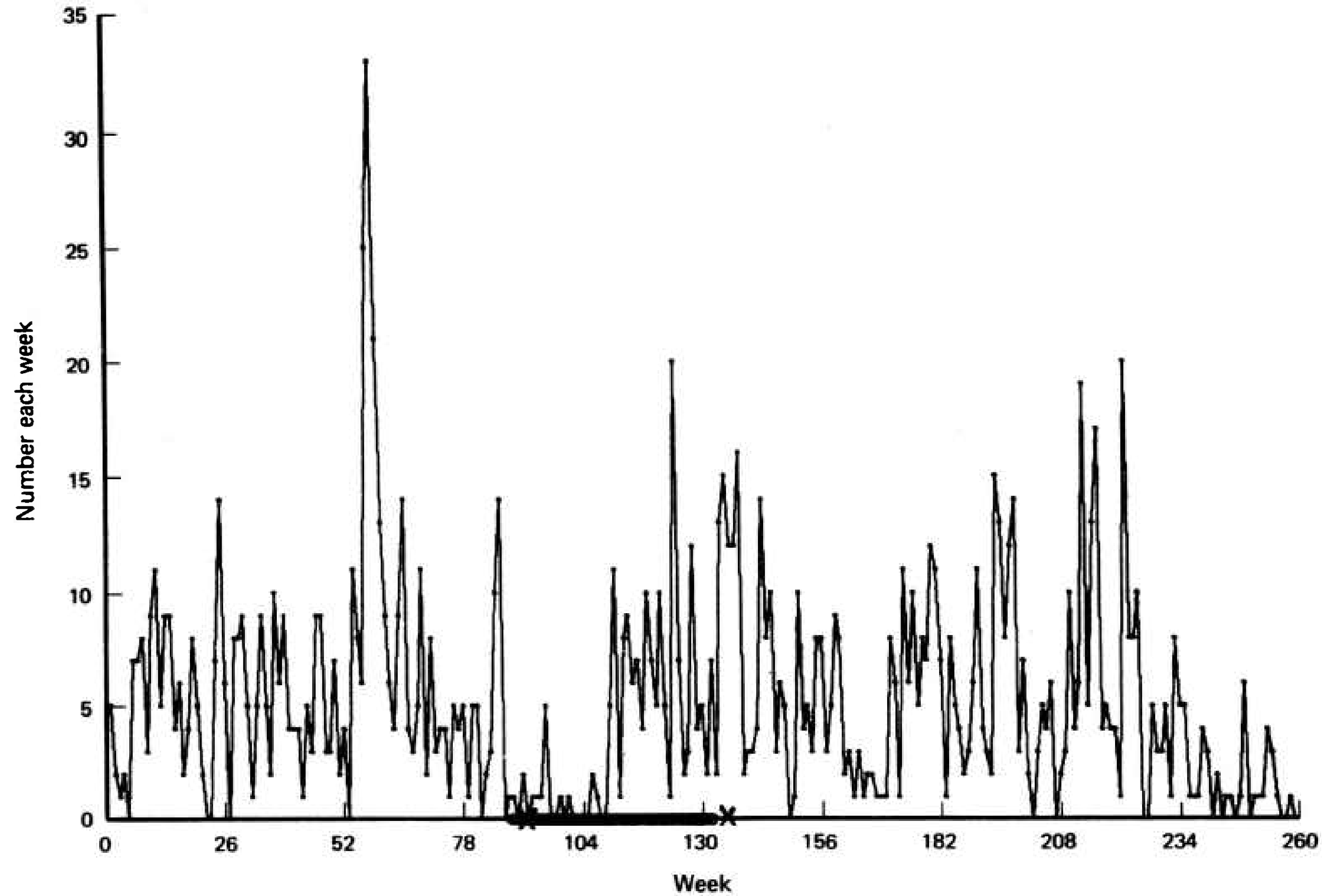

FIG. J-1: COMPLETIONS OF MAINTENANCE ACTIONS (DDG 4)

