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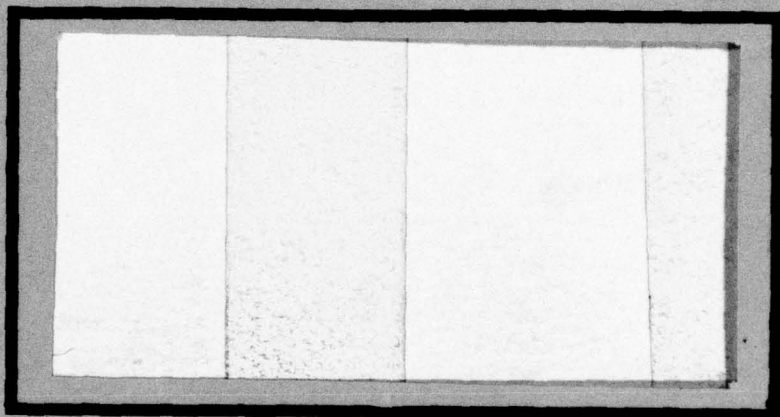
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PRODUCTIVITY: A FUNCTION OF SKILL

Bruce D. French, Captain, USAF
Robert P. Steele, Captain, USAF

LSSR 11-79B

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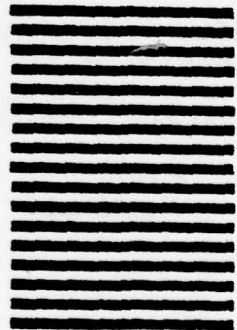


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Two major findings resulted from this research: (1) the relative productivities of the different skill levels of aircraft maintenance personnel were measured. Specifically, the productivity of the three-level, of the five-level, and of the seven-level were compared and the relative differences determined; and (2) the Maintenance Data Collection (MDC) system may be questionable as a source of useful management information. The research looked at the productivity of the seven, five, and three-level worker, 431X1 AFSC, at three F-4E bases. Data was collected over a six-month period. Analysis was accomplished using multiple regression and path analysis. The results were surprisingly consistent with the authors' forecasts. The authors conclude that it is possible to determine relative productivity factors for various skill levels using data from MDC. Their recommendations include a further investigation and improvement of MDC and a feasibility study of the application of the research to Air Force manpower problems.

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PRODUCTIVITY: A FUNCTION OF SKILL

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Logistics Management

By

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Captain, USAF

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September 1979

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(Captain Bruce D. French)

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(INTERNATIONAL LOGISTICS MANAGEMENT MAJOR)
(Captain Robert P. Steele)

DATE: 7 September 1979

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CHAPTER I

INTRODUCTION

Overview

The Comptroller of the United States has determined that millions of dollars could be saved by improving the systems that determine manpower requirements (14:i-iii). This is especially true in the area of aircraft maintenance manpower. Defense manning represents about 60 percent of the total defense budget, and 30 to 40 percent of the total manning is comprised of aircraft maintenance personnel (14:i). Maintenance manpower must be well managed, not just because of budget considerations, but because the aircraft that are maintained represent an enormous investment and are critical factors in the conduct of war.

A vital factor in the management of manpower is the ability to gauge the productive capacity of assigned people. Without this ability, a manager cannot accurately determine how many people are needed or what mixes of people of different ability would be appropriate. An examination of the problems that are involved in measuring the productive potential of assigned manpower is provided in this thesis.

One of the main problems is that the Air Force does not have a meaningful measure of a person's productivity.

This leads to another major problem; the Air Force does not have a method to predict what a person's productivity will be (18).

This thesis addresses these problems by examining the theory that a person's skill is a major determinant of a person's productivity. The research investigates how levels of skill can be used to predict productivity. The point of view taken in this research is that of the maintenance manager in the field. He is the one who deals directly with the resources. Thus, the methods developed in this thesis were designed with the requirements and limitations of the base-level manager in mind.

The remainder of this chapter contains the justification for this research and the background of the research problem. The chapter concludes with the description of the scope and limitations of this research.

Statement of the Research Problem

What is the productivity potential of aircraft maintenance personnel (3, 5, and 7 skill levels) in base-level maintenance?

Justification for this Research

The primary reason for the research has already been mentioned. To manage its maintenance manpower properly, the Air Force must know the productivity potential of people (5). The Air Force has neither an operational

definition of a person's productivity nor a way of predicting it. This is a general reason for this research. In the next few paragraphs are some specific justifications for this research.

