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AN ANALYSIS OF MH-53E AIRCRAFT MAINTENANCE MANPOWER IN JAPAN MARITIME SELF-DEFENSE FORCE (JMSDF)

by

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June 1994

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AN ANALYSIS OF MH-53E AIRCRAFT MAINTENANCE MANPOWER IN JAPAN MARITIME SELF-DEFENSE FORCE (JMSDF)

by

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Submitted in partial fulfillment
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ABSTRACT

The author examines the MH-53E helicopter maintenance policy in view of the JMSDF's concern. The maintenance data from December 1989 through June 1993 was examined using descriptive statistics and multiple regression analysis. In particular, the manpower reallocation, learning-effect and adequacy of spare-parts are discussed in this context.

The study indicates successful maintenance practice in reducing the unscheduled maintenance hours and awaiting supply hours. A statistically significant learning effect was not observed using the existing available data set. The regression analysis has identified statistically significant factors that explain the behavior of the mission-capable hours and the maintenance-work hours.

Two policy recommendations are formulated: The first is a need for a more flexible manning policy that reflects and incorporates the actual maintenance experience and requirement. The study proposes a more dynamic and flexible manning policy based on actual requirements and experience. The second recommendation deals with a need for more detailed costs and manpower data to achieve MSDF-wide cost-effective resource allocation. For the maintenance policy to be cost-effective, it is imperative to develop such a data set.

TABLE OF CONTENTS

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Lastly and most importantly, the greatest support was from the author's wife, Mrs. Kyoko Motohashi and their son.

EXECUTIVE SUMMARY

Japan Maritime Self-Defence Force (JMSDF) defines the aircraft operating hours (OPS_HR) as the sum of mission capable hours (MC_HR), maintenance hours (MNT_HR), administration hours (ADMN_HR) and awaiting supply hours (AWS_HR). JMSDF is interested in maximizing the mission capable hours (MC_HR) by managing both quantity and quality mix of maintenance work force, and the level of inventory for repair-parts.

The author examines the MH-53E helicopter maintenance policy in view of the above stated JMSDF's policy concern. The maintenance data from December 1989 through June 1993 was examined using descriptive statistics and multiple regression analysis. In particular, manpower reallocation, the learning-effect and adequacy of spare-parts are discussed in this context.

The study indicates successful maintenance practice at the shop level in reducing the unscheduled maintenance hours and awaiting supply hours for MH-53E. However, the future staffing policy should reflect a more realistic manpower usage at the shop level. A statistically significant learning effect was not observed using the existing available data set. This may be more due to the limitations of the data set than to the reflection of reality. The regression analysis has identified statistically significant factors that explain the behavior of the mission-capable hours and the maintenance-work hours.

Two policy recommendations are formulated: The first is a need for a more flexible manning policy that reflects and incorporates actual maintenance experience and requirements. Under current policy, manpower requirements per aircraft remains fixed based on prior knowledge rather than actual operating experience. The total requirement for a given aircraft type is computed by multiplying such an initial estimate by the total number of aircraft deployed. This practice resulted in significant over/under staffing of the maintenance workforce and further retraining. The study proposes a more dynamic and flexible manning policy based on actual requirements and shop experience.

The second recommendation deals with a need for more detailed cost and manpower data to achieve MSDF-wide cost-effective resource allocation. JMSDF currently collects limited numbers of aggregate data points which are not totally suited for marginal cost analysis. In examining the manpower policy, the need for a trade-off analysis between manpower vs spare/repair parts inventory or an analysis between scheduled vs unscheduled maintenance hours became quite clear. We are unable to conduct either of these analyses due to a lack of appropriate micro-data. For the maintenance policy to be cost-effective, it is imperative to develop such a data set.

In the absence of a correct trade-off framework, we are bound to be too "efficient" in one of such endeavors and perpetually finding ourselves in a costly sub-optimal world.

I. INTRODUCTION

A. BACKGROUND

With the end of the Cold War, "peace dividend" meant significant reduction in military budget of many countries. This reduction in force is being carried out not only in the United States but in many other countries. The military planners are obliged to review the scale of their national defense. Nowadays, it is essential for defense planners to optimize defense resources.

Among the myriad of resources, human resources are still the most important component in armed services, especially in maintenance activities. The share of human related expenses easily exceeds more than a half of defense budgets and equals to two-thirds of the life cycle costs of weapon systems. Therefore, it is essential to examine how the manpower resources have been used and to explore ways to improve their future usage.

B. PURPOSE

The purpose of this thesis is to analyze the factors that influence the productivity of MH-53E maintenance personnel in the Japan Maritime Self-Defense Force (JMSDF). The maintenance data from December 1989 through June 1993 was examined using descriptive statistics and multiple regression analysis.

Two primary research questions are asked:

1. What has been the nature of maintenance manpower policy for MH-53E mine counter-measure helicopters?

2. How can we improve the manpower policy for MH-53E in the future?

C. FRAMEWORK OF THE RESEARCH

1. Outline

There are four parts of this thesis. The first part defines the concept of efficiency in military manpower policy. The second part provides the background information about MH-53E maintenance in JMSDF. The third part examines and analyzes historical maintenance data of MH-53E Squadron. The final part presents findings and conclusion.

2. Methodology

Historical aircraft status and maintenance data on JMSDF's MH-53E was collected from the Reliability Management Division, Aircraft Repair Facility, Shimofusa in Japan. This data was used to form descriptive statistics and to conduct multiple linear regression. Several software packages were used to conduct the data analysis. U.S. Navy data was used as a reference to compare with the JMSDF's data.

3. Scope

The maintenance productivity was examined by analyzing the relationship between maintenance works performed, mission capable hours and the flight hours created. In the process of the analysis, we are able to identify and evaluate a dynamic work-mix adjustment by the MH-53E maintenance managers.

In order to obtain for a more cost-effective maintenance policy for MH-53E, one needs to examine trade-offs between the scheduled vs unscheduled maintenance hours and between manpower and spare/repair parts inventory. This thesis, however, due to the limited nature of the available data and time limitation focuses only on the maintenance activities at the squadron level.

II. DEFENSE MANPOWER EFFICIENCY

A. INTRODUCTION

In the design of military weapons systems the problem is usually stated as: "Given a mission requirement and a fixed budget, what are the optimal number and design of weapon systems?"

This general problem statement has received considerable attention in recent years because of the phenomenal increase in unit cost of the military system. Some observers consider the increases as evidence of "military inefficiency" or "waste due to bureaucracy." However, the cost increases are not confined to the military but are also observed in commercial systems. For example, the cost of a B747 aircraft is about one thousand times that of a DC-3, but no one would argue that a DC-3 is more economical and efficient. The concept of efficiency, when the dimension of output is changing, is not as easy to define as one might consider.

The manpower requirement, the major cost driver for operating and maintaining a weapon system, is a function of future "work load". Manning efficiency is accompanied with a prediction of future scenarios. The manning policy, therefore, must have a reasonable way to assess both present and future operating conditions and personnel and training parameters to be effective.

The estimates of wartime demands and wartime productivity are often derived from historical episodes, peacetime maintenance experience, and military exercises that simulate wartime conditions. Therefore, large "waste" or "military defeat" could easily occur if a policy maker fails to properly estimate wartime conditions. The coordination between wartime demand and designing force level under a particular scenario is crucial in minimizing such losses.

U.S. Navy establishes manpower requirements that insure a validated and justifiable determination of both military and civilian billets through qualitative and quantitative analysis. Although the requirement process is clear and transparent, it is not always certain that the policy is efficient. This process is not even transparent at JMSDF. JMSDF does not publish the procedure in determining what manpower requirement is necessary. It is indeed challenging to judge the effectiveness of JMSDF's manpower policy in this environment.

B. EFFICIENCY CRITERIA

If the taxpayers' money is spent prudently on the manpower component of national defense, three conditions must be satisfied. First, for the money spent on manpower, the taxpayer should receive the maximum possible increase in the national security. Second, the last unit of money spent on manpower should contribute just as much to the nation's security as the last unit of money spent on procurement, stock of spare parts, or any other defense resource input. Third, taxpayers should expect the same value from the last unit of money spent on the national defense as that from the last unit spent on any other government program.

The first condition ensures efficiency within the defense manpower program, such that the government receives the most out of each manpower expenditure. The second ensures proper balance between defense manpower and all other factors that contribute to national security. If the last unit of money spent on manpower contributes less than the last unit used on procurement, then a reallocation of funds from manpower to procurement will improve national security. Finally, the third condition ensures that the nation spends the "right" amount on national defense compared to other government programs. Determining that amount is largely a matter of subjective judgment and the political process. Consequently, only the first two considerations will be discussed in this thesis.

Manpower requirement processes are designed to achieve technical efficiency in the use of defense manpower. During this process, analysts measure the work load and develop a standard work day for a particular skill level. Then they compute the manpower sufficient to accomplish the work, given the technological relationship between inputs and outputs.

The starting point for assessing efficiency within the manpower program is the identification of goals and functions that manpower is tasked to achieve. Force structure, of which the weapons systems are a part, and the configuration of the structure are not something that manpower policy-makers could change. Instead, the goal for the manpower policy maker [illegible]o staff the existing force structure with its [illegible]d configuration of weapons systems as efficiently as possible.

Two types of efficiency may be distinguished. The first involves technical efficiency, which achieves the most out of the resources employed. The second type is economic efficiency that requires not only technical efficiency but requires the least cost mix of resources to produce a given level of output.

Knowledge of the technological relationship between inputs and outputs is a prerequisite for technical efficiency. Attaining technical efficiency in defense manpower requires information concerning the number of man-hours at a specified skill level needed to perform particular work. The least man-hours method is technically efficient while it does not reflect economic efficiency because the cost of labor is not considered. Therefore, the policy currently in-place can achieve only technical efficiency at best to the extent that managers often ignore the opportunity costs of using a different skill-mix.

C. MANPOWER IN ILS CONCEPT

The size of flight and ground maintenance crews are determined during the weapons system design phase. From the earliest acquisition process, the human element must be an integral part of system design and logistic support in the ILS process[1]. The integration is achieved by systematically seeking ways to improve methods of operations and by identifying the appropriate occupation, skill level and manpower mix. The staffing standards developed during this process tries to identify the most efficient manpower mix and quantity.

The most common method of developing a manpower requirement is through regression analysis[2]. In deriving manpower requirements, analysts often simply divide given man-hours demand by an estimated amount of labor productivity. Although there are many sources of complications and potential errors, the end products are typically used as a cost effective manpower baseline to support defense policy.

ILS: A composite of all the support considerations necessary to ensure effective and economical support of a system for its life cycle. It is an integral part of all other aspects of system acquisition and operation. (OPNAVINST 4790.2E)

Statistical Techniques For Manpower Planning (Bartholomew, David J, John Wiley & Sons Ltd 1979)

III. MH-53E MAINTENANCE IN JMSDF

A. ISSUES SURROUNDING MH-53E

From 1958, JMSDF has adopted major weapon systems that have been used by the United States Navy. Most of this procurement was made by Foreign Military Sale, or licensed production under bilateral negotiations. MH-53E airborne MCM helicopter was first introduced in 1989 under the Midterm Defense Program. Only one squadron consisting of eleven aircraft is currently planned (TABLE I). As of today, ten aircraft are deployed and another one is in pipeline.