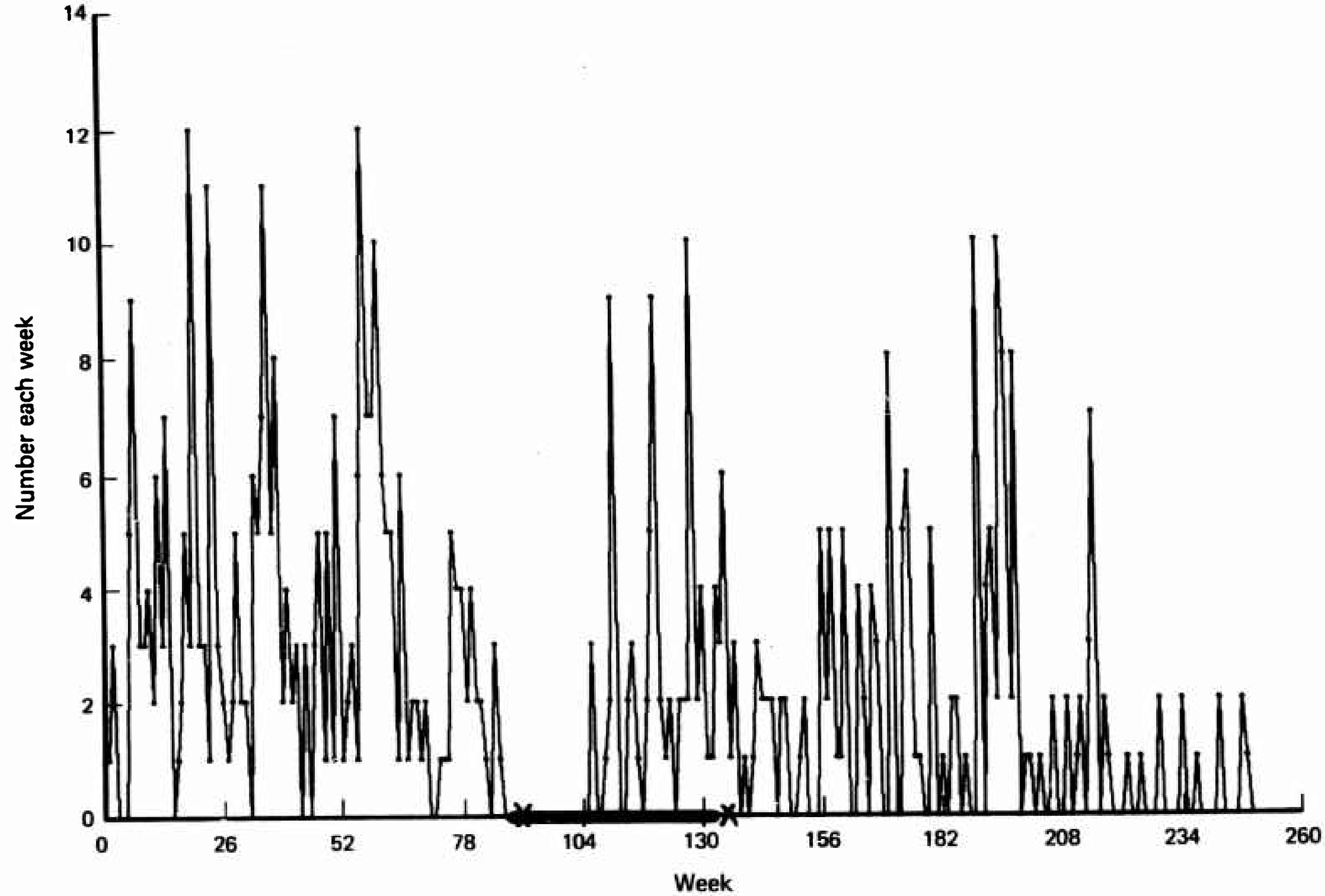

FIG. J-2: ISSUES OF PARTS (DDG 4)