The 4400th Management Engineering Squadron (TAC), Langley AFB, asked this research team to investigate the effects of variations in skill level on unit effectiveness (5:1). TAC uses the Logistics Composite Model (LCOM) to develop many of their manpower requirements. However, LCOM is insensitive to levels of skill. It assumes an average skill for all assigned people. This research provides important inputs for consideration in the use of LCOM, an increasingly significant management tool.

At the unit level, this research could be useful in determining an organization's capability. Another thesis team from the Air Force Institute of Technology (Fitzgerald and Miller) developed a computerized model of the interactions of men, equipment, and management which could be used to determine a unit's capability. Their model indicated a marked sensitivity to the level of skill of maintenance personnel (7:62,79,80). Because of the complexity of the relationship between skill levels and productivity, Fitzgerald and Miller recommended further research on the subject (7:56,61).

This research would also be useful in the evaluation of training programs. Training is a very large part of the

defense budget. The selection of the right kind and right amount of training is very important. The problem is "How do you select the most effective training program?" A RAND study examined this question and determined that the biggest problem was identifying the costs and the returns from the training (8:3). The study concluded that it is feasible to measure the cost and returns, though it did not indicate how it was to be done. This research provides a way to measure the return on training, i.e., measure the change in relative productivity of the graduates. The same study went on to state "assignment and utilization policies determine how trained manpower is used [8:30]." The implication is clear: you can train all you want, but if you don't use the people effectively, the training is wasted. This thesis provides a tool for better personnel allocation.

Background

Aircraft maintenance is performed basically at two locations--at a base or at a depot. At the base level, the actual work on the aircraft and its systems largely is performed by enlisted personnel. These personnel are designated by an Air Force Specialty Code (AFSC) and a skill level (SL). The AFSC describes what group of tasks the individual may be expected to perform. The skill level is designed to provide an indication of the relative

contribution a person can make to the maintenance effort. Most of the actual work is done by the 3, 5, and 7 level personnel, with the 7 level generally being the most technically proficient. Grade (rank) is another means to classify personnel. Though grade is used to establish a chain of command and a career ladder for promotion and pay systems, it also fairly accurately reflects experience. Experience, because it may be highly correlated with skill, may sometimes be a good predictor of skill.¹ However, a person of any one skill level could hold any of several grades, and a person of one grade could possibly be in any of the three skill levels (depending upon the current personnel system). Thus grade may not predict skill as well as the skill level designators. But why do we need to be able to predict skill?

Imagine the following management situation. You are a manager with a job to do and a pool of people to do that job. For this example, imagine you are the Wing Commander or the Deputy Commander of Maintenance. Manpower engineering teams have determined that in order to perform your mission you need a specific number of people, and these people should be divided into the particular skill levels in specific proportions. For simplicity, assume all

¹In this paper *skill* is the expected or potential productivity of a person or persons. *Productivity* is an amount of work measured in terms of the number of different types of tasks a person can do, the time it takes to do the tasks, and the quality of task accomplishment.

people have one AFSC and there are only three skill levels (3, 5, 7). Your manning *requirement* (Figure 1-1) may look like this example:

		Number Authorized (<i>required</i>)
Skill Levels	{	SL ₇ 10
		SL ₅ 20
		SL ₃ <u>30</u>
		60 = Total

Fig. 1-1. Manpower Grid--Authorized

In the Air Force the classifications of people are broken down further into different combinations of skill level and grade. This thesis hypothesizes that skill level is an adequate predictor of productivity, simplifying the classifications to just skill levels. However, it is not necessary for the reader to agree with this hypothesis in order to appreciate the significance of this example. The point to remember is that required manning is specified by numbers of people in each category of skill. In the example, compare the *authorized* and *assigned* manpower (Figure 1-2).

Not only is the total manning not the same, but the distribution among the skill levels is not the same. You, as the commander looking at these figures, would like to know if your organization is still capable of

	Authorized	Assigned
Skill Levels	SL ₇ 10	7
	SL ₅ 20	16
	SL ₃ <u>30</u>	<u>35</u>
	60 = Total	58 = Total

Fig. 1-2. Manpower Grid--Authorized Versus Assigned

accomplishing 100 percent of the mission. More specifically, "How is your productivity affected by the difference between authorized and assigned manning?" Can you expect to do 100 percent of the job, or only 90 percent, 80 percent, etc.? If only 3-levels (SL₃) are available for assignment to your organization, how many do you need to make up for the missing 5- and 7-levels (SL₅, SL₇)?

