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MAINTENANCE COSTS OF COMPLEX EQUIPMENT

Allan Sherman and Stanley A. Horowitz

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CENTER FOR NAVAL ANALYSES
1401 Wilson Boulevard
~~Arlington~~, Virginia 22209
Alex.

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INTRODUCTION

One of the chief responsibilities of Navy managers is the material condition of ships in the fleet. They must be aware of equipment deterioration and must decide how to best allocate resources to reduce equipment downtime, thereby reducing maintenance costs and improving the material condition of the fleet. Among the questions this paper addresses are:

- How much more is complex equipment down? and
- Are high quality enlisted personnel more valuable in dealing with more complex equipment?

The answers to these questions indicate that fleet material condition can be improved by revised personnel policies. By more precisely assigning skilled men to ships with complex equipment, the Navy could reduce equipment downtime thereby improving readiness and decreasing maintenance costs.

A MODEL OF THE MATERIAL CONDITION OF SHIPS

The amount of time that equipment fails to function in a specified time period can be expected to depend on the kind of equipment, the age of the ship, length of time since the ship was last overhauled, and manning.[1] We used regression analysis to estimate the relationship between downtime due to shipboard equipment failures and its hypothesized determinants.

We have confined our examination to cruisers and destroyers: 40 destroyers (DDs), 18 guided missile destroyers (DDGs), 17 frigates (FFs), 4 guided missile frigates (FFGs) and 12 cruisers (CGs). These 91 ships are all the active ships of these types that underwent overhauls in fiscal years 1972, 1973, and 1974. To be sure that we were looking at comparable periods on all the ships, the entire period from one overhaul to a ship's next overhaul was considered.

Whenever a ship suffers an equipment failure that degrades its operational capability, it must file a casualty report (CASREPT). We have used CASREPT information to derive measures of maintenance effectiveness. CASREPT downtime per month is our key measure of shipboard material condition. CASREPT downtime is the number of casualties a ship had multiplied by the average time CASREPTs on that ship took to be fixed. CASREPT downtime in a month is equivalent to the average number of CASREPTs outstanding during that month.

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[1]Of course, additional factors such as morale and the availability of spare parts also affect equipment condition. We were unable to address thes factors explicitly in this paper.

Rather than study the determinants of CASREPT downtime for entire ships, we concentrated on several sub-systems. These sub-systems were chosen because they are common to a large number of cruisers and destroyers, and are maintained by men in a small number of ratings. The sub-systems are boilers, engines, gun systems, missile systems, anti-submarine warfare (ASW) systems, and sonars. Table 1 shows the ratings of the personnel who are responsible for the maintenance of these sub-systems.

TABLE 1

SUB-SYSTEMS STUDIED

Sub-system	Associated rating
Boilers	Boiler Technician (BT)
Engines	Machinist's Mate (MM)
Gun Systems	Fire Control Technician (FT) Gunner's Mate (GM)
Missile Systems	Fire Control Technician (FT) Gunner's Mate (GM)
ASW Systems	Gunner's Mate (GM) Sonar Technician (ST) Torpedoman's Mate (TM)
Sonars	Sonar Technician (ST)

As the table shows, the same ratings are sometimes responsible for part of the maintenance of more than one sub-system. To properly match men and equipment, we allocated CASREPTs both by rating and by sub-system.

In the equipment failure data we received, every CASREPT was classified according to the four-digit equipment identification code (EIC) of the piece of equipment responsible for the CASREPT. By examining the EIC's, every relevant CASREPT was assigned to one of the six ratings we are concentrating on: BTs, MMs, GMs, FTs, STs, and TMs.[1] In addition, for guns, missiles, and ASW, we used the EICs to

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[1]FMSO supplied a tape from the 3-M data system of all corrective maintenance actions taken on our 91 ships since 1970. This tape included information on who performed every action. We derived frequency counts of repair ratings for all relevant EICs. This allowed the assignment of CASREPTs (which do not include information on who did the work) referred to in the text.

derive sub-system-wide measures of material condition. These were correlated with the characteristics of crewmen in all relevant ratings.