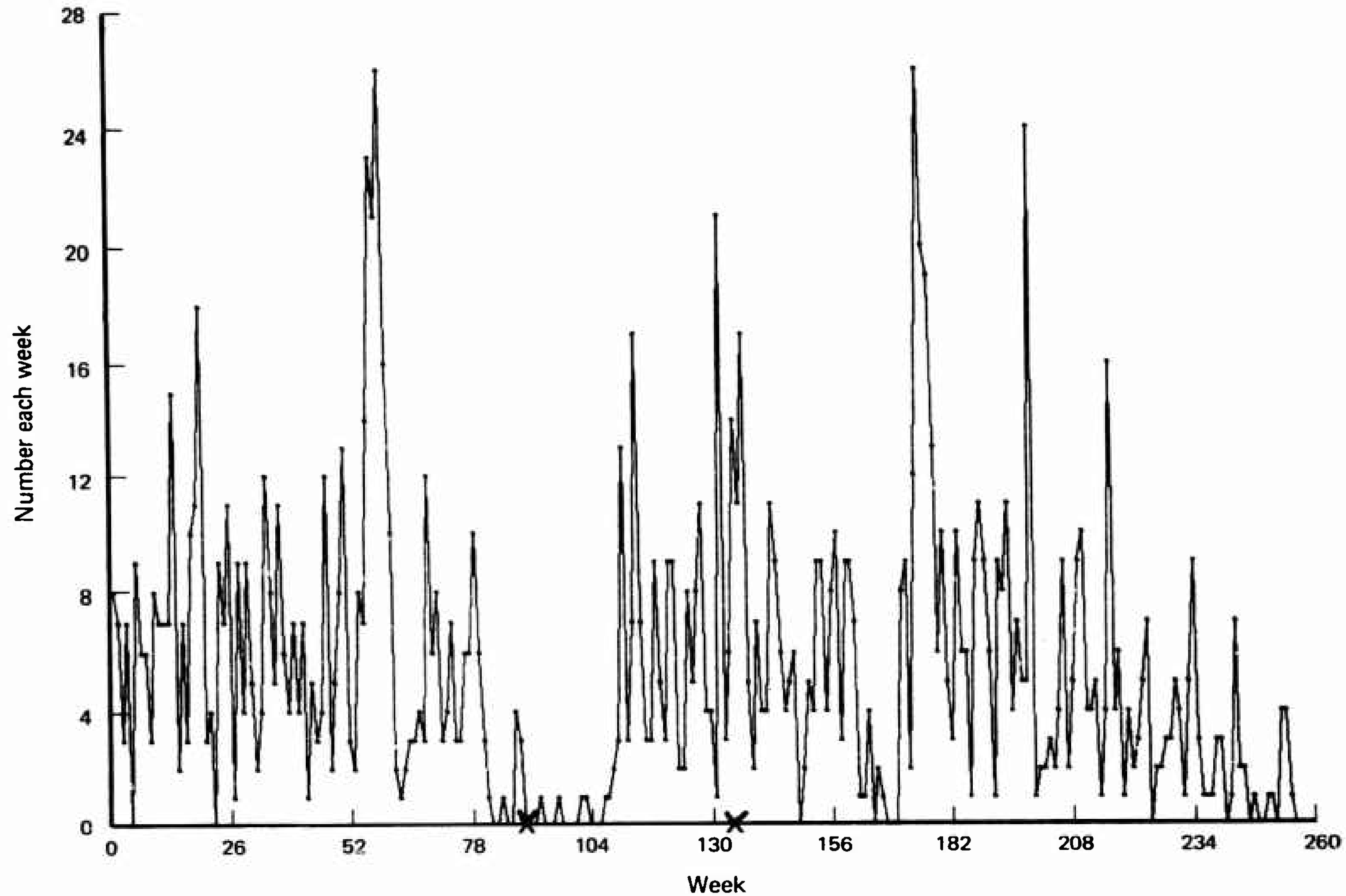

FIG. J-3: DISCOVERIES OF MAINTENANCE ACTIONS (DDG 4)