Present methods used by the Air Force to determine manpower do not help solve these problems. The present system of determining the manpower of a work center follows these basic steps (13:2-13; 16:Ch.1-19; 17:2).

1. The tasks and the amount of time spent on individual tasks are determined. While this step is accomplished in many different ways and with varying degrees of accuracy, the end result is the same: a list of tasks and the number of hours spent on each task per month.

2. Total man-hours are determined. All the hours of work for all of the tasks are added together.

3. Total manning is calculated. The total man-hours are divided by 145.2 man-hours/month. This figure is called the man-hour availability factor (MAF) and it applies to all Air Force personnel in the continental United States. The result of this division is the number of people needed in the work center.

4. AFSCs are determined. Tasks are reviewed and matched with AFSCs. A work center may be manned with one AFSC, or with several.

5. Skill levels are assigned. For some tasks there are statutory requirements for specific skill levels and/or rank assignments. For the 3, 5, and 7 level jobs that we are considering, the statutory requirements account for very few assignments (2). The rest of the assignments of skill levels are based on the subjective judgement of the assigning individual (2). This person is guided by Specialty Training Standards (STS), but these guides are general in nature and require interpretation (17:2).

6. Grade levels are assigned. As mentioned before, some grades are required by statute. Grades are also assigned depending upon the official interaction of supervisory personnel among work centers. The rest of the grade assignments are generally subjective, based on many things not considered significant to this research, such as chain-of-command and career-progression factors.

7. All bases with similar missions (F-4E bases, for example) submit these manpower calculations to a central office. A standard manpower configuration is then established, based on these inputs.

Certain underlying assumptions are implied by this procedure. In step 1, the time spent on the task is almost always a measure of the time it took for a *qualified* person to do the task. Total man-hours (step 2) is therefore the total time needed by *qualified* personnel to accomplish the work center's tasks. It follows that the total manning figure (step 3) is the number of *qualified* people needed. In step 4 the tasks are grouped together by AFSC. In the case of a sheet metal work center, one AFSC covers all the tasks. Let us suppose that the total manning requirement is 25. The way this number was calculated implies that 25 qualified people are required. Next, the skill levels are assigned. Statutes require that only 7-levels (SL₇) may do certain things, such as document that a severe crack has been repaired. So a certain number of SL₇s are assigned, based on statutes and the number of shifts. The rest of the work is done by qualified personnel--the 5-level (SL₅). Now we have arrived at the crux of the problem. The rest of the manning is not made up of just SL₅s, but includes SL₃s as well. But SL₃s are only *partially* qualified, and nowhere is there a precise definition of how qualified is partially qualified. The Air Force guide on this topic is

the Specialty Training Standard (STS). To determine the partial ability of a SL₃, the STS uses phrases such as the following (17:2):

Can do simple parts of the task.

Can do most parts of the task.

Can name parts, tools, and simple facts about the task.

Can identify basic facts and terms about the subject.

While some of these standards can be measured, their correlation with an ability to do the work of the organization is unmeasured. So back to the example. Of 25 slots, 5 are filled by SL₇s. The rest of the slots should be filled by qualified people; but they aren't. A certain number of SL₃s are assigned--let us assume that 7 SL₃s are assigned. Since these are *partially* qualified people, the work center is already short of manpower.

The problem compounds itself. In the example, the manning requirement is for

$$\begin{array}{r} 5 \text{ -- SL}_7 \\ 13 \text{ -- SL}_5 \\ \underline{7} \text{ -- SL}_3 \\ 25 \text{ Total} \end{array} \left. \vphantom{\begin{array}{r} 5 \\ 13 \\ 7 \\ 25 \end{array}} \right\} = \text{some aggregate skill level (ASL)}$$

But, as so often happens, what is "required" is seldom what is assigned. Suppose assigned manning looks like this:

4 -- SL ₇	}	= some ASL
11 -- SL ₅		
<u>10</u> -- SL ₃		
25 Total		

How does this affect the ability of the work center to do its assigned work? How many SL₃s are needed to offset the loss of the SL₅? What manning changes, if any, can be made to offset the loss of the SL₇?

LCOM is receiving increased interest throughout the Air Force as a method to determine manpower requirements. TAC uses LCOM to determine most of its maintenance manpower requirements (5). However, LCOM, just like the manpower standard, does not deal with the productivity of each skill level-grade classification.