The personnel characteristics examined are shown in table 2, along with other factors included in our analyses. The bulk of the personnel analysis in this paper relies on crew histories compiled from the Navy's Enlisted Master Record (EMR). To build these histories, we reviewed the records of the entire enlisted force between 1967 and 1975, and picked out the men on the 91 ships. We then developed aggregate statistics describing the characteristics of each crew by rating. This required weighting the characteristics of individuals by the fraction of the observation period they were assigned to the ship.

TABLE 2

DETERMINANTS OF MATERIAL CONDITION STUDIED

Personnel characteristics[a]

- Number of enlisted personnel
- High school graduation
- Entry test scores
- Paygrade profile
- Length of service (LOS)
- Time aboard this ship
- Time aboard other ships
- Number of Navy schools attended
- Number of NECs attained[b]
- Race
- Marital status

Other factors

- Ship age
- Overhaul frequency
- Equipment complexity

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[a]Data were also gathered on the age of enlisted men and on the number of officers aboard the ships. These factors did not prove to be important.

[b]Some Navy Enlisted Classification (NECs) on individuals can be gained only via school attendance; others can be earned on the job. We differentiated between these two types, and used the number of NECs of each type that men possessed as a measure of the extent of advanced training.

EXPECTED RELATION BETWEEN DETERMINANTS OF MAINTENANCE AND DOWNTIME

Maintenance downtime and costs should depend in part on the quantity and quality of men operating and maintaining the equipment. As a result the level of CASREPT downtime should vary inversely with the number of enlisted personnel. Men with more pre-Navy education and higher entry test scores in relevant areas should do better maintenance. We expect more experienced men to be more productive than less experienced men, and men in higher paygrades to be more productive than men in lower paygrades. Since more experienced men are more likely to have higher rank, an analysis which focused only on rank, for example, would be unable to determine how much of the added productivity of senior men reflected selection of the best men for promotion and how much was merely the result of experience. Including both paygrade and LOS in the analysis would disentangle the quality dimension of higher paygrade from the effect of experience. We did not assume that more experienced (or higher ranked) men continuously get better at their jobs. We examined the possibility that after a break-in period junior men reach a higher level of proficiency beyond which they tend not to improve, or that further significnt improvement only occurs after a considerable time.

Experience at sea may be more important in increasing the productivity of enlisted men than shore duty. We examined whether men with more prior sea duty tend to have ships with less CASREPT downtime and whether ships with more stable crews have less downtime. If either of these variables reflects higher productivity, the Navy's policy regarding sea-shore rotation will be open to question.

The completion of more Navy courses should lead to higher productivity, and thus to better maintenance.

The acquisition of certain advanced skills confers Navy Enlisted Classifications (NECs) on individuals. Some NECs can be gained only via school attendance; others can be earned on the job. We differentiated between these two types, and used the number of NECs of each type that men possessed as a measure of the extent of advanced training.

The impact of the race variable, the percent of the crew that is black, is not predictable, but its inclusion was nonetheless appropriate. If blacks receive lower quality educations, more blacks, holding educational attainment constant, may be associated with worse maintenance. If the Navy's entry tests discriminate against blacks, more blacks, holding text scores constant, may be associated with better maintenance. We hoped to discover whether the Navy's use of high school graduation and of entry tests as guides to recruitment and assignment is equally appropriate for blacks and whites.

We were also unable to predict how marital status correlates with the productivity of enlisted men. Married men may be more stable and more serious workers, and hence more productive. On the other hand, some married men may dislike sea duty a great deal. This disaffection may make them less productive.

For each of nine groups (BT, MM, GM, FT, TM, ST, guns, missiles, ASW) we estimated a relationship of the following form.[1] Ships are the units of observation in the analysis.

$$\text{Downtime} = f(\text{age, ovh diff}, \overline{\text{equipment}}, \overline{\text{pers}}) \quad (1)$$

where

Downtime = average CASREPT downtime per month;

age = age of the ship at the time of its overhaul in FY 72-74 (years);

ovh diff = number of months between overhauls;

$\overline{\text{equipment}}$ = a vector of dummy variables reflecting the kinds of equipment deployed on our ships;

$\overline{\text{pers}}$ = a vector of the enlisted personnel variables listed in table 2.

It was expected that newer ships would, other things equal, have less CASREPT downtime.

A longer gap between overhauls should lead to more equipment downtime. If it does not, ships are being overhauled too frequently.