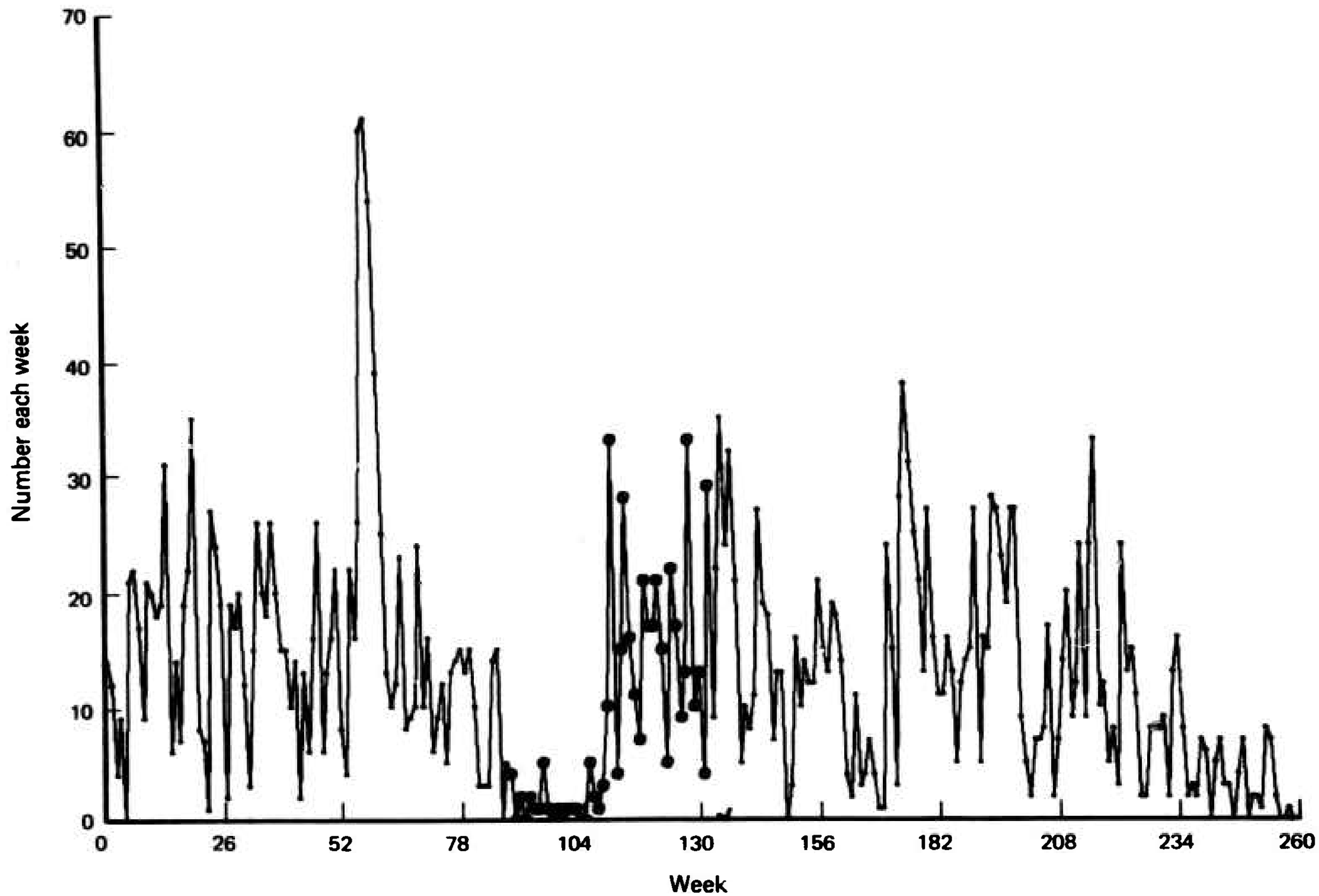

FIG. J-4: DISCOVERIES + COMPLETIONS + ISSUES (DDG 4)

TABLE J-6

BIAS IN MDT DUE TO ERRORS IN BACK-DATING

Shipboard delay		Documents		
Range	Mid-point	Number	%	Expected error[a]
0-2 days	1 days	167	7.9	.00 days
3-5	4	255	12.1	.02
6-8	7	273	12.9	.03
9-11	10	193	9.1	.03
12-14	13	187	8.8	.04
15-17	16	168	7.9	.04
18-20	19	88	4.2	.03
21-23	22	93	4.4	.03
24-26	25	64	3.0	.03
27-29	28	59	2.8	.03
30-45	37.5	191	9.0	.12
46-60	53	81	3.8	.07
61-90	75.5	131	6.2	.16
91-120	105.5	55	2.6	.10
121-180	150.5	50	2.4	.12
181-365	273	47	2.2	.21
365-754	559.5	14	0.7	.13
		2116	100%	1.20 days[b]

[a]Average error = $\sum_{i=1}^{17}$ (shipboard delay x 10%)$_i$ x (% documents x 35%)$_i$ (shipboard delay is taken at mid-point of range).

[b]Assuming all errors are in same direction.

As an example of a 10-day shipboard delay due to backdating, a documentor on March 25 enters a completion date of March 15 and then transmits the form immediately. If backdating were not the sole cause, but there was a 3-day delay between when the form was filled out and its transmittal, the 10 days between completion and transmittal would mean only 7 days of actual backdating (the documentor enters the March 15 completion date on March 22 and transmits the form on March 25). By ignoring this complication, we will obtain high estimates of the bias due to backdating.

Suppose now that documentors systematically underestimate by 10 percent how long ago the completion took place, so that the completion in the example above really occurred on March 14. This means that downtime was overestimated by one day in 3.2 percent of the cases[1], giving an expected error of .032 days.

Adding up all such contributions produces a resultant bias of only 1 day in mean downtime. Even if documentors erred by 50 percent, and always in the direction of underestimating the time since completion, the bias would be only 5 days, hardly enough to explain much of the 46-day MDT for electronics actions, for example.