Aircraft inventory in JMSDF is quite diversified: eleven types and approximately 220 aircraft are in service (TABLE II). This characteristic drives up not only the acquisition costs but also operating and support costs. Under tighter budget constraints, logistic support for minor systems have been given a lower priority compared with major systems such as antisubmarine warfare (ASW) aircraft. Although the procurement cost per aircraft for MH-53E is not a small sum and may not be considered as a minor system, the logistic support activities for MH-53E have languished. Compared with other aircraft, the MH-53E does not show explicit maintenance

TABLE I DEPLOYMENT OF MH-53E IN JMSDF

A/C No	DATE	Description	Procurement (FY85 Yen)
8621	Nov 30 1989 Feb 28 1992 Jan 29 1993	Receipt from MC[*1] First PAR (MHI[*2]) Complete	19,484,030,000
8622	Feb 22 1990 May 15 1992 Feb 26 1993	Receipt from MC Fist PAR (MHI) Complete	
8623	Jan 26 1990 Mar 23 1992 Feb 19 1993	Receipt from MC First PAR (MHI) Complete	
8624	Mar 31 1990 Apr 4 1990 Apr 14 1992 Sep 1 1992 Mar 26 1993	Receipt from MC Repair (MHI) Complete First PAR Complete	
8625	Oct 23 1990 Jan 18 1993	Receipt from MC Fist PAR	8,709,357,000
8626	Nov 29 1990 Mar 8 1993	Receipt from MC First PAR	
8627	Aug 26 1992	Receipt from MC	52,443,026,000
8628	Oct 6 1992	Receipt from MC	
8629	Oct 30 1992	Receipt form MC	
8630	Dec 8 1992	Receipt from MC	

*1 MC: Mitsubishi Corporation Ltd.
*2 MHI: Mitsubishi Heavy Industry Ltd.

TABLE II JMSDF AIRCRAFT INVENTORIES

Mission	Type	QTY
MR	P-3C	87
	P-2J	6
ASW	HSS-2B	75
MCM	MH-53E	10
EW	EP-3C	2
TRANSPORT	YS-11M	4
TEST	P-3C	3
	HSS-2B	2
	SH-60J	2
SAR	US-1A	7
	S-61A	10
	UH-60J	3
TRAINING	T-5	24
	TC/UC-90	23
	YS-11T	10
	OH-6D/J	12
	HSS-2B	10

SOURCE:The Military Balance (International Institute for Strategic Study 1993-1994 BRASSEY, London 1993) productivity gain with time. Some possible reasons for this are listed below[3].

1. Lack of operational and technical information from the U.S. Navy:

   Since the acquisition is not through Foreign Military Sales, JMSDF did not receive operational and technical information from U.S. Navy in a timely manner.

2. Absence of formal maintenance training specific to MH-53E:

   Those instructed in service school are organized not for a particular type of aircraft but for the generalized common work required for major aircraft systems. Because of this practice, frequent "on the job-training" was necessary.

3. Difference in organizational structure:

   Although both JMSDF and USN used same Maintenance Requirement Cards (MRC), the differences in organization and maintenance levels prevented JMSDF from taking full advantage of the MRC system resulting in inefficient planning and coordination. (See Appendix A)

However, any of the reasons listed below may explain the low productivity, but may not account for the apparent lack of "productivity gain." For example, one might argue that the lack of technical information at the beginning should actually enhance the learning effect. A more likely explanation may be that the measurement is not appropriate.

B. DATA USED IN ANALYSIS

A data set from December 1989 to June 1993 is used in this research. The primary data is categorized by aircraft status hours and maintenance man-hours. The maintenance man-hours, in turn, are categorized by types of maintenance task and work center and specialties (See Appendix B and C). Most of all the maintenance work is conducted at the 111st Helicopter Mine Countermeasure Flight Squadron and the 31st Maintenance Squadron (31MSQ). The raw data reported in the Aircraft Status Record (Form A) and Work Order/Record (Form C) is sent daily to a mainframe computer at Engineering Management Department, Shimofusa Aircraft Repair facility. The mainframe computer stores this information and processes it periodically. The processed output is used to assess the reliability of each aircraft and validity of the maintenance plan.

IV. DATA ANALYSIS

The data analysis portion of this paper consists of two parts, descriptive and forecasting. All man-hours are assumed to be homogeneous in quality for a given time period. This assumption was considered reasonable to the extent that the maintenance work was always conducted by a team and the skill mix of a team remained stable across teams. Recorded maintenance man-hours for the same job among different teams seem to collaborate this assumption.

A. DESCRIPTIVE ANALYSIS

1. Overview of Data

a. *Outline of Monthly Total Man-hours*

Monthly maintenance man-hours data is categorized into three major groups based on the types of maintenance activities, types of organizations, and the job specialties. The maintenance activities, in turn, are categorized into six activities: major inspection (MAJ_MH), minor inspection (MIN_MH), pre/post-flight check (PFT_MH), unscheduled maintenance (UNS_MH), common work (COM_MH) and others[4] (OTR_MH). The organizational classifications divide man-hours

[4]others: major component maintenance, special order maintenance, cannibalization, periodic replacement

into five groups: Line Division (LIN_MH), Inspection Division (INS_MH), Aircraft Shop (ACS_MH), Avionics Shop (ATS_MH) and Ordnance Shop (AOS_MH). The job-specialty classification divides the man-hours into six job categories: Avionics Machinist's Mate (AD_MH), Avionics Electrician's Mate (AE_MH), Aviation Structural Mechanic (AM_MH), Aviation Electronics Technician (AT_MH), Aviation Ordnance man (AO_MH) and Aircrew Survival Equipment man (PR_MH).

Figure 1a shows monthly maintenance man-hour trends for the six maintenance activities during the time period from December 1989 through June 1993 (total of 14 quarters). (See also Appendix B and C). The scheduled maintenance man-hours, consisting of the sum of the major and minor inspections and pre/post flight check, is by far the largest component (71%) of the total maintenance work-hours). Since the majority of the scheduled maintenance is conducted by Line and Inspection Divisions, the organizational share of these divisions are shown a similar dominance in Figure 1b.

b. Outline of Operating Hours

Figure 2 shows the trends in monthly operating hours of MH-53E broken into six components: mission capable hours (MC_HR), administration hours (ADMN_HR), awaiting supply hours (AWS_HR), scheduled maintenance hours (SCH_HR), unscheduled maintenance hours (UNS_HR) and other hours (OTR_HR). The difference in monthly operating hours reflects changes in the actual number of aircraft deployed in the squadron.

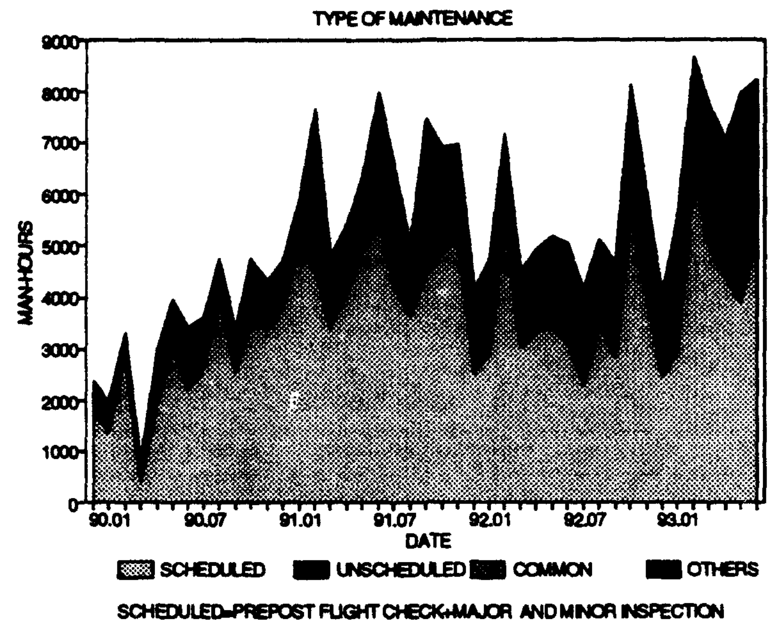


Figure 1a
Monthly Maintenance Man-hours

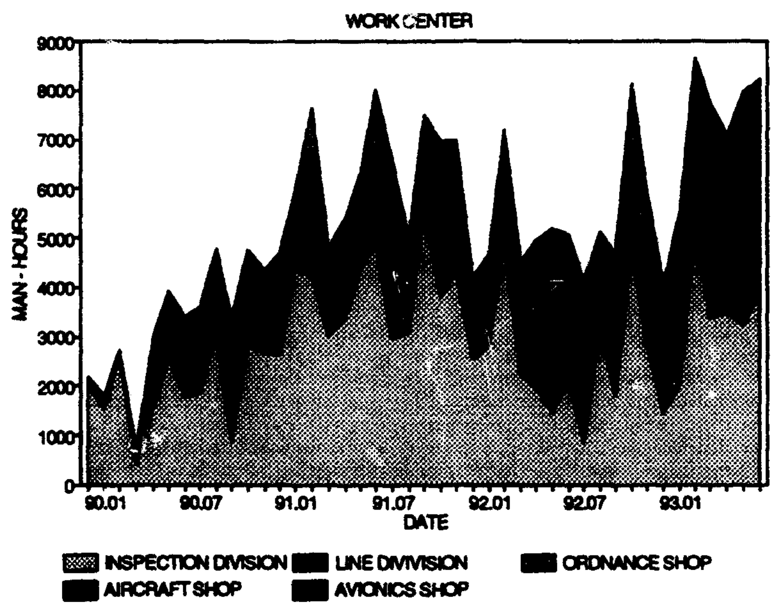


Figure 1b
Organizational Share of Monthly Man-hours

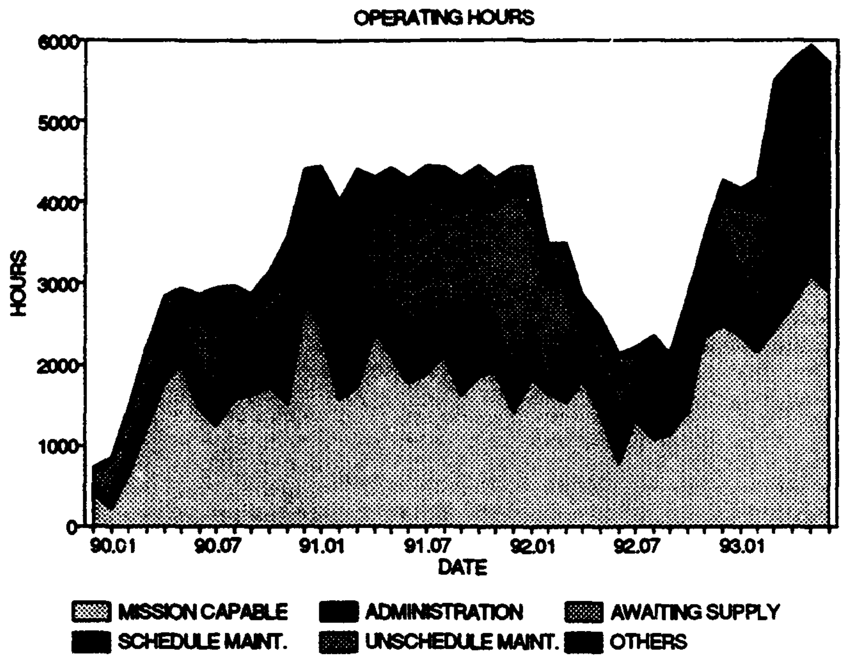


Figure 2
Trends in Monthly Operationg Hours

In fact, it is both convenient and instructive to divide the period (December 1989 to June 1993) into four phases based mainly upon the number of aircraft deployed as shown in Figure 3.