Ships vary to some extent in their equipment. Usually these differences correspond to ship types or class differences; sometimes they do not. Obviously this may influence ships' maintenance histories. For instance, the 1200-pound boilers on some ships have had more problems than the older 600-pound type because of technical innovations in their design. In general, more complex equipment is expected to be down more often. Because of the differences between these two types of boilers, allowed for the possibility that personnel contributions to the maintenance of boilers were different for ships with 600-pound plants and

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[1]In addition, the relative condition of ships based on the east and west coasts was examined. The west coast ships appeared to have less CASREPT downtime (they also steamed significantly more). Finally, using a procedure for looking at all our ratings simultaneously, we checked for whether there were systematic tendencies for some ships to be better than others in all areas. In some cases there were. Inclusion of these coast and ship variables did not have a large effect on the impact of the variables in equation (1) on CASREPT downtime, thus we have concentrated on the results of the estimating formulation in the equation.

1200-pound plants.[1] On other sub-systems we also allowed for the possibility that characteristics related to crew quality were more valuable on ships with more complex equipment. Our tests of this possibility are the main focus of this paper. Equipment variations for the sub-systems will be discussed along with the empirical results.

We estimated equation (1) using ordinary least squares. The period of observation for the dependent variables was either the entire time between a ship's overhaul in FY 1972, 1973, or 1974 and its previous overhaul, or as much of this period as possible (always at least 18 months before the more recent overhaul). For the explanatory variables, the entire inter-overhaul period was used. The condition of a piece of equipment depends not only on the care it is getting now, but also on the care it received in the past. This is why a long observation period was used, and why it seemed desirable to use a longer observation period for the explanatory variables than for downtime when the complete CASREPT data set was not available. We hoped to capture the long-run effects of variation in the determinants of maintenance effectiveness.

DISCUSSION OF RESULTS

The relationships between individual characteristics and downtime varied widely across enlisted ratings and, for a large part, depended on the complexity of the equipment being maintained. Not only was complex equipment in worse condition, but it required more-skilled men to maintain it. For reasons of brevity, only the estimated equations for boilers and those areas related to equipment complexity will be presented in detail. A summary of results will also be included.[2]

ENGINEERING

For the most part, the ships have one of four kinds of propulsion plants. All of the DDs in the Forrest Sherman Class, all the DDGs, and all the CGs have 1200 p.s.i. main propulsion plants and two screws. The older DDs also have two screws, but 600 p.s.i. plants. The FF 1052 class has one screw and 1200 p.s.i. plants, while the FF 1040 (Garcia) class

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[1]This was done by multiplying each personnel variable by both a 600-pound ship dummy and a dummy for ships with 1200-pound plants. The two variables were entered separately into the equation being estimated. If this procedure did not improve the explanatory power of the equation, its results were discarded.

[2]A complete presentation of results can be found in "Personnel Performance and Ship Condition," CNA Study 1090, March 1977, and is available from the authors upon request.

and FFGs have one screw and pressure-fired boilers.[1] Distinguishing among these kinds of systems proved to be very important in explaining the material condition of boilers as measured by CASREPT downtime.

Table 3 lists the CASREPT downtime for different kinds of plants. The more complicated 1200 p.s.i. plants obviously have more boiler trouble than 600 p.s.i. plants. Because boiler downtimes for the two types of one-screw plants were similar, they have been treated together in the rest of the analysis. We suspect that the FRAM DDs have more engine downtime because their engine rooms contain equipment that is in the fire rooms of other ships and so MMs do work that BTs do elsewhere.

TABLE 3

CASREPT DOWNTIME FOR ENGINEERING SYSTEMS

Ship classes or types	Number of ships	Kind of equipment	Average CASREPT downtime (hrs/mo) BT-related	MM-related
CG, DDG, Forrest Sherman destroyers (except DD 933)	36	2 screws, 1200 p.s.i.	730[a]	222
FRAM destroyers	33	2 screws, 600 p.s.i.	218	349
FF 1040, FFG 1	11	1 screw, 1200 p.s.i. pressure-fired	318	279
FF 1052	8	1 screw, 1200 p.s.i.	301	143

[a]730 is approximately the number of hours a month. This means that on the average, these ships have one boiler CASREPT outstanding. Since they have four boilers, three are usually CASREPT-free. In any case, existence of a CASREPT does not necesarily imply complete inability to operate. 75 percent of all CASREPT downtime is C-2, implying minor degradation of mission-essential equipment. If equipment is C-3, it is termed marginally ready. C-4 means not ready. In this study all three types of CASREPTs have been aggregated together.