Another reporting hypothesis is that the completion dates of most actions are reported accurately, but that a few "2-kilo" forms get lost in the shuffle and are not found and completed until long after the work is done. Suppose that we take a downtime of 400 days or longer as an indication that this has occurred, and eliminate these actions from the calculation of MDT. Table J-7 shows the results. For electronics APLs, for example, only 1.4 percent of the failures take 400 days or longer, but deleting them lowers mean downtime by almost 22 percent. The increases in reliability (MTBF) are more modest, and A_o is already too large to increase much.

The long downtimes might, of course, not be due to misreporting at all; they could be for actions requiring depot-level attention not scheduled until the next overhaul (assuming the failure is not critical). What table J-7 shows is that if long downtimes are due to misreporting, then the correct values of MDT are much less than what we have measured in this study.

Our final sensitivity check concerns the long final delay between last issue and completion for those actions needing parts. Table J-8 shows the same general character as above: eliminating a relatively few actions with long final delays (over 90 days) on suspicions of misreporting leads to much lower values of MSRT and MDT.

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[1] 9.1 percent of the documents showed a shipboard delay of 10 days (fourth line in table J-6), but only 35 percent of these were due to backdating; 9.1% x 35% = 3.2%.

TABLE J-7

EFFECT OF LONG-MDT ACTIONS ON MAINTENANCE VARIABLES

	Complete sample[a]	Excluding actions with MDT over 400 days	Change
Electronics			
Number of actions	9458	9331	-1.4%
A_o	.94	.96	+2 percentage points
MTBF	1269 days	1344 days	+5.9%
MDT	32 days	25 days	-21.9%
Ordnance			
Number of actions	1099	1065	-3.1%
A_o	.88	.91	+3 percentage points
MTBF	625	698	+11.7%
MDT	60 days	45 days	-25%
HM&E			
Number of actions	999	958	-4.1%
A_o	.89	.91	+3 percentage points
MTBF	1076	1121	+4.2%
MDT	85	52	-38.8%

[a]All failures reported by "2-Kilo"forms.

TABLE J-8

EFFECT OF LONG-FINAL-DELAY ACTIONS ON SUPPLY VARIABLES

	Complete sample[a]	Excluding actions with delay over 90 days	Change
Electronics			
Number of actions	3477	3230	-7.1%
Final delay	25	8	-68%
MSRT	15	12	-20%
MDT	40	20	-50%
Ordnance			
Number of actions	226	184	-18.6%
Final delay	52	11	-78.8%
MSRT	26	20	-23.1%
MDT	78	31	-60.3%
HM&E			
Number of actions	154	133	-13.6%
Final delay	41	15	-63.4%
MSRT	27	21	-22.2%
MDT	68	36	-47.1%

[a]All failures reported by "2-Kilo" forms with issues records.

Bias in MSRT Due to Parts Issues Reported

There is also possibly a bias in MSRT due to the parts issues which are reported. If a 3-M action is also reported as a CASREPT, the parts needed are shown only on the CASREPT and not on the "1250" issues forms. If CASREPTs have a higher priority than 3-M actions in general, they may also have shorter supply response times. Since MSRT is based on our data base of "1250" forms, these shorter CASREPT supply times do not enter the calculations, so our MSRT may be too large. If this is true, then the residual MADT is too small, and there is even more of MDT to be possibly explained by personnel or misreporting.

APPENDIX K

METHOD FOR CALCULATING A_0 WHICH AVOIDS "OVERLAP BIAS"

APPENDIX K

METHOD FOR CALCULATING A_o WHICH AVOIDS "OVERLAP BIAS"

This appendix suggests a new measure of A_o which avoids underestimation because of overlap -- different maintenance actions on the same unit of equipment occurring at the same time. Actions need not overlap completely (i.e., start and end exactly together) to cause bias.