Phase I. *Initial Learning Period (10 months)*

(December 1989 through August 1990) Expansion of deployed aircraft from one to 4 with an average aircraft of 3.4

Phase II. *Steady Mid-Level Deployment Period (17 months)*

(September 1990 through February 1992) The deployed aircraft remained around 6.

Phase III. *First Overhaul Period (9 months)*

(March 1992 through November 1992) The deployed aircraft decreased from 5 to 3 and back to 5 with an average aircraft of 4.

Phase IV. *Higher Deployment Period (7 months)* (December 1992 through June 1993) The deployed aircraft expanded from 7 to 8 with an average aircraft of 8.

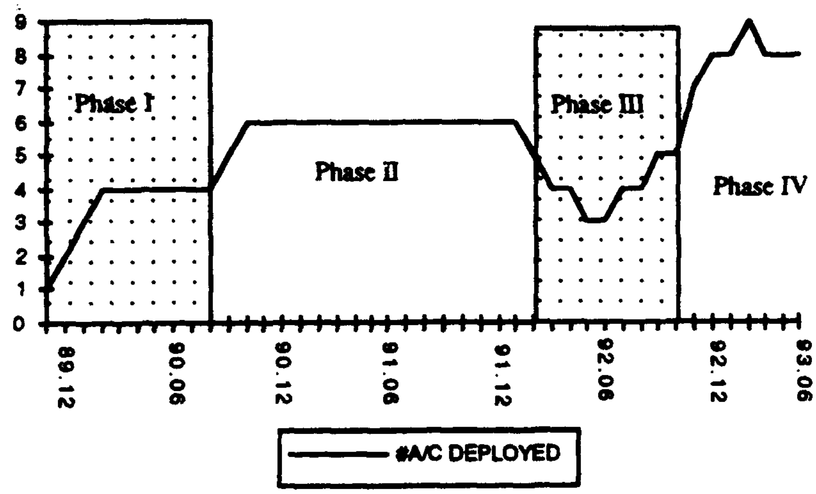


Figure 3
Four Phases of Maintenance History

Table III shows learning effect measured in reduced awaiting supply time and unscheduled maintenance hours. The average monthly mission-capable hours per aircraft (MC_HR/AC) remained fairly constant at around 330 (hours/AC/m) throughout the four phases. The average monthly scheduled maintenance hours (SCH_HR/AC) and the administration hours (ADMN_HR/AC) per aircraft also remained fairly at 50 and 145 (hours/AC/m) respectively. The mission-capable hours may be considered as the output of the maintenance activity and the sum of the scheduled maintenance and the administration hours as the planned inputs. The fact that they remained fairly stable may not be too surprising to the extent that their numbers are more or less requirement driven. However, the trend in unscheduled maintenance (UNS_HR/AC) and awaiting for supply hours (AWS_HR/AC) seemed to indicate a real learning effect on the part of maintenance management. Both numbers show decreasing trend after two years of maintenance experience. This is particularly remarkable in Phase III where the aircraft were used intensively. In comparison to the first two years, AWS has improved by almost 2 to 3 times and unscheduled maintenance hours improved by 20%.

TABLE III LEARNING EFFECT MEASURED IN REDUCED AWS AND UNSCHEDULED MAINTENANCE HOUR

Phase	MC_HR/AC	SCH_HR/AC	UNS_HR/AC	ADMN_HR/AC	AWS_HR/AC
I	342	50	27	133	104
II	319	52	24	132	179
III	344	51	27	177	45
IV	325	49	15	160	68
TOTAL	331	51	24	146	115

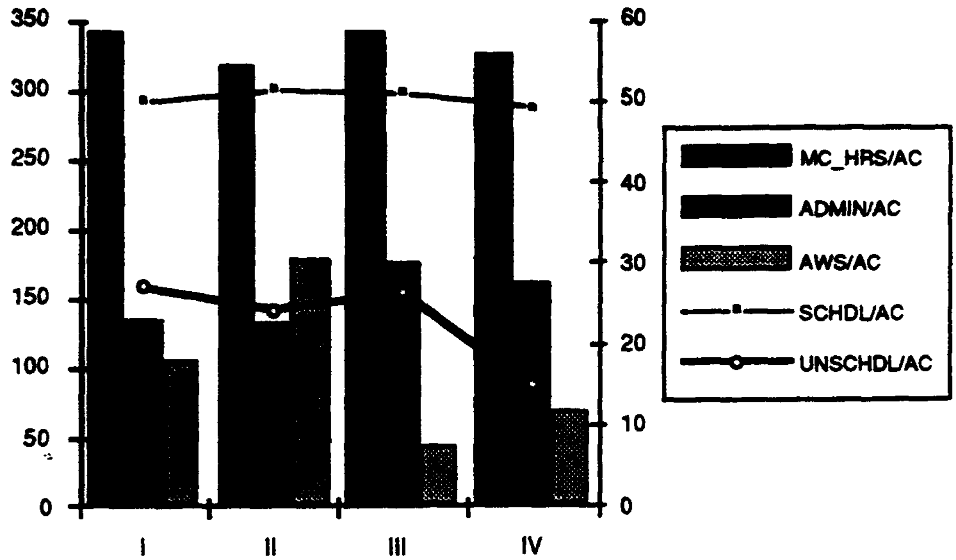


Figure 4
Learning Effect in Maintenance

c. Optimal Skill Composition for MH-53E Maintenance

The table VIa shows the initial staffing standard called for a total of 18 crew members per aircraft and their actual workload. The skill composition of the crew specified 5 Aviation Machinist's Mates (AD), 4 Aviation Electrician's mates (AE), 6 Aviation Structural Mechanics (AM), 2 Aviation Electronics technicians (AT) and 1 Aviation Ordinance men and Aircrew Survival Equipment men (PR). However, the actual experience measured in work hours shows a shift in the required skill mix. During Phase I, for example, 5% more of Machinist's and 4% less of Electronic technician's services were required. The deviation from the initial standard grew with each successive phase from a low of 0.04 in Phase I to a high of 0.11 in Phase III. This adjustment seems to reflect a better understanding of true needs of MH-53E maintenance in the JMSDF's operating environment. The adjustment is accomplished without any noticeable increase in scheduled maintenance hours (See previous Figure IV) but with a reduction in unscheduled maintenance hours and awaiting supply hours. Although the average productivity measured for Phase III and IV does not show any noticeable increase, the reduction in unscheduled maintenance hours does enhance the readiness level of the MH-53E force. TABLE IVb shows the more efficient skell-composition obtained from historical maintenance requirement. Maintenance manager will be able to acheive improvement by using this composition.

TABLE IVa SKILL-COMPOSITION FOR MH-53E MAINTENANCE: INITIAL STANDARD AND EXPERIENCE

Skill Class*1	AD	AE	AM	AT	AO+PR	
Initial Staffing Standard Per Aircraft Composition in (%)	5 28%	4 22%	6 33%	2 11%	1 6%	Level of Changes in (StDev) from the Standard
Phase I	33% (5%)	20% (-2%)	36% (3%)	7% (-4%)	4% (-2%)	0.04
Phase II	28% (0%)	15% (-7%)	49% (16%)	3% (-8%)	5% (-1%)	0.09
Phase III	21% (-7%)	11% (11%)	46% (13%)	4% (-7%)	18% (12%)	0.11
Phase IV	23% (-5%)	13% (-9%)	41% (8%)	4% (-7%)	18% (12%)	0.10

*1. AD refers to aviation machinist's mates, AE refers to aviation electrician's mates; AM refers to aviation structural mechanics; AT refers to aviation electronics technicians; AO+PR refers to aviation ordnance men and aircrew survival equipment men.

TABLE IVb RECOMMENDED SKILL COMPOSITION

Skill Class	*AD*	*AE*	*AM*	*AT*	*AO+PR*
Recommended Composition (%)	22%	12%	44%	4%	18%
Recommended Staffing Level (Per Aircraft)	4.0	2.2	7.8	0.7	3.3

2. Productivity

The maintenance productivity discussed in this thesis is limited to the average productivity of maintenance man-hours. Although the marginal productivity as opposed to the average productivity is the more relevant measure in determining the efficient resource allocation, we are not able to compute the marginal productivity due to data limitation. Since our interest in the productivity mainly lies in finding how JMSDF managed and adjusted to the introduction of MH-53E over the years, the average productivity is considered adequate.

There are two candidates in measuring the output of MH-53E maintenance squadron: one output measure is flight hours and the other is mission capable hours. Flight hours, however, may be influenced not only by the squadron's maintenance activities but also by the operational requirement considerations. Because of this, many analysts prefer the mission capable hours as a more accurate output measure for the maintenance activities. However, in case of JMDSF, the maintenance resource staffing was based more upon the expected flight hours than the level of "mission-capable hours."

In another word, it would cost considerably more maintenance resources to produce more flight-hours even though the mission-capable hours remain the same. This creates some difficulty in interpreting the computed productivity, where mission-capable hours are expressed as an output of maintenance services independent of flight-hours. The problem may be compounded by the fact that the "mission-capable-hours" are an order of magnitude larger than the typical flight-hours (10 to 15 times larger.)

If mission-capable hours and flight-hours are correlated to a high degree, then the choice does not matter for our purpose. Figure 5 shows 43 monthly mission-capable-hours and flight-hours between December 1989 through June of 1993. 23 months out of 43 months, they moved in the same direction and the correlation coefficient between the two was at the indecisive level of 0.63.