[1]The 91 ships included one diesel-powered ship, one 600 p.s.i. ship with one screw, and one Forrest Sherman ship without automatic combustion control. All three ships were deleted from the BT analysis.

Boiler Technicians

The predictive relationship estimated for equipment maintained by BTs are displayed in table 4. The coefficients are the best estimates of the effect of a one-unit change in each of the explanatory variables on the average number of hours of boiler CASREPT downtime per month. These results are never in an unexpected direction and are often quite significant.

Equipment complexity affected not only material condition, but also the effect of the crew on material condition. Crew quality, as measured by entry test scores, paygrade, training, and length of service, seems to have mattered much more on 1200 p.s.i. ships, particularly those with two screws. We estimate that an increase of one percentage point in the average Shop Practices Test scores of BTs on two-screw, 1200 p.s.i. ships would lower CASREPT downtime by an average of 138 hours per month. There is also a very high payoff to having rated personnel. A one percentage point drop in the fraction of BTs who are unrated (E-3 or below) is associated with a drop of 25.19 hours in CASREPT downtime per month. Married BTs are less productive than single BTs on two-screw, 1200 p.s.i. ships. Perhaps they are less willing to put in the long hours the job requires. Training was important on one-screw ships, though not as important as on two-screw, 1200 p.s.i. ships. If a quarter of the BTs attended one extra school, we estimate that CASREPT downtime would fall by 72 hours a month on the one-screw ships. Crew size, on the other hand, was more important on 600 p.s.i. ships. We estimate that an additional BT would reduce downtime by 71 hours per month.[1]

These results do not mean that crew size makes no difference on 1200 p.s.i. ships or that Navy training makes no difference on 600 p.s.i. ships. They do mean that variations in these characteristics within the ranges observed in the fleet are not likely to make much difference.

Not surprisingly, we found that, other things equal, older ships had significantly more boiler problems.

Table 5 gives our best estimate of how personnel policies could be changed to cut boiler-related CASREPT downtime by 50 hours per month on destroyers with different kinds of fire rooms. The greater the indicated

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[1]The data on crew size that were used here came from BuPers Form 1080. We gathered this information only for the DDs in the sample. Perhaps if we had had it for all 88 ships in this analysis, crew size would have appeared more important for the 1200 p.s.i. ships. (There were six 1200 p.s.i. DDs in this sample.) When data on crew size from the Enlisted Master Record were used, no effect of crew size was found. Usually the EMR and Form 1080 measures of crew size correlated quite highly (an average of .67). For BTs, the only rating for which results using Form 1080 data are presented, the correlation was only .48.

TABLE 4

DETERMINANTS OF MATERIAL CONDITION FOR BOILERS
(CASREPT downtime, hours per month)

Explanatory variable	Coefficient	t-value
Personnel variables		
On two-screw, 1200 p.s.i. ships		
Average score on Shop Practices Test	-138	-3.34[c]
Percent of BTs who are E-3 or below	25.19	3.00[c]
Percent of BTs who are E-8 or above	-34.06	-1.19
Percent of BTs with under one year in the Navy	35.65	2.50[b]
Average number of school-related NECs per BT	-1586	-4.26[c]
Percnt of BTs who are single	-23.20	-3.29[c]
On one-screw ships		
Average number of Navy schools attended by BTs	-287	-1.87[a]
On two-screw, 600 p.s.i. ships		
Average number of BTs	-71	-3.72[c]
On all ships		
Percent of BTs with under 10 years in the Navy	8.94	1.29
Non-personnel variables		
Equipment complexity		
Two-screw, 1200 p.s.i. plant	7924[1]	3.60[c]
Logarithm of ship age (years)	515	3.22[c]
Constant	-635	