The following example illustrates the effect of overlap. Consider figure K-1, which shows the up and down times for a hypothetical equipment. The two maintenance actions do not overlap, and the method used earlier in this paper for calculating operational availability gets the correct result. Under this method, the mean time between corrective maintenance actions (MTBCMA) is obtained by dividing the total time (100 days) by the number of actions (2), yielding 50 days.[1] Mean downtime (MDT) is estimated by the average duration of maintenance actions, which here equals 20 days. The formula obtains the result -- obviously correct from inspecting the figure -- that the unit is up 60 percent of the time:

$$A_0 = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} = \frac{\text{MTBCMA} - \text{MDT}}{\text{MTBCMA}} = \frac{30}{50} = .60 \qquad (1)$$

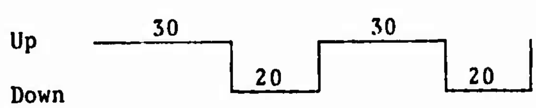

FIGURE K-1

In figure K-2, however, where the two actions have been made to coincide, the formula produces incorrect results. MTBCMA and MDT, as defined above, are unchanged, so that the formula once again finds an A_o of 60 percent. Inspection of the figure, however, shows that the equipment is actually up for 80 percent of the time.

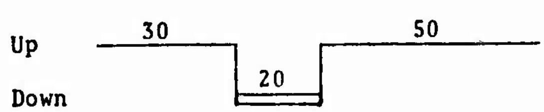

FIGURE K-2

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[1] "Time between corrective maintenance actions" is measured from when an equipment fails to the next time it fails. The "time between failures" is from when an equipment comes up to when it next fails. This measure excludes down time, and is thus a pure measure of reliability. In terms of averages, MTBF = MTBCMA - MDT, and the formula below would read A_o = MTBF/(MTBF + MDT).

In general, when there is overlap, keeping track of equipment downtimes on a calendar produces higher estimates of A_o than formula (1). The reason is that the total duration of all maintenance actions exceeds the total downtime for the equipment. Viewed another way, when actions overlap, dividing total time by the number of actions produces an estimate for MTBCMA which is low.

In order to get unbiased estimates of A_o, it is thus necessary to account for overlap.[1] The practical importance of doing so is indicated by the large bias that may result (as in the above example), and by the large amount of overlap found in actual Fleet data.

This last point is illustrated by figure K-3, which shows the duration of all 48 3-M actions reported during 1970-74 for a particular ordnance item (APL no. 005000002) on a single ship (the DD-743). On October 1, 1972, for example, fully 25% of all 48 actions were in progress at the same time.

New Method

To obtain an unbiased estimate of operational availability, given the significant amounts of overlap observed, we have used this formula for A_o:

$$A_o = \left[\frac{\text{simultaneous uptime of all units on a given ship}}{\text{total time}}\right]^{1/\text{no. units}} \qquad (2)$$

Consider a given equipment (APL number), on a given ship, during a given year. Suppose that the ship has 2 units of this equipment. 3-M data does not always identify which unit is involved in a given action, but it does give the discovery and completion dates of all actions on both units. By keeping these dates in mind, and not just their total duration, we can count the number of days on which there are no outstanding actions at all. This time might be, say, 180 days during the year, so that the fraction above would be roughly .50 (180 days divided by 360 days of total time).

However, there are 2 units involved, and we must make some assumption about how actions on the 2 units are correlated if we are to identify the "uptime" percentage of each unit. The above formula assumes that the actions are independent (perfectly uncorrelated), so that A_o of each unit is the square root ($\frac{1}{2}$ power) of the percentage of "uptime" for both together. Thus, each unit must have an A_o of 71 percent of the time for both to be available only 50 percent ($\sqrt{.50} = .71$).

By keeping track of the actions on a calendar, this measure of A_o clearly avoids the problem of overlap.

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[1] Use of biased estimates, however, may still produce useful indications of trends over time.