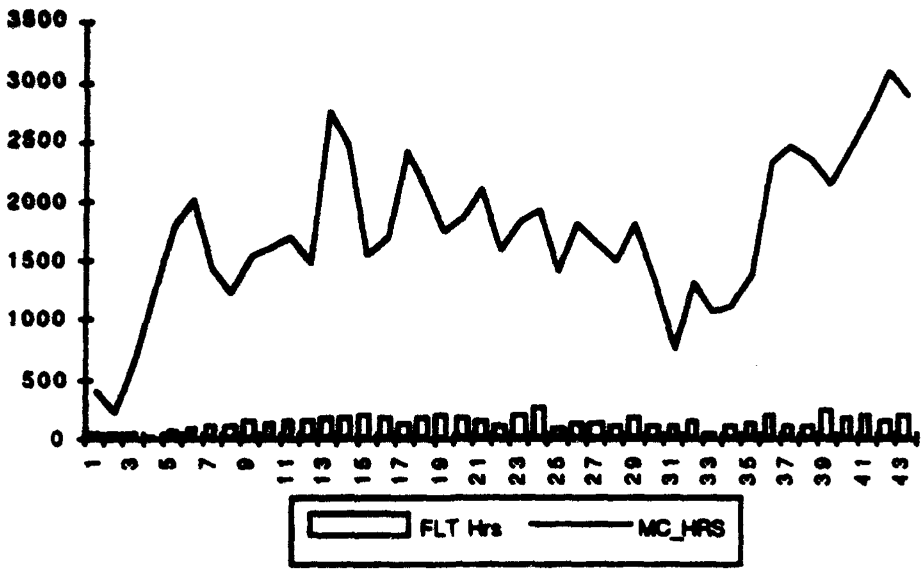


FIGURE 5
Mission-Capable-Hours VS Flight-Hours

For this reason, we examined the two productivity measures in this thesis: Flight-hour Productivity (F_ Prod) and Mission-Capable Productivity (MC_Prod). F_ Prod is defined as the ratio of total monthly flight hours over total monthly maintenance man-hours. MC_Prod is defined as the ratio of total monthly mission-capable hours over total monthly maintenance man-hours.

Table V shows that mission-capable-hours are typically ten to 16 times larger than flight-hours. The MC-Hr/Flt-Hr ratio tends to be larger when the deployed number of aircraft is expanding such as in Phases I and IV and smaller when the number is steady or decreasing such as in Phases II and III. This is consistent with the known fact that the flight-hours per aircraft tends to expand when the deployed number decreases to satisfy operational requirements.

TABLE V SCALE EFFECT ON AIRCRAFT DEPLOYED

	No of Aircraft Deployed	Flight Hours	Mission Capable Hours	Flt_Hr per A/C	MC_Hr per A/C	MC_HR per FLT_HR
Phase I (Initial expansion)	3.3	75	1,162	23	349	15.5
Phase II (Steady Level)	5.8	164	1,878	28	322	11.4
Phase III (Overhaul)	4.1	135	1,414	34	344	10.5
Phase IV (Expansion)	8.0	172	2,589	21	324	15.0
Average for Entire Phases	5.3	141	1,747	27	329	12.4

1. Average monthly flight and mission-capable hours for each phase is reported here.

Table VI shows opposite moves in "productivity" between Phase I to II, and Phase III to IV. According to F-PROD, productivity increases from Phase I to II and decreases from Phase III to IV, and the converse holds for MC-PROD. The results seem to be driven by the changes in the number of aircraft deployed and the resulting changes in operating procedures for the aircraft. However, the regression analysis using time, cumulative flight-hours, and deployed number of aircrafts as explanatory variables for F-PROD and MC-PROD did not produce any statistically meaningful results. The statistical analysis using the aggregate macro data neither confirms nor rejects the existence of learning. This may be mainly due to the limitation of the data than the nature of the reality.

TABLE VI THE CHANGES IN PRODUCTIVITIY

	Total Maintenance Man-Hours	F-PROD (FLT/MMHR)	MC-PROD (MC/MMHR)
Phase I (Initial expansion)	5,351	0.014	0.217
Phase II (Steady Level)	10,016	0.016	0.0187
Phase III (Overhaul)	8,860	0.015	0.160
Phase IV (Expansion)	12,131	0.014	0.213
Average for Entire Phases	9,143	0.015	0.191

3. Work Load

To determine the numbers of workers required for a given work load is not an easy task in the military. Although microeconomics tells us that demand for labor in a competitive market is determined by the value of marginal product of labor, monetary value of mine countermeasure by MH-53E is difficult to calculate. Therefore, an economical efficient staffing standard for a particular work center is difficult to determine.

Table VII shows a part of the staffing standard and required maintenance personnel. This proportional staffing standard makes two assumptions. First, it assumes no return-to-scale effect on man-hours expended. Second, it assumes that the initial assumption of worker productivity is accurate, thus the manpower requirement is simple matter of multiplication.

If the standard does not reflect actual required manpower, it causes significant labor shortages or surpluses at a squadron level. Efficient manpower allocation cannot be obtained without studying the actual work load. Developing a staffing standard should not be a one-time effort and the standard must be reviewed periodically. Manpower managers should monitor the man-hours requirement and the current productivity to achieve fairness and an effective work load assignment among workers.

TABLE VII MANNING STANDARD FOR MH-53E

Current Staffing Standard

Standard	AD	AE	AM	AT	AO&PR	TOTAL
Per Aircraft	5	4	6	2	1	18

Recommended Staffing Standard

Standard	AD	AE	AM	AT	AO&PR	TOTAL
Per Aircraft	5(5.5)	3(2.5)	7	1	2	18

B. REGRESSION ANALYSIS

1. General Concept

A production function can be defined as the relationship between input man-hours and output mission capable hours as an output. To find the relationship, a multiple linear regression technique was used under the assumption that no scale effect exists between input and output.

In regression analysis, we try to find the mix of man-hour elements that best describes the variations in mission capable hours. Mission capable hours is assumed to have a probability distribution and each man-hour element is assumed to be deterministic.

One of the goals in estimating a regression production equation is to answer the "what if" question such as, "What man-hour elements, assuming that the past maintenance environment holds, should be increased, if we want to increase the mission capable hours?" However, such applications may be more difficult than merely improving the regression statistics since that will involve a detailed understanding of how this data was initially generated in the organization.

2. Correlation among The Data Set

Table VIII shows a simple correlation matrix among the different maintenance categories. The matrix helps one to get an intuitive understanding of the relations among the different work categories. For clarity only the correlation coefficients higher than 0.6 are shown in this table. (See Appendix D for a more complete correlation matrix.)

Table VIIIa shows that the number of aircraft deployed (No_AC) has a universally high correlation among many components of Total Aircraft Operating Hours (OP_HR). For example, it is highly correlated with mission capable hours, administration hours, flight hours and scheduled maintenance hours. Total Aircraft Operating Hours is defined as: (OP_HR) =(MC_HR) + (MNT_HR) + (ADMIN_HR) + (AWS_HR) + (OTR_HR). The Maintenance Hours (MNT_HR), on the other hand, is defined as the sum of the Scheduled Maintenance Hours (SCH_HR) plus the Unscheduled Maintenance Hours (UNS_HR). Since scheduled maintenance work frequently requires more than a day to complete, the maintenance cycle includes both working hours and the night-time non-working hours (referred as administration hours). The high correlation (0. 78) between maintenance hour and administration hours reflect this situation.

TABLE VIIIa CORRELATION MATRIX (COMPOSITION OF OPERATING HOURS)

	NAC	Total OP_HR	MC_HR	MNT_HR	ADMN_HR	AWS_HR	OTR_HR	FLT_HR	SCH_HR	UNS_HR
NAC	1									
OP_HR	0.94	1								
MC_HR	0.83	0.87	1							
MNT_HR	0.73	0.61	0.67	1						
ADMN_HR	0.63	0.67		0.77	1					
AWS_HR						1				
OTR_HR							1			
FLT_HR	0.62	0.68	0.63	0.68				1		
SCH_HR	0.78	0.82	0.69	0.93	0.75			0.62	1	
UNS_HR				0.66						1

Table VIIIb shows that total activity based man-hours are largely influenced by the changes in major/minor inspection and unscheduled maintenance man-hours.

TABLE VIIIb CORRELATION MATRIX (ACTIVITY BASED MAN-HOURS)

	NAC	Total Activities	MAJ_MH	PFT_MH	MIN_MH	UNS_MH	CAN_MH	SPT_MH
NAC	1							
Total Activities	0.65	1						
MAJ_MH		0.81	1					
PFT_MH				1				
MIN_MH	0.67	0.62			1			
UNS_MH		0.66				1		
CAN_MH							1	
SPT_MH								1

The Line and Inspection Division seem to influence the changes in the total organizational man-hours behavior with correlation coefficients of 0.72 and 0.83 respectively.

Similarly, the significant coefficient of skilled speciallity for AD(0.73), AE(0.62), AM(0.86) imply that the changes in these areas affect the overall changes in speciality-based work hours. In other word, these speciallities are the major determinants for the maintenance.

Table VIIIc Correlation Matrix (Organization Based Man-Hours)

	NAC	TOTAL Organization	LINE	INSP	A/C SHOP	AT SHOP	AO SHOP
NAC	1						
TOTAL	0.72	1					
LINE		0.72	1				
INSP		0.83		1			
A/C SHOP					1		
AT SHOP						1	
AO SHOP							1

TABLE VIIId CORRELATION MATRIX (SKILL SPECIALTY BASED MAN-HOURS)

	NAC	Total Skill	AD	AE	AM	AT	AO	PR	OTR
NAC	1								
Total	0.71	1							
AD		0.73	1						
AE		0.62	0.79	1					
AM		0.86			1				
AT						1			
AO							1		
PR								1	
OTHER		0.66							1

3. Model Building

It is noted that the categorization of the original data by three different windows (such as Maintenance Activity, Organizational division, and Skill Specialties) will be likely to create colinearity problems in the regression. This problem was finessed by treating the man-hours data of each window in a mutually exclusive manner. Mission capable hours and maintenance hours were treated as dependent variables in the regression models.

The following consideration went into building the production function:

1. Each man-hour element (including square and square root expression) which is considered to reflect reality was used as a possible independent variable.

2. Six regression equations (two equations per category for three categories) that showed the best fit were selected.

3. In order to test the validity of the regression, five randomly chosen observations were excluded from the final testing.

4. The data for Pre-flight Checks was removed from the prediction model of mission capable hours since, by

definition, maintenance hours does not include pre-flight check.

5. The non-zero constant models were used for the regression of mission capability hour. (Zero-constant models were also tested but rejected based on both analytical and statistical grounds.)

6. Linearity of the normal plot of the residuals was confirmed (i.e. we have the errors terms normally distributed with constant variance.)

7. The Durbin-Watson statistic was used to examine first order auto correlations. The final regression model chosen did not fail the Durbin-watson test.

8. In order to confirm the absence of multicollinearity, the variance inflation factor was evaluated and very little evidence of multicollinearity was found in the final regression model.

9. The Standard error was used as a primary performance indicator for the obtained equation. The regression coefficients were tested at 0.05 level of statistical significance to evaluate the regression models.

10. After several dozen equations were tested, the following regression equations were selected (See also Appendix E for further detail).