Corrected R^2 = .52
Degrees of freedom = 76

[a]Significant at the 10 percent level.
[b]Significicnt at the 5 percent level.
[c]Significant at the 1 percent level.
[1]The coefficient of 7924 does not mean that two-screw, 1200 p.s.i. ships have on average 7924 more hours of downtime a month than other ships. In cases like this, where different coefficients are estimated for different types of equipment, or where the characteristics that enter the predictive relationship differ by equipment type, one cannot look at the coefficient of an equipment-type dummy variable as reflecting the differential downtime of that kind of equipment. To derive an average difference in downtime per month by equipment type, one must use the entire relationship to estimate average downtimes for different kinds of equipment at reasonable values of the independent variables. A comparison of the numbers in the third column of table 3 gives a good indication of the impact of equipment complexity on the material condition of boilers.

TABLE 5

POTENTIAL WAYS TO CUT BT-RELATED CASREPT DOWNTIME BY 50 HOURS PER MONTH

Type of propulsion plant	Crew characteristics	Observed level	Required level
Two-screws, 1200 p.s.i.	Average score on Shop Practices Test[c]	55	56
	Percent E-4 or below[c]	33	31
	Percent E-8 or above	3.8	5.2
	Percent with LOS under 1 year[b]	6.9	5.8
	Percent with LOS 1-10 years	72.9	67[a]
	Average number of school-related NECs per man[c]	.46	.49
	Percent single[c]	47	49
One screw	Percent with LOS under 10 years	79.4	73.8
	Average number of Navy schools attended per man[a]	1.90	2.07
Two screw, 600 p.s.i.	Crew size[c]	22.4[b]	23.1
	Percent with LOS under 10 years	79.4	73.8

[a]Significant at the 10 percent level.

[b]Significant at the 5 percent level.

[c]Significant at the 1 percent level.

statistical significance (one percent is more significant than five percent), the more confident we are that movement in the indicated direction would improve material condition. Our estimates indicate that it would be fairly easy to accomplish such an improvement in material condition, especially in the most complex fire rooms. This may be because the two-screw, 1200 p.s.i. plants are in relatively poor condition to begin with.

Machinist's Mates

In examining the determinants of the condition of engines, we distinguished among different kinds of main propulsion plants in the same way we did for boilers. As might be expected, steam pressure played a smaller role in engine condition than it did in boiler condition. Table 3 demonstrated this.

Factors that influence CASREPT downtime seem to be quite similar on all two-screw ships.

Experience seems to be the most important characteristic of MMs. Not all experience is equally important, however. On all 89 ships in this sample,[1] it helped to have men who have been in the Navy over three years. For all but the one-screw ships, sea experience was apparently more valuable than shore duty. Frequent rotation seemed to detract from maintenance. On two-screw, 1200 p.s.i. ships in particular, sea duty had a high payoff. Even holding LOS and time in current billet constant, having a smaller proportion of unrated men helped on 600 p.s.i. ships.

Having more MMs on board improved material condition on the two-screw ships. Apparently larger crews were more important on the 600 p.s.i. ships. This is similar to our finding for BTs. Perhaps this illustrates the greater importance of the number of workers when there is a less complex plant.

Training was found to improve the productivity of MMs in some cases. Holding the number of NECs constant, additional schooling was estimated to detract from maintenance. This may reflect the attendant decrease in valuable sea experience.[2] When an NEC was attained, however, the gain more than made up for the loss due to school attendance. NECs that do not require formal schooling may be particularly valuable, although the

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[1]The Forrest Sherman destroyer (DD 933) without automatic combustion was included in this sample.

[2]Sometimes men attend schools while they are assigned to ships. In such cases our sea experience variable will overstate actual sea experience. The school variable may pick this up.

cost of picking up skills on the job is very hard to measure and may be quite high.[1] Once again, older ships were in significantly worse shape.

GUNS AND MISSILES

Because both FTs and GMs are responsible for part of the operation and maintenance of both guns and missiles,[2] analysis of these systems is a bit more complicated than analysis of the engineering systems where different ratings are responsible for boilers and engines. As noted earlier, we used 3-M data to assign CASREPTs to the rating responsible for the equipment, regardless of what subsystem it is part of. The equations we derived from this assignment by rating are our best estimates of the influence of crew characteristics on maintenance. They do not, however, allow us to address questions regarding how best to improve the condition of particular subsystems.