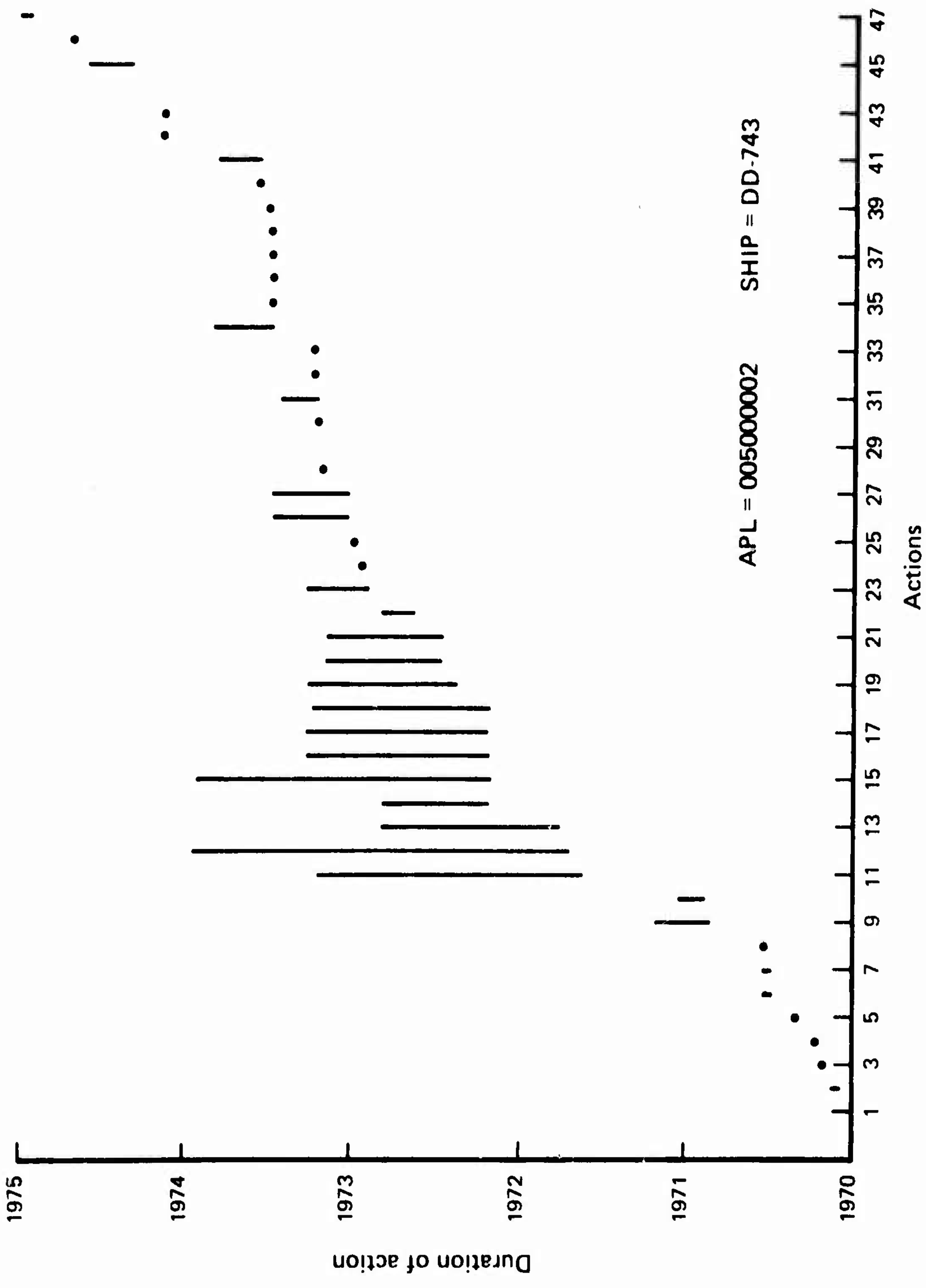

FIG. K-3: SIMULTANEOUS OCCURRENCE OF CORRECTIVE ACTIONS

A_o Results

Using formula (2), we evaluated A_o for each APL and each ship over the 5 years from 1970 to 1974, and took a simple average over ships. The resulting A_os are shown in table K-1. (From table B-1, electronic APL no. 1 refers to APL 49401930, etc.) There is substantial variation across APLs, as expected. The first two electronic APLs, for example, are far apart (.91 and .29), and by a large amount compared with the standard deviation across ships (.02 and .23).

Table K-2 evaluates A_o for failures: the sub-class of actions in which the equipment was non-operational upon discovery. These A_os are higher and less variable across ships. Because there is less overlap for failures, these A_os are in some cases quite similar to those shown in table F-1 which were calculated using formula (1). The average taken across time and across APLs is about 10 percent higher for the calendar method (formula (2)) as shown in table K-3.

Problem with A_o

Despite the advantages of the new A_o defined above and listed in tables K-1 and K-2, it cannot be evaluated yearly for our data base to indicate trends. Take the first year, for example. We would measure "up" time for 1970 by noting when the equipment is not down. However, our data contains information only for actions <u>starting</u> in 1970. Obviously, some units were down in 1970 because of actions that started in 1969 and earlier.

The situation is better in 1971 because few actions starting before 1970 will still be in progress in 1971, but there will be some.

On the other end of the time period there is a different kind of bias. Our data for 1974 excludes those actions starting in 1974 for which the 3-M 2-Kilo forms filled out by the ships had not found their way to Mechanicsburg by the time our data tapes were created in early 1975: some actions were still in progress in early 1975, and some others that were completed were delayed in transmission from the Fleet. A recent study by the Navy Manpower and Material Analysis Center, Atlantic,[1] found an average shipboard processing time of 38 days for 3-M forms filled out by units of CruDesLant, followed by delays for mailing, screening, and data processing which added additional weeks.