11. Care must be exercised when the equations are to be used for practical policy-making purpose, since the reason for including some of the independent variables is not obvious. Independent variables are considered and must fixed numbers and must be within the range that is consistent with the past maintenance environment. Therefore, the range of dependent variable must be within certain bounds.

Following observations are based on the Regression Analysis:

1. The regression using elements of maintenance activity showed the best fit for predicting MC_HR_i and MNT_HR_i (See Equation 1 and 4). On the other hand, regression using elements of skill specialty such as Equation 3 and 6 did not do too well.

2. MNT_HR_i forecasting model showed a better fit than MC_HR_i model. This might be due to some uncertain factors such as ADMIN_HR and AWS_HR that influence the mission capable hours.

3. MAJ_MH_i, UNS_MH_i and INS_MH_i which make up the majority of total man-hours are not included in the robust MC_HR_i prediction model. A possoble reason for this omission is that since their changes are relatively minor, their contributions are expressed in the regression's constant term.

4. The man-hour elements expressed in the MC_HR prediction models may be used as the candidates for improving maintenance productivity.

1) $MC\text{-}HR_i = 655 + 0.5 MIN\text{-}MH_i + 0.982 SPT\text{-}MH_i + 55.3\sqrt{CAN\text{-}MH_i}$
2) $MC\text{-}HR_i = 838 + 0.427 LIN\text{-}MH_i + 0.537 ACS\text{-}MH_i$
3) $MC\text{-}HR_i = 1133 + 0.317 AM\text{-}MH_i$
4) $MNT\text{-}HR_i = 98.8 + 0.000068 MIN\text{-}MH_i^2 + 4.69\sqrt{PFT\text{-}MH_i} + 0.000047 UNS\text{-}MH_i^2$
5) $MNT\text{-}HR_i = 8.22\sqrt{LIN\text{-}MH_i} + 0.0399 INS\text{-}MH_i + 0.000039 ACS\text{-}MH_i^2 + 0.000106 ATS\text{-}MH_i^2 - 3.97\sqrt{AOS\text{-}MH_i}$
6) $MNT\text{-}HR_i = 115 + 0.181 AD\text{-}MH_i + 0.0509 AM\text{-}MH_i$

4. Production Forecast

To predict future output by using the regression models, we need to determine the values for the independent variables involved. The deterministic adaptive exponential smoothing technique was used for this purpose. The principle of this calculation is similar to the moving average method, except that more recent data points are given more weight. The new forecast is descriptively equal to the old one plus some proportion of the past forecasting error. The least square error technique used in the regression is also used in this method. It is important that the forecasting error of independent variables (or required maintenance man-hours) directly influences the prediction intervals of dependent variables.

Table IX shows the results of the forecasting model. Once the various man-hour elements are determined by the adaptive smoothing method, then the mission capable hours and maintenance hours are computed with a 95% prediction interval. The interpretation of each man-hour element is important because it implicitly conveys important information such as future operating scale or maintenance productivity. Since we use deterministic extrapolation for forecasting the data, the result is only applicable in the short run. The regression model can only predict the near-future with some confidence intervals (or prediction intervals) under specified maintenance environment.

TABLE IX FORCASTED MAN-HOURS ELEMENT

	MAN-HOURS FORCASTED BY EXPONENTIAL SMOOTHING					
	FORCASTED	MAD*	MSD*	MEAN	LOWER	UPPER
CAN_MH	51.1	27	1727	51.1	0.0	120.4
MIN_MH	1812.4	242.71	111153.6	1812.4	1256.1	2368.7
PFT_MH	1294.7	354.73	239867.3	1294.7	477.5	2111.9
SPT_MH	575.9	88.48	25723.48	575.9	308.3	843.5
UNS_MH	967.4	967.4	192658.4	967.4	235.0	1699.8
LIN_MH	2422.0	408.9	307414.9	2422	1496.8	3347.2
INS_MH	3518.7	920.37	1396803	3518.7	1546.6	5490.8
ACS_MH	1061.8	161.89	116616.7	1061.8	492.0	1631.6
ATS_MH	104.9	118.93	58560.17	104.9	0.0	508.7
AOS_MH	573.9	107.88	22685.77	573.9	322.6	825.2
AD_MH	1211.1	316.45	161799.3	1211.1	539.9	1882.3
AM_MH	2592.6	578.07	590508.3	2592.6	1310.4	3874.9
OPS_HR	5740.78	332.28	20981	5740.8	5499.1	5982.5

MAD: MEAN AVERAGE DEVIATION
MSD: MEAN SQUARE DEVIATION

TABLE IX(cont'd)

	FORECAST BY REGRESSION MODEL			
MODEL	FORCASTED	FIT	LOWER	UPPER
1	MC_HR(BEST)	2532.1	1529.6	3537
2	MC_HR	2604.9	1403.9	3479.5
3	MC_HR	1954.9	759.6	3152.4
4	MNT_HR(BEST)	534.9	352.5	716.3
5	MNT_HR	541.7	310.4	680.2
6	MNT_HR	466.2	231.9	680.2

Suppose aircraft *availability* as a ratio of mission capable hours (MC_HR) and operation hours (OPS_HR) is required as a part of performance measure. In this case, awaiting supply hours (AWS_HR) and administration hours (ADMN_HR) are needed for such a calculation. The determination of these

values has to be coordinated and allocated by decision makers (See Appendix F).

5. Marginal Analysis

The foregoing forecasting analysis assumes that maintenance man-hours and operational requirements are fixed and that the maintenance productivity is constant at a specific level. Under this assumption, improving the productivity is precluded. Maintenance managers, however, can still improve efficiency by reallocating a worker from one work center to another. A worker cannot change his own productivity but he can shorten the time required to complete a particular maintenance chore through his participation. The maintenance time saving resulting from a shift in workforce can improve the overall productivity. The effect of additional workers and an increased work load is examined in the following section.

a. Additional worker

Suppose an additional worker can provide 160 man-hours per month, then we can calculate the effect of his contribution by using the forecasting model. Table XI shows the result of such a calculation.

TABLE X ADDITIONAL LABOR AND MAINTENANCE HOURS

		ADD ONE WORKER TO				
	FORCASTED	LINE DIV	INSP DIV	A/C SHOP	AT SHOP	AO SHOP
LIN	2422.0	2262.0	2422.0	2422.0	2422.0	2422.0
INS	3518.7	3518.7	3358.7	3518.7	3518.7	3518.7
ACS	1061.8	1061.8	1061.8	901.8	1061.8	1061.8
ATS	104.9	104.9	104.9	104.9	0.0	104.9
AOS	573.9	573.9	573.9	573.9	573.9	413.9
MNT_HR	495.0	481.4	488.6	482.7	493.8	509.3
NET TIME SAVINGS		13.6	6.4	12.3	1.2	----

NEW MAINTENANCE HOURS FORECASTED			
	MEAN	LOWER	UPPER
Add to LIN	481.4	300.4	700.4
Add to INS	488.6	311.5	705.5
Add to ACS	482.7	312.7	692.5
Add to ATS	493.8	317.9	697.3
Add to AOS	509.3	338.6	723.5

(UNIT:HOUR)

It shows that the most efficient use of his time is to allocate it to the Line division. The allocation saves the maintenance hours by 13.6 hours a month and results in an increase in the mission capable hours. From the efficiency point of view, a worker should be hired when the benefit of the additional 13.6 mission capable hours is greater than the cost of hiring the worker.

b. Additional aircraft

The JMSDF currently plans to operate a mine countermeasure squadron with eleven aircraft. Ten assets have been already delivered and one aircraft is in the pipeline.

The question we pose now is to measure how much extra mission capable hours we can generate with the addition of one more aircraft. To solve this question, we need to know the marginal maintenance man-hours required to maintain additional aircraft and the proportion of man-hours each work center has to bear. By using the regression model we developed, the solution can be generated and additional mission capable hours will be also computed. Table XI shows the estimated mission capable hours and maintenance hours for an additional aircraft. The marginal cost of maintaining an additional aircraft should be compared to the marginal benefit of an additional aircraft before such an addition. Since the current model assumes the constancy of maintenance productivity, the changes we analyze must not be too large to violate that assumption.

6. Manpower Management

Our discussions on the maintenance productivity and forecasting analysis assumed that all maintenance activities and current maintenance planning are efficiently organized and conducted. Although some recommendations are made based on the model, they are fundamentally short-term and sub-optimal in nature. Full optimization, for example, requires trade-off analysis in manpower vs spare/repair inventory and trade-off analysis in scheduled vs unscheduled maintenance hours.

Two approaches might be considered in analyzing more complete optimization issues: one short-run, the other longer-run.

TABLE XI ADDITIONAL AIRCRAFT AND MISSION CAPABLE HOURS

	ADDITIONAL MH to ACFT	CURRENT FORECAST			NEW FORECAST		
		MEAN	LOWER	UPPER	MEAN	LOWER	UPPER
LIN	316.8	2422	1496.8	3347.2	2738.8	1813.6	3664.0
INS	542.6	3518.7	1546.6	5490.8	4061.3	2089.2	6033.5
ACS	50.7	1061.8	492.0	1631.6	1112.5	542.7	1682.3
ATS	23.4	104.91	0.0	508.7	128.3	23.4	532.1
AOS	67.9	573.89	322.6	825.2	641.8	390.5	893.1
MC_HR	----	2442.4	1741.3	3143.4	2604.9	1903.8	3305.9
MNT_HR	----	495.0	317.9	711.9	541.7	366.5	760.0

the model, they are fundamentally short-term and sub-optimal in nature. Full optimization, for example, requires trade-off analysis in manpower vs spare/repair inventory and trade-off analysis in scheduled vs unscheduled maintenance hours. Two approaches might be considered in analyzing more complete optimization issues: one short-run, the other longer-run.

a. *Short-run approach*

One approach assumes that maintenance activities are based on the status quo and that decisions have to be made only to allocate the manpower to save the maintenance hours (MNT_HR), administration hours (ADMIN_HR) or improve the supply system to reduce awaiting maintenance hours (AWS_HR). This can be theoretically solved at the point where the marginal cost of an additional worker is equal to marginal

benefit resulting from a reduction in MNT_HR, ADMN_HR and AWS_HR.

The productivity could be also improved without any changes in the maintenance hours but through reduction in the maintenance man-hours. This is accomplished by more cost-effective reallocation in of speciality -based man-hours.

b. Long-run policy

Another approach assumes that current preventive maintenance system are changeable and all resources can be re-allocated efficiently within the budget constraint. The objective is to maximize mission capable hours while taking into account of various key variables. Such key variables include the cost of man-hours for preventive maintenance, the cost of corrective maintenance and the cost of improving the supply system and the cost of overtime. Then the analysis takes the form of the Integral Logistics Support concept. Although a large scale data base is required to utilize this framework, the investment will be cost-effective since the manpower costs are significant for any weapon systems and continue to grow in the future.