To address these questions, we have also estimated equations by subsystem. Thus, the material condition of guns is studied as a function of the characteristics of both GMs and FTs, as is the material condition of missiles.[3] These subsystem equations do not associate men with all the work they do, but they allow us to analyze the condition of specific weapon systems.

It is clear, from table 6, that CASREPT downtime varies widely among ships with different kinds of equipment. Ships with 5"54 guns have more GM and gun downtime. This is especially true of Forrest Sherman ships, which also have 3"50 guns. Missile ships with the Mk 72 fire control system have much more FT and missile downtime than other ships. These ships are equipped to use the Navy Tactical Data System (NTDS). 5"54 guns also seem to be associated with fire control problems, except on the FF 1052 class, which has only one mount and the simplest missile system.

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[1]See Weiher and Horowitz, "The Relative Costs of Formal and Job Training for Navy Enlisted Occupations," CNA Professional Paper 83, November 1971.

[2]GMs also work on ASW equipment.

[3]We did not distinguish between, for example, GMMs and GMGs because the distinction disappears above paygrade E-6.

TABLE 6

	Number of ships	Gun downtime	GM downtime
Forrest Sherman class DD's	7	860	567
Others with 5"54 guns	34	302	237
All others	50	212	184
	91		

	Number of ships	Missile downtime	FT downtime
Ships with Mk 72 FCS	12	828	905
Other DDGs (5"54 guns)	18 }	318	369
FFGs	4 }		178
FF 1052 class (5"54 guns)	25		117
Forrest Sherman class (5"54)	7		348
All others	42		164
	91		

Gunner's Mates

Despite the substantial differences in GM-related downtime between ships with different kinds of equipment, the effect of crew characteristics on downtime appears to be similar on all the ships we examined. Experience seems to be the best predictor of the value of GMS. Men with less than one year of service bring about much higher levels of CASREPT downtime. Other first termers also significantly degrade material condition.

The presence of E-8s and E-9s was associated with improved material condition. This may reflect the inherent ability of men who reach those paygrades. To some extent it may reflect their training. We point this out as a warning against too simplistic a view of our results here regarding training. As was the case for MMs, attending more schools was associated with more equipment downtime -- when paygrade and LOS were held constant. Schooling may, however, play an important role in making senior people better than junior people. Our results indicate that men who reach senior status with less schooling are better than those who require more schooling to reach the same position. Once again, we find that attainment of NECs reflects improved performance, whether or not school attendance was a requirement.

Fire Control Technicians

The relationship between the characteristics of FTs and the amount of CASREPT downtime suffered by equipment in their care seems to vary considerably among ship classes. In general these variations reflect differences in the complexity of equipment. NTDS ships, i.e., CGs and the DDG 37 class, seem to need high quality personnel more than other ships.

Paygrade and experience are the only personnel characteristics estimated to be important on all ships, although these estimates did not pass standard tests of statistical significance. More frequent overhauls also seemed to cut FT-related downtime on all ships. Paygrade seemed to relate to proficiency in two discrete steps (except on FF 1052 class ships): men who have not reached E-5 are less proficient than those in paygrades E-5 through E-7; E-8s and E-9s are yet more proficient. Variation (in the range we observed) in the number of FTs seemed to cut CASREPT downtime only on FRAM destroyers and FF 1040 class frigates, among the least complex ships studied. This is similar to our findings for the engineering ratings. The use of high quality recruits as FTs was important, especially if they were assigned to NTDS ships. High school graduates and men who scored well on the Arithmetic Reasoning Test were associated with less CASREPT downtime.

Somewhat surprisingly, since almost all of them scored quite high, variation in the entry test scores of FTs mattered. The importance of entry tests is reinforced by the finding that, on some guided missile ships, black FTs are estimated to be more productive than whites. FTs are the only rating where a racial difference was observed. This may mean that, because high ability blacks have more trouble with the entry test, blacks who do score high enough to become FTs are better than whites who meet the screening criterion.

Among those areas we examined, one of the easiest ways to cut the amount of fire control downtime would be to screen out non-high-school-graduates even more carefully and to find more blacks who meet the FT requirements. Shifting high quality personnel to the most complex ships would be expected to decrease fire control downtime on a fleet-wide basis.