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[1] DoN Navy Manpower and Material Analysis Center, Atlantic, Report 4: fem, 4790, Ser 481/4, "NAVMMACLANT Task FWL-083, Accuracy and Timeliness of Ships 3-M Data," 4 April 1974

TABLE K-1

OPERATIONAL AVAILABILITY OF 60 APLs
(All actions, 1970-1974)

	E		O		HM&E	
APL	A_0	SD[1] Across Ships	A_0	SD[1] Across Ships	A_0	SD[1] Across Ships
1	.91	.02	.14	.11	.42	.15
2	.29	.23	.10	.07	.53	.16
3	.50	.22	.54	.12	.67	.00
4	.95	.05	.46	.22	.57	.19
5	.90	.10	.52	.24	.92	.05
6	.33	.25	.88	.09	.77	.08
7	.92	.05	.55	.28	.73	.19
8	.91	.09	.89	.08	.78	.16
9	.65	.19	.93	.06	.65	.23
10	.57	.20	.92	.06	.79	.14
11	.90	.11	.81	.27	.90	.10
12	.35	.23	.65	.18	.73	.19
13	.28	.23			.85	.12
14	.81	.15			.84	.14
15	.86	.12				
16	.88	.08				
17	.94	.08				
18	.91	.10				
19	.91	.12				
20	.90	.08				
21	.93	.06				
22	.93	.06				
23	.84	.15				
24	.79	.17				
25	.65	.26				
26	.75	.16				
27	.89	.16				
28	.91	.09				
29	.87	.09				
30	.88	.11				
31	.89	.12				
32	.94	.06				
33	.91	.12				
34	.85	.13				
Across All Ship-APL Combinations:	.83	.20(N=1128)	.64	.27(N=256)	.76	.20(N=263)

[1]Standard deviation

TABLE K-2

OPERATIONAL AVAILABILITY OF 60 APLs
(Failures, 1970-1974)

	E		O		HME	
APL	A_0	SD[1] Across Ships	A_0	SD[1] Across Ships	A_0	SD[1] Across Ships
1	.97	.05	.68	.25	.73	.15
2	.72	.15	.81	.12	.84	.10
3	.87	.13	.91	.07	.78	.00
4	.99	.00	.83	.17	.82	.03
5	.98	.04	.95	.09	.98	.02
6	.83	.14	.94	.06	.97	.02
7	.96	.01	.87	.16	.93	.07
8	.95	.07	.96	.05	.96	.10
9	.95	.07	.97	.06	.89	.13
10	.78	.15	.99	.02	.94	.09
11	.95	.05	.98	.03	.94	.08
12	.85	.14	.92	.07	.90	.11
13	.81	.14			.91	.11
14	.93	.07			.97	.04
15	.95	.06				
16	.97	.04				
17	.97	.05				
18	.96	.05				
19	.96	.04				
20	.96	.04				
21	.98	.02				
22	.98	.02				
23	.92	.11				
24	.93	.10				
25	.90	.13				
26	.92	.10				
27	.95	.07				
28	.98	.02				
29	.94	.05				
30	.96	.07				
31	.95	.08				
32	.98	.03				
33	.97	.05				
34	.96	.05				
Mean Across All Ship-APL Combinations:	.94	.09(N=979)	.91	.13(N=203)	.91	.11(N=208)

[1]Standard deviation

TABLE K-3

COMPARISON OF A_o AVERAGES*
COMPUTED FROM TWO METHODS
(Failures)

	A_0 (formula 1)	A_0 (formula 2)
E	.86	.94
O	.81	.91
HM&E	.82	.91

*Averaged across time and APLs.

Because of this problem, we measured operational availability using formula (1) to estimate time trends using our data base. Even though this measure is biased in absolute value our confidence in using it is increased by the fact that results from formulas (1) and (2) vary together, across one APL to the next. Table K-4 shows that the average value for the two measures are highly correlated.

TABLE K-4

CORRESPONDENCE BETWEEN A_o AND A_o'
(A_o for 1970-74, A_o' averaged over 1970-73)

		Correlation Coefficient
E		
	All actions	.90
	Non-operational actions	.93
O		
	All actions	.91
	Non-operational actions	.96
HME		
	All actions	.57
	Non-operational actions	.97

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