V. CONCLUSIONS AND RECOMMENDATION

A. CONCLUSION

Under the typical environment of the aircraft maintenance, efficient manpower policy requires a continued increase in worker productivity because of keen time constraints that workers must satisfy in order to produce high mission capable hours.

Although the regression analysis did not confirm nor reject any gain in the worker productivity, the author believes that the JMSDF's MH-53E maintenance policy has successfully adapted over the years and reduced both the unscheduled maintenance work and awaiting time for the supply parts. However, the future staffing policy should reflect more realistic manpower usage practiced at the shop level.

The reason for the absence of statistically significant learning effects may be more due to the limitation of the data set than the reflection of the reality. This leads to the need and recommendation to develop a more detailed micro data set.

The regression analysis has identified statistically significant factors that explain the behavior of the mission-capable hours and the maintenance-work hours. Based upon such model, the author constructed a prediction model that answers various "what if" questions pertaining to efficient resource allocation issues.

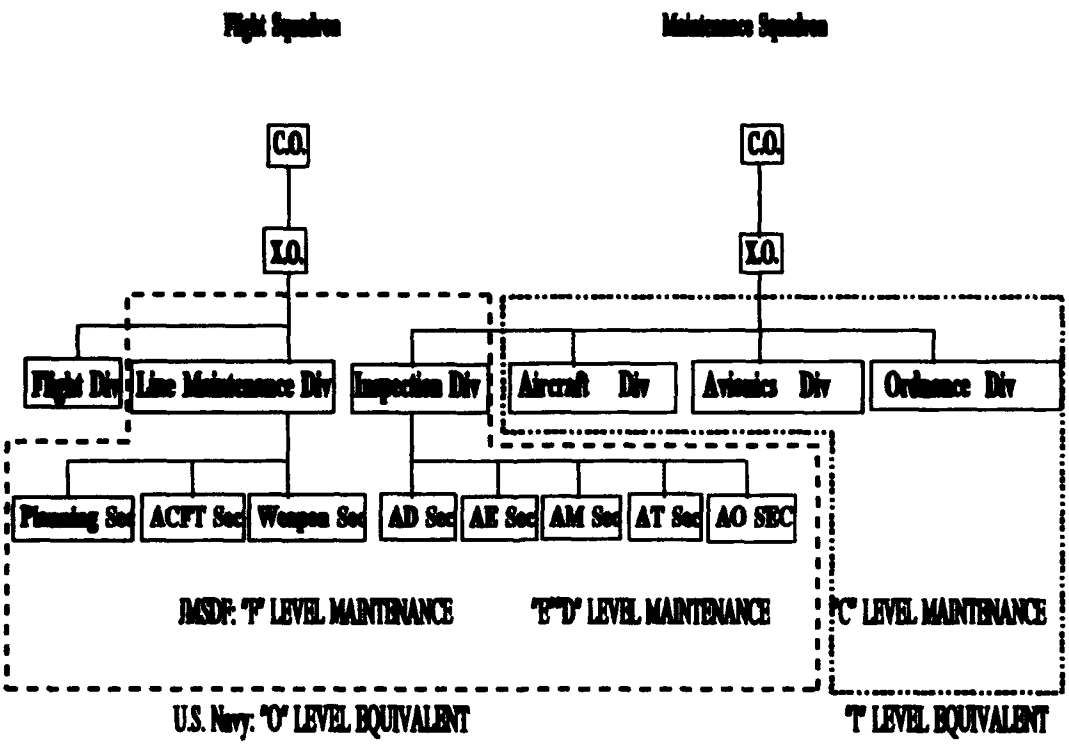
B. RECOMMENDATIONS

Two policy recommendations are formulated: The first is a need for a more flexible manning policy that reflects and incorporates the actual maintenance experience and requirement. Under current policy, the manpower requirement per aircraft remains fixed based on the knowledge prior to actual operating experience. The total requirement for a given aircraft type is computed by multiplying the initial estimate by the total number of aircraft deployed. This practice initially caused over/under staffing of the maintenance work force and retraining of the work force. The study proposes a more dynamic and flexible manning policy based on actual requirement and shop experience.

The second recommendation deals with a need for more detailed cost and manpower data to achieve JMSDF-wide cost-effective resource allocation. JMSDF currently collects limited number of aggregate data which are not totally suited for marginal cost analysis. In examining the manpower policy, the need for a trade-off analysis between manpower vs spare/repair parts inventory or an analysis between scheduled vs unscheduled maintenance hours became quite clear. We are unable to conduct either of these analyses due to lack of appropriate micro data. For the maintenance policy to be cost-effective, it is imperative to develop such a data set. In the absence of correct a trade-off framework, we are bound to be too "efficient" in one of such endeavors and perpetually finding ourselves in a costly sub-optimal world.

APPENDIX A

MAINTENANCE ORGANIZATION IN JMSDF



APPENDIX B

DEFINITION OF SYMBOLS

Categories	Symbols	Definition
Unit	HR MH NAC	Hour or Hours Man-hour or man-hours Number of aircraft deployed
Aircraft Status	OPS_ FLT_ MC_ SCH_ UNS_ MNT_ AWS_ ADMN_ MOD_ OTR_	Operating (=MC+MNT+AWS+ADMN+OTR) Flight Mission capable Scheduled maintenance Unscheduled maintenance Maintenance (=SCH+UNS) Awaiting supplies Administration*1 Modification Others
Type of Maintenance	MAJ_ MIN_ PFT_ UNS_ CAN_ SPT_	Major inspection*2 Minor inspection*3 Pre, Post-flight check Unscheduled maintenance Canibalization Support work
Work Center	LIN_ INS_ ACS_ ATS_ AOS_	Line Division Inspection Division Aircraft Shop Avionics Shop Ordnance Shop
Specialities	AD_ AE_ AM_ AT_ AO_ PR_	Aviation Machinist's Mate Aviation Electrician's Mate Aviation Structual Mechanic Aviation Electronics Technician Aviation Ordnance man Aircrew Survival Equipment man

*1 Administration hours: Awaiting maintenance hours due to the planned work (e.g., the schedule maintenance during off-working hours)
*2 Major inspection: Phased Inspection (A, B, C, D)
*3 Minor inspection: other Special Inspections

APPENDIX C

MAIN DATA USED IN ANALYSIS

DATE	89.12	90.01	90.02	90.03	90.04	90.05	90.06	90.07
NAC	1	2	3	4	4	4	4	4
MC_HR	397.1	223.7	631.9	1203.0	1786.5	2001.5	1431.0	1231.9
FLT_HR	28.4	48.1	38.7	16.6	69.8	81.4	113.0	123.1
SCH_HR	96.4	58.3	113.1	99.9	166.7	190.3	199.2	157.1
UNS_HR	1.1	37.1	49.3	78.1	158.4	133.3	150.7	180.6
ADMN_HR	115.0	130.0	432.7	392.3	586.0	538.7	602.2	333.5
AWS_HR	131.8	424.5	268.2	425.2	137.8	48.8	452.6	1065.1
OTR_HR	2.5	2.7	5.9	41.3	44.3	63.1	42.9	7.0
MNT_HR	97.5	95.4	162.4	178.0	325.1	323.6	349.9	337.7
MAJ_MH	741.0	564.0	1500.0	0.0	680.5	1492.5	749.0	771.0
PFT_MH	0.0	0.0	0.0	0.0	567.0	672.0	609.0	945.0
MIN_MH	1064.2	780.7	1318.9	401.5	640.6	818.5	840.5	884.0
UNS_MH	456.2	435.5	234.0	362.0	253.5	607.2	847.5	746.2
CAN_MH	0.0	0.0	0.0	0.0	0.0	20.0	16.0	37.0
SPT_MH	13.0	183.6	123.6	0.0	109.5	39.0	46.0	30.0
LIN_MH	21.4	214.9	137.7	66.5	978.9	964.8	1074.4	1401.4
INS_MH	1993.5	1504.5	2587.0	376.0	1516.5	2544.8	1774.0	1861.0
ACS_MH	108.5	89.0	36.0	28.0	121.0	101.0	177.6	193.0
ATS_MH	77.0	4.0	16.0	270.0	30.3	30.5	153.5	69.5
AOS_MH	8.0	0.0	0.0	0.0	362.4	331.0	251.5	84.0
AD_MH	681.9	558.3	733.6	176	740.3	1048.8	924.5	944.2
AE_MH	703.8	513	919	81	352	591	357.5	383
AM_MH	727	778.6	1077.6	176	600.3	1065	711.95	826
AT_MH	77.0	11.5	16.0	281.0	30.3	31.5	162.0	71.0
AO_MH	8	0	0	0	361.4	316	251.5	84
PR_MH	0.0	0.0	0.0	0.0	1.0	15.0	0.0	0.0
OTR_MH	198.7	135.2	577.4	89.0	923.8	904.8	1024.0	1300.7
DMMH	2396.4	1996.6	3323.6	803.0	3009.1	3972.1	3430.5	3608.9

APPENDIX C(cont'd)

DATE	90.08	90.09	90.10	90.11	90.12	91.01	91.02	91.03
NAC	4	4	5	6	6	6	6	6
MC_HR	1553.0	1614.7	1718.7	1491.0	2756.0	2484.5	1556.7	1696.8
FLT_HR	153.7	140.5	161.3	158.9	178.1	176.8	184.2	175.6
SCH_HR	328.6	209.6	250.0	318.9	261.0	335.6	434.1	306.9
UNS_HR	122.7	108.4	109.0	229.1	175.3	153.3	284.7	200.3
ADMN_HR	886.9	701.4	687.9	1090.6	465.3	1105.0	1415.2	1193.6
AWS_HR	57.7	232.0	394.0	461.5	761.5	380.0	313.5	998.2
OTR_HR	26.4	14.4	18.0	31.4	14.2	5.0	26.7	46.5
MNT_HR	451.3	318.0	359.0	548.0	436.3	488.9	718.8	507.2
MAJ_MH	1998.0	0.0	1608.0	705.5	873.5	2621.2	2535.5	1065.0
PFT_MH	1029.0	1806.0	1029.0	903.0	1008.0	1008.0	991.0	987.0
MIN_MH	950.5	748.4	812.6	1763.5	1866.5	1355.5	1116.0	1364.0
UNS_MH	698.9	576.0	957.8	699.5	668.5	718.1	2624.3	519.[illegible]
CAN_MH	26.0	12.5	35.5	29.7	23.2	11.8	72.3	93.0
SPT_MH	27.0	79.5	58.2	31.0	55.0	82.2	45.0	123.5
LIN_MH	1432.9	2395.4	1593.7	1531.8	1949.4	1496.5	1756.0	1555.5
INS_MH	3027.0	855.0	2805.9	2663.0	2618.5	4324.1	4236.9	2992.0
ACS_MH	74.0	19.0	260.5	122.5	79.0	126.5	266.0	191.5
ATS_MH	252.5	61.5	4.5	28.5	40.0	5.5	1418.0	39.0
AOS_MH	0.0	0.0	114.0	2.0	26.0	6.2	30.0	18.5
AD_MH	1308.5	283.3	1206.9	890.6	915	1877.2	1652.4	1447.6
AE_MH	747.5	114	677.4	660.2	658.7	802.3	753.2	573.2
AM_MH	1129.9	627.6	1404.5	1368.5	1428.7	1819.6	2344.8	1324.2
AT_MH	254.0	64.5	5.0	29.5	40.0	7.5	1442.5	45.5
AO_MH	0	0	60	1	16	4.2	28	17.5
PR_MH	0.0	0.0	54.0	1.0	10.0	2.0	2.0	1.0
OTR_MH	1347.5	2241.5	1370.8	1397.0	1644.5	1446.0	1484.0	1387.5
DMMH	4785.4	3330.9	4778.6	4347.8	4712.9	5958.8	7706.9	4796.5