ANTISUBMARINE WARFARE

The operation and maintenance of ASW equipment is performed by men in three ratings: sonar technicians, torpedoman's mates, and gunner's mates. The ASW tasks handled by GMs have already been included in our estimates of the relative productivity of different kinds of GMs.

Our ships had two kinds of sonars, SQS-23 and SQS-26.[1] Ships with the SQS-26 had substantially more ST-related downtime than those with the SQS-23, an average of over 250 hours per month, compared to 94 hours per month.

[1]The FF 1036 had an SQS-32 sonar. It was omitted from the ST regression, but included in the TM and ASW regressions.

All 91 ships had Mk 32 torpedo tubes. Most had Mk 16 ASROC launchers. Table 7 shows how downtime varied according to equipment.

The ASROC ships had much more ASW downtime than the others. Although SQS-26 sonars were associated with more sonar downtime, they may have had less ASW fire control downtime. ASROC ships with SQS-26s had less ASW downtime than those with SQS-23s, and the same pattern was observed on non-ASROC ships.

Torpedoman's Mates

As table 7 shows, eqiupment maintained by TMs has very little CASREPT downtime. Some ships do not have one TM on board at all times, and thus, not much equipment is the responsibility of TMs. Still we were able to find significant connections between TMs and the condition of their equipment on ships equipped with ASROCs. Ships that had more TMs had less CASREPT downtime. In addition older ships and ships that go longer between overhauls have more TM-related CASREPT downtime.

Sonar Technicians

Equipment complexity has a great deal to do with how frequently sonar equipment is down. Equipment maintained by STs has more CASREPT downtime on ships with SQS-26 sonars and on ASROC ships. Surprisingly, the impact of differences in the characteristics of STS was estimated to be the same on all 90 ships in this sample, regardless of their equipment.

STs who have graduated from high school are more productive than non-graduates.

Sea duty is the key element in the experience of STs. Longer length of service and higher paygrade are associated with higher productivity only if they reflect more sea experience. A related finding is that single STs are more productive than married men. This may be due to a lesser aversion to sea duty.

GENERAL CONCLUSIONS

The condition of shipboard equipment was affected by the complexity and age of the equipment, the length of time since it was last overhauled, and the number and characteristics of the men who operate and maintain it. Crew characteristics that influenced the productivity of enlisted men included high school graduation, entry test scores, race, marital status, length of service, paygrade, sea experience, and advanced training. Not all of these factors made a difference for all kinds of equipment, but in all cases some of them mattered.

Our results are summarized in table 8. It displays the characteristics found to influence the productivity of men in each of the six

TABLE 7

DOWNTIME FOR DIFFERENT KINDS OF ASW EQUIPMENT
(CASREPT downtime, hours per month)

<table>
<tr><th></th><th>Ship classes</th><th>Number of ships</th><th>TM downtime</th><th>ST downtime</th><th>ASW downtime</th></tr>
<tr><td>SQS-26 sonar plus ASROC</td><td>FF 1037 class, FF 1040 class, FF 1052 class, FFG 1 class</td><td>20</td><td rowspan="2">18</td><td>268</td><td>103</td></tr>
<tr><td>SQS-23 sonar plus ASROC</td><td>FRAM destroyers, DD 933, DDG 2 class, DDG 31 class, DDG 35 class, DDG 37 class, CG 16 class</td><td>58</td><td>95</td><td>127</td></tr>
<tr><td>SQS-26 sonar without ASROC</td><td>CG 26 class</td><td>6</td><td rowspan="2">10</td><td>234</td><td>2</td></tr>
<tr><td>SQS-23 sonar without ASROC</td><td>Forrest Sherman DDs, except for DD 933</td><td>6</td><td>83</td><td>37</td></tr>
</table>

ratings examined. It also shows other factors that affected the condition of equipment handled by men in each of the ratings. A check signifies a relationship that was expected; an "X" means that it was not. A blank means that no relationships were found.

Equipment complexity was a major influence affecting the condition of all kinds of equipment. An important facet of our results not captured by table 8 is that in several ratings higher skill levels reflected in education, test scores, experience, or training increased productivity only when men handled relatively complex equipment. On the other hand, variations in crew size seemed to make the most difference on simpler ships.

In all ratings, men in higher paygrades were more productive than their juniors, even when length of service was held constant. Except for TMs, some measure of LOS related positively to productivity. For STs, sea duty was the only kind of experience found to increase productivity. Sea duty was also important in several other ratings.

The results regarding paygrade and experience must be interpreted carefully. They mean that men who get promoted under existing policies are more productive than men who do not. They do not mean that more men should be promoted. The mere act of promotion does not make men more valuable.

In calculating productivity differences for men with different lengths of service, other factors that differ with LOS must be considered. For example, men who have been in the Navy ten years are likely to be in higher paygrades than men who have been in five years. The probability of promotion and the estimated additional productivity of men in higher paygrades must be taken into account in comparing the value of men with different lengths of service.

FTs and STs were more productive when they were high school graduates. In less technical ratings, high school graduates were not found to be more productive than other men of the same paygrade and LOS. Entry test scores predicted the performance of BTs, GMs, and FTs.

Variations in productivity reflected variations in training in all of the ratings except FTs. Perhaps FTs are so highly trained that variations do not matter much. When paygrade and LOS were held constant however, additional school attendance helped MMs and GMs only when it led to attainment of an NEC. (Interestingly, there were two ratings where sea experience was more valuable than shore duty in increasing men's productivity.) Some of the value of training may have been picked up by

TABLE 8

DETERMINANTS OF PERSONNEL PRODUCTIVITY AND EQUIPMENT CONDITION AS MEASURED BY CASREPT DOWNTIME

Crew characteristics or other determinant of material condition	BT	MM	GM	FT	TM	ST
Crew size	✓	✓		✓	✓	
High school graduation				✓		✓
Entry test scores	✓		✓	✓		
Paygrade	✓	✓	✓	✓	✓	✓
Length of service	✓	✓	✓	✓	X	
Sea experience } aboard prior ships		✓	✓			✓
Sea experience } aboard current ship		✓				
Training } number of schools attended	✓	X	X		✓	✓
Training } number of NECs attained	✓	✓	✓			
Marital status	✓					✓
Race				✓		
Ship age	✓	✓			✓	
Time between overhauls			✓	✓	✓	
Equipment complexity	✓	✓	✓	✓	✓	✓

paygrade variables. This will be the case if some men benefit from training and others do not, and if those who benefit are more likely to be promoted.

Single STs and BTs were found to be more productive than married men in those ratings.

Entry tests may discriminate against black FTs, who were more productive than expected on the basis of test scores and high school graduation. The effect was not found in other ratings.[1]

Older ships had more CASREPT downtime, particularly in engineering. Ships with longer gaps between overhauls also had more downtime, especially in weapons.

Our results have implications for what policies should be followed to improve the management of enlisted personnel. In many cases, discovery of the precise nature of these implications requires calculation of the cheapest way to improve material condition. This, in turn, requires that estimates of differences in productivity be combined with estimates of differences in the cost of personnel with various levels of education, ability, experience, and training. In other cases, the implications of our results are apparent without further analysis:

- o Particularly for BTs and FTs, place a higher proportion of senior men and highly trained men on ships with complex equipment. This would both cut total equipment downtime and increase the availability of high-performance equipment.
- o Pay more attention to the level of manning on ships with less complex equipment, especially in engineering and fire control. We would not recommend manning cuts where we found no effect of crew size, however, because maintenance is not the only task men have.
- o Do not screen men so strictly on the basis of high school graduation and entry test scores in ratings where these characteristics do not seem to increase productivity.
- o Try to get STs to spend more time at sea by paying special sea pay selectively to certain ratings.
- o Although higher entry test scores do not always indicate higher productivity, they usually do not seem to discrimiante against blacks. FTs are a exception. Perhaps give blacks waivers to become FTs, even if they do not quite meet the usual criteria.

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[1]CNS Study 1039, "Enlisted Selection Strategies," by R.F. Lockman, found that entry tests are relatively poor predictors of the success of blacks in electronics schools in the Navy (p. 10).

- Re-examine the policy of paying single men less than married men. Currently, housing allowances and other benefits (PX privileges, medical care) favor married men. Wherever we found a difference in productivity between single and married men, the single men were better.

- Pay more attention to the maintenance implications of introducing complex new equipment.

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