APPENDIX C(cont'd)

DATE	91.04	91.05	91.06	91.07	91.08	91.09	91.10	91.11
NAC	6	6	6	6	6	6	6	6
MC_HR	2419.8	2112.7	1756.5	1862.7	2107.4	1601.1	1839.2	1916.4
FLT_HR	143.7	178.3	188.8	182.8	163.3	128.2	191.7	253.2
SCH_HR	439.2	396.1	262.1	340.7	251.3	328.5	345.9	244.0
UNS_HR	84.8	55.0	230.8	114.3	101.0	127.1	94.3	173.7
ADMN_HR	495.8	726.5	813.1	614.6	514.0	1093.4	1084.2	654.5
AWS_HR	868.0	1151.0	1242.0	1507.9	1481.5	1150.0	1077.5	1315.[illegible]
OTR_HR	11.5	21.1	14.4	23.3	8.5	18.8	22.5	15.[illegible]
MNT_HR	524.0	451.1	492.9	455.0	352.3	455.6	440.2	417.[illegible]
MAJ_MH	1723.5	2055.5	2834.0	797.0	1208.5	2150.0	2052.5	2518.[illegible]
PFT_MH	1091.0	1176.0	1260.0	2352.0	1113.0	987.0	1296.0	1469.0
MIN_MH	1250.5	1665.0	1460.5	1071.5	1316.5	1268.5	1489.0	1176.5
UNS_MH	790.0	894.4	1208.1	1564.5	911.0	2110.9	1087.9	1239.9
CAN_MH	136.6	99.9	30.5	227.8	137.5	13.0	53.6	86.0
SPT_MH	62.7	21.5	698.0	85.0	25.5	133.5	107.0	22.0
LIN_MH	1656.8	1703.7	1995.1	3163.9	1598.5	1573.9	2414.4	1992.3
INS_MH	3384.5	4312.0	4897.5	2965.0	3061.0	5558.5	3777.7	4284.5
ACS_MH	205.5	67.5	815.0	117.3	169.4	139.5	101.0	115.0
ATS_MH	44.0	45.0	81.0	107.0	8.0	45.0	122.0	294.0
AOS_MH	148.5	239.0	246.5	263.0	162.0	198.0	546.5	316.5
AD_MH	1023.6	1211.8	1585.4	837.5	801.5	1265.9	1084.1	1258.4
AE_MH	701	638.5	937	540.3	513	608	565	629.4
AM_MH	1976.7	2580.9	3340.7	1829.9	1968.4	4039.5	2427.5	2595.1
AT_MH	53.5	51.0	85.5	117.5	17.0	55.5	128.0	311.9
AO_MH	148.5	238	246.5	263	162	198	546.5	297
PR_MH	0.0	1.0	0.0	0.0	0.0	0.0	0.0	38.0
OTR_MH	1536.0	1646.0	1841.0	3028.0	1537.0	1330.0	2210.5	1872.5
DMMH	5439.3	6367.2	8034.1	6616.2	4998.9	7496.9	6961.6	7002.3

APPENDIX C(cont'd)

DATE	91.12	92.01	92.02	92.03	92.04	92.05	92.06	92.07
NAC	6	6	6	5	4	4	3	3
MC_HR	1401.4	1816.8	1577.3	1511.9	1814.0	1368.6	758.7	1335.5
FLT_HR	80.5	140.8	131.6	131.0	180.5	110.6	111.9	164.3
SCH_HR	235.7	207.9	273.4	231.5	226.0	195.6	225.3	110.7
UNS_HR	85.1	164.6	76.1	70.5	81.0	96.5	166.5	101.1
ADMN_HR	580.0	649.0	157.9	820.7	603.2	683.4	702.5	495.8
AWS_HR	2150.4	1622.0	1263.2	660.5	117.0	196.2	251.4	64.3
OTR_HR	11.3	3.7	121.9	220.0	37.9	36.9	54.7	124.0
MNT_HR	320.8	372.5	349.5	302.0	307.0	292.1	391.8	211.8
MAJ_MH	1253.5	889.5	2847.0	837.5	916.0	506.0	1055.0	0.0
PFT_MH	338.0	588.0	1158.0	1224.0	1479.0	2250.0	1514.0	1404.0
MIN_MH	939.5	1389.0	1470.0	958.5	961.7	662.0	539.5	889.5
UNS_MH	613.4	1088.4	783.0	775.4	433.0	770.3	930.8	668.9
CAN_MH	59.5	25.0	30.0	7.0	28.5	0.0	34.5	3.0
SPT_MH	126.5	61.0	80.3	57.0	31.0	38.1	76.0	262.0
LIN_MH	802.4	1252.9	1474.3	1591.6	1953.7	2679.6	1887.5	2257.3
INS_MH	2500.5	2853.5	4918.0	2207.0	1951.0	1424.8	2094.3	855.4
ACS_MH	68.5	153.0	226.0	200.0	623.5	346.5	232.0	306.5
ATS_MH	129.0	33.0	10.0	0.0	0.0	212.0	227.0	229.0
AOS_MH	660.5	443.5	591.0	525.0	425.0	545.0	640.5	503.0
AD_MH	883.4	796	1469.5	684.7	753.9	638.5	697.8	188.9
AE_MH	332.5	449.5	876	359.5	351.5	419	296.5	34.5
AM_MH	1488.5	2017.9	2884.8	1466.4	1627.6	865.9	1495	1117.3
AT_MH	134.0	38.0	16.0	6.0	5.0	220.0	231.5	234.0
AO_MH	661.5	442	589	524	425	545	640.5	458
PR_MH	0.0	1.5	2.0	1.0	0.0	0.0	0.0	45.0
OTR_MH	661.0	991.0	1384.0	1482.0	1790.2	2519.5	1720.0	2073.5
DMMH	4160.9	4735.9	7219.3	4523.6	4953.2	5207.9	5081.3	4151.2

APPENDIX C(cont'd)

DATE	92.08	92.09	92.10	92.11	92.12	93.01	93.02	93.[illegible]
NAC	4	4	5	5	7	8	8	
NC_HR	1073.7	1135.2	1391.3	2338.5	2478.9	2352.2	2144.1	2423.[illegible]
FLT_HR	56.6	118.8	134.8	203.8	116.7	121.3	242.4	175.[illegible]
SCH_HR	196.0	186.5	296.6	220.0	233.1	205.1	303.4	540.[illegible]
UNS_HR	72.4	87.1	100.7	157.6	77.4	67.7	109.6	74.4
ADMN_HR	972.0	641.8	816.8	719.4	1208.9	815.1	557.2	1199.[illegible]
AWS_HR	24.0	41.5	229.7	144.1	276.5	740.4	1188.9	829.7
OTR_HR	25.6	79.3	44.2	19.9	10.0	19.6	12.1	447.[illegible]
MNT_HR	268.4	273.6	397.3	377.6	310.5	272.8	413.0	614.9
MAJ_MH	1887.5	783.5	3249.0	1497.0	633.0	843.0	3397.8	1508.6
PFT_MH	756.0	1260.0	1428.0	1225.0	799.5	762.0	1382.0	2096.0
MIN_MH	824.5	761.0	946.5	1180.0	1044.0	1270.8	1671.0	1359.0
UNS_MH	602.0	655.5	914.4	948.7	276.5	756.0	650.4	509.6
CAN_MH	6.0	0.0	34.0	22.0	4.0	32.0	52.5	91.8
SPT_MH	37.4	72.0	235.1	259.4	402.0	666.0	277.0	337.3
LIN_MH	907.4	2043.5	2219.0	2140.1	1776.9	1808.8	2484.9	3100.2
INS_MH	3201.0	1749.5	4746.4	2802.8	1416.5	2006.5	5150.8	3351.2
ACS_MH	346.0	130.0	449.5	295.0	81.6	261.5	283.7	163.5
ATS_MH	32.0	32.0	64.0	184.0	42.0	548.0	6.0	77.0
AOS_MH	666.5	752.0	694.0	528.0	719.6	919.5	774.5	1084.5
AD_MH	860.5	532	1554.9	1049.8	468.9	1149.5	1826.9	1199.3
AE_MH	592.5	271.5	1053.4	548.5	390.6	346	966	648.5
AM_MH	2088.9	1271	2837.6	1693.6	706	931.8	2802.5	1957.6
AT_MH	59.0	47.0	90.0	246.7	79.0	617.0	44.0	108.0
AO_MH	561.5	664	457	570.3	473.6	875.7	848.5	823
PR_MH	105.0	88.0	237.0	25.0	291.0	136.5	54.5	304.0
OTR_MH	885.5	1833.5	1943.0	1816.0	1627.5	1487.8	2157.5	2736.0
DMMH	5152.9	4707.0	8172.9	5949.9	4036.6	5544.3	8699.9	7776.4

APPENDIX C(cont'd)

DATE	93.04	93.05	93.06	TOTAL
NAC	8	8	8	--------
MC_HR	2722.7	3104.7	2894.7	75037.2
FLT_HR	190.7	150.0	209.0	6049.0
SCH_HR	542.7	437.2	517.7	11518.4
UNS_HR	141.1	164.2	188.5	5234.5
ADMN_HR	2095.5	1608.5	1450.0	33449.7
AWS_HR	163.2	21.5	658.5	26988.4
OTR_HR	94.0	615.3	20.8	2526.1
MNT_HR	683.8	601.4	706.2	16752.9
MAJ_MH	1721.0	1670.0	1457.0	60195.6
PFT_MH	1004.0	830.0	1318.2	45113.7
MIN_MH	1690.0	1400.0	2414.9	49795.3
UNS_MH	1296.8	956.6	1134.9	35975.5
CAN_MH	16.5	24.0	90.5	1722.7
SPT_MH	3 51.5	700.0	786.8	7057.7
LIN_MH	2367.0	2034.1	2779.7	72230.7
INS_MH	3457.0	3189.7	3927.7	123724.0
ACS_MH	537.0	2277.5	853.2	11557.8
ATS_MH	57.0	63.0	145.0	5336.3
AOS_MH	686.5	428.5	545.0	15485.7
AD_MH	1379.7	879.4	1360.9	42831.8
AE_MH	663	638.5	960.2	24216.7
AM_MH	2188.8	4190.9	2688.9	74490.0
AT_MH	120.0	114.0	234.0	6031.9
AO_MH	558	572.5	677	14613.2
PR_MH	239.5	0.0	0.0	1655.0
OTR_MH	1955.5	1597.5	2329.6	65464.0
DMMH	7104.5	7992.8	8250.6	229295.6

APPENDIX D

SIMPLE CORRELATION MATRIX

	MC_HR	MNT_HR	FLT_HR	NAC	SCH_HR	UNS_HR	ADMN_HR	AWS_HR
MNT_HR	0.671							
FLT_HR	0.639	0.672						
NAC	0.825	0.734	0.651					
SCH_HR	0.691	0.929	0.618	0.776				
UNS_HR	0.306	0.66	0.457	0.294	0.336			
ADMN_HR	0.565	0.768	0.413	0.633	0.751	0.432		
AWS_HR	0.134	0.154	0.295	0.412	0.161	0.066	-0.171	
OTR_HR	0.327	0.292	0.086	0.352	0.375	-0.017	0.368	-0.172
MAJ_MH	0.241	0.451	0.46	0.403	0.467	0.199	0.238	0.229
PFLT_MH	0.326	0.408	0.64	0.328	0.43	0.166	0.219	0.097
MIN_MH	0.596	0.612	0.586	0.665	0.631	0.279	0.416	0.343
UNS_MH	0.178	0.581	0.419	0.315	0.473	0.519	0.411	0.251
CAN_MH	0.321	0.447	0.461	0.417	0.498	0.126	0.065	0.572
SPT_MH	0.492	0.346	0.274	0.548	0.354	0.162	0.47	-0.025
LIN_MH	0.57	0.59	0.777	0.58	0.607	0.268	0.455	0.105
INS_MH	0.332	0.584	0.545	0.527	0.598	0.272	0.318	0.406
ACS_MH	0.416	0.384	0.203	0.337	0.359	0.249	0.457	-0.198
ATS_MH	-0.031	0.271	0.117	0.077	0.143	0.399	0.22	-0.093
AOS_MH	0.263	0.091	0.201	0.434	0.227	-0.23	0.256	0.041
AD_MH	0.382	0.627	0.571	0.532	0.589	0.401	0.373	0.263
AE_MH	0.223	0.451	0.33	0.34	0.476	0.182	0.216	0.121
AM_MH	0.411	0.586	0.515	0.557	0.603	0.268	0.423	0.327
AT_MH	0.02	0.302	0.146	0.129	0.182	0.399	0.267	-0.103
AO_MH	0.3	0.118	0.244	0.447	0.231	-0.171	0.236	0.088
PR_MH	0.262	0.145	0.114	0.401	0.287	-0.214	0.407	-0.189
OTR_MH	0.503	0.529	0.746	0.508	0.558	0.214	0.387	0.102

APPENDIX D(cont'd)

	OTR_HR	MAJ_MH	PFT_MH	MIN_MH	UNS_MH	CAN_MH	SPT-MH	LIN_MH
MAJ_MH	0.011							
PFT_MH	0.178	0.141						
MIN_MH	0.067	0.399	0.101					
UNS_MH	-0.041	0.405	0.285	0.236				
CAN_MH	-0.02	0.182	0.447	0.314	0.352			
SPT_MH	0.371	0.159	0.071	0.45	0.076	-0.005		
LIN_MH	0.262	0.191	0.91	0.349	0.353	0.431	0.362	
INS_MH	0.02	0.922	0.214	0.599	0.555	0.341	0.194	0.288
ACS_MH	0.657	0.19	0.093	0.255	0.155	-0.032	0.652	0.268
ATS_MH	-0.069	0.1	0.021	-0.091	0.584	0.095	0.041	0.067
AOS_MH	0.343	0.151	0.352	0.058	-0.067	-0.026	0.425	0.471
AD_MH	-0.043	0.868	0.167	0.535	0.438	0.266	0.227	0.265
AE_MH	-0.015	0.809	0.02	0.614	0.253	0.214	0.251	0.105
AM_MH	0.338	0.739	0.273	0.545	0.585	0.279	0.39	0.395
AT_MH	-0.045	0.113	0.031	-0.05	0.588	0.1	0.107	0.103
AO_MH	0.359	0.157	0.341	0.127	-0.028	-0.003	0.476	0.474
PR_MH	0.249	0.12	0.175	0.039	-0.118	-0.066	0.33	0.317
OTR_MH	0.217	0.179	0.941	0.314	0.311	0.459	0.291	0.985

	INS_MH	ACS_MH	ATS_MH	AOS_MH	AD_MH	AE_MH	AM_MH	AT_MH
ACS_MH	0.188							
ATS_MH	0.043	-0.012						
AOS_MH	0.1	0.188	-0.049					
AD_MH	0.864	0.141	0.174	0.067				
AE_MH	0.805	0.216	-0.034	-0.055	0.788			
AM_MH	0.855	0.562	-0.001	0.216	0.594	0.582		
AT_MH	0.059	0.031	0.996	0.001	0.193	-0.015	0.027	
AO_MH	0.125	0.294	-0.037	0.966	0.084	-0.048	0.283	0.017
PR_MH	0.047	0.005	-0.038	0.635	0.097	0.089	0.02	0.004
OTR_MH	0.268	0.198	0.037	0.426	0.23	0.107	0.347	0.065

	AO_MH	PR_MH
PR_MH	0.44	
OTR_MH	0.422	0.285

APPENDIX E

OUTCOMES OF REGRESSION CALCULATION

$\mathbf{MC\_HR_i = 665 + 0.500\ MIN_i + 0.982\ SPT_i + 55.3\ CAN^2}$

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	665.4	232.3	2.86	0.007	
MIN	0.5004	0.2327	2.15	0.039	1.6
SPT	0.9822	0.4108	2.39	0.022	1.3
$CAN^{1/2}$	55.31	23.64	2.34	0.025	1.3

s = 462.0 R-sq = 52.2% R-sq(adj) = 48.0%

$\mathbf{MNT\_HR_i = 98.8 + 0.000068 MIN^{1/2}{}_i + 4.69\ PFT^{1/2}{}_i + 0.000047 UNS^2{}_i}$

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	98.80	39.84	2.48	0.018	
MIN^2	0.00006783	0.00001298	5.22	0.000	1.0
$PFT^{1/2}$	4.694	1.211	3.88	0.000	1.1
UNS^2	0.00004692	0.00001140	4.11	0.000	1.1

s = 85.47 R-sq = 70.7% R-sq(adj) = 68.1%

$\mathbf{MC\_HR_i = 838 + 0.427\ LIN_i + 0.537\ ACS_i}$

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	837.7	185.8	4.51	0.000	
LIN	0.4268	0.1053	4.05	0.000	1.1
ACS	0.5371	0.2138	2.51	0.017	1.1

s = 478.6 R-sq = 47.2% R-sq(adj) = 44.2%

$\mathbf{MNT\_HR_i = 8.22\ LIN^{1/2}{}_i + 0.0399\ INS_i + 0.000106\ ATS^2{}_i + 0.000039\ ACS_i - 3.97\ AOS^{1/2}{}_i}$

Predictor	Coef	Stdev	t-ratio	p
Noconstant				
$LIN^{1/2}$	8.218	1.322	6.22	0.000
INS	0.03990	0.01226	3.25	0.003
ATS^2	0.00010595	0.00004609	2.30	0.028
ACS^2	0.00003927	0.00001734	2.26	0.030
$AOS^{1/2}$	-3.970	1.924	-2.06	0.047

s = 87.97

$\mathbf{MC\_HR_i = 1133 + 0.317\ AM_i}$

Predictor	Coef	Stdev	t-ratio	p
Constant	1132.9	206.8	5.48	0.000
AM	0.3175	0.1022	3.10	0.004

s = 576.7 R-sq = 21.1% R-sq(adj) = 18.9%

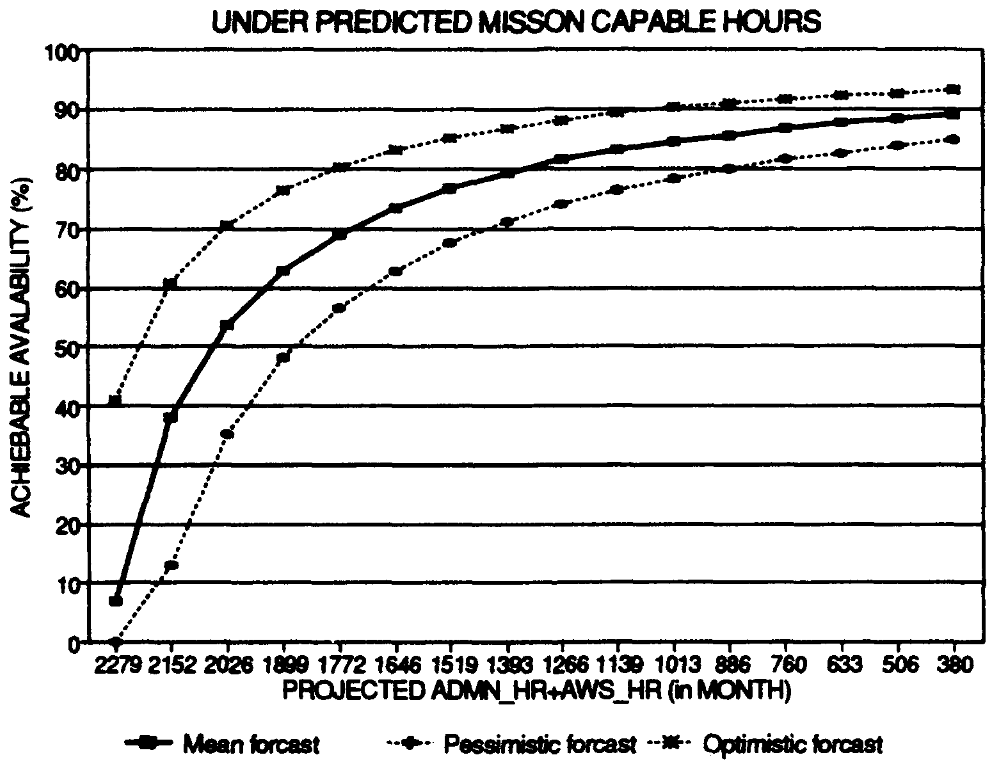
$\mathbf{MNT\_HR_i = 115 + 0.181\ AD_i + 0.0509\ AM_i}$

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	115.10	52.84	2.18	0.036	
AD	0.18080	0.06044	2.99	0.005	1.6
AM	0.05088	0.02490	2.04	0.049	1.6

s = 112.7 R-sq = 47.5% R-sq(adj) = 44.5%

APPENDIX F

TRADE OFF BETWEEN SUPPLY(AWS_HR) AND LABOR(ADMIN_HR)



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