The total number of required "bodies" is determined by LCOM using procedures similar to those just described. However, the method used by LCOM to develop the authorized manning document from the "total bodies" is a little different. Actually, the LCOM program does not build the manning document. A subprogram of LCOM, the Moody Manpower Program, does the actual breakdown of total manpower figures into grade and skill categories (16:9). The Moody program develops the manning document by apportioning the total manpower among 10 skill level-grade categories. The ratios are dependent upon the total population of the maintenance

organization. In Figure 1-3 are the ratios (current as of January 1, 1979) for organizations of 500 or less people (5).

<u>Categories</u>		<u>Percentage of Personnel</u>
<u>Grade</u> - <u>Skill Level</u>		<u>%</u>
CMSgt	9	0.77
SMSgt	9	1.50
MSgt	9	2.00
MSgt	7	4.62
TSgt	7	11.10
SSgt	7	6.505
SSgt	5	17.512
Sgt	5	26.447
A1C	5	9.675
A1C	3	<u>19.871</u>
		100 %

Fig. 1-3. LCOM Skill Level-Grade Breakdown

The same percentages are applied to the manning of all the work centers of a particular base (for which LCOM is determining the manpower) (5). A closer look at this procedure reveals some weaknesses.

1. All work centers do not require the same ratio of skill levels. An avionics shop, for example, may need a larger portion of SL₅s and SL₇s. The sheetmetal shop, on the other hand, may be able to do its job with a larger portion of SL₃s.

2. The total *required* manpower (as determined by LCOM) is based on all SL₅s. Then the total is split up,

some becoming SL₃s and some becoming SL₇s. The assumption may be that everything averages out to a SL₅. No evidence exists that anyone knows how many SL₃s it takes to "average out" a SL₇. When the percentages of people that are SL₃s was determined, the percentages were not based on any established tradeoff factor among skill levels. Thus, when LCOM assigns some of the total "bodies" (based on SL₅) to become SL₃, it is changing a fully qualified person into a partially qualified person. There is a chance that the skill represented by the total manpower figure (average SL₅) is not equal to the skill of the people on the manning document that the Moody program produces.

$$\frac{\text{Skill of Total Manpower (Average SL}_5\text{)}}{\text{Skill of People on Moody Manning Document}} =$$

3. If, as in the example of the commander who was not assigned all his required manpower, LCOM is asked to describe the resulting effect, LCOM will only react to the change in totals, not to the changes in skill levels.

There is one other relationship that neither LCOM nor any other present system addresses, and that is the interrelationship among the skill levels. What effect does the number of SL₃s have on the productivity of the SL₇s? How will an increase in the number of SL₅s affect the productivity of the SL₃s? From experience, managers

"feel" that these relationships exist, but the effects of these relationships have not been measured.

The present Air Force manpower determination systems cannot address the questions that involve the mixing of skill levels and their respective relative productivities. In addition, Army and Navy manpower determinations are also based on man-hour calculations (14:34-36,42-53). As long as manpower requirements are defined strictly in terms of man-hours, as opposed to some accurate measurement of skill, the same problems will exist as do in the Air Force system.

Thus, the results of the background research have shown two important aspects of the proposed project. First, there is a definite need for the information this research attempts to obtain. Secondly, no other useful method has yet been devised to measure the relationship of skill to productivity.

Scope and Limitations

The goal of this research was to develop a methodology to be used to determine the productivity potential for different skill classifications of people. This methodology is meant to be used by base-level managers as a management tool. The method is applicable to all kinds of groups of people, whether they be grouped by work center,

AFSC, base, or even larger organizations. The actual scope of this research has been limited to one AFSC.

The research was limited because the thesis was developing a method, not actual figures for an entire base. The research was therefore limited to the study of the 431X1 AFSC at F-4D/E bases in the continental United States (CONUS). The 431X1 AFSC (Aircraft General) was selected because it represents a large proportion of the maintenance personnel. The 431X1 AFSC performs a wide variety of tasks, some are simple and some are complex; some tasks are highly repetitive. Additionally, all three SLs are well represented in the career field. The F-4D/E weapons system was selected for several reasons. First, TAC offered to help in the collection of data and in other aspects of the research. A second reason for selecting the F4D/E was the apparent abundance of historical data that was available. Finally, the F-4D/E was selected because it was an old, established weapons system. The relationship among the skill levels and their productivities was considered to be stable. In a new weapon system the relationships could be expected to be in a state of change, and thus harder to analyze. Only CONUS bases were used because the difference of overseas environments might cause relationships of skill levels and productivity to be different than at CONUS bases. Also, the logistics of data and information collection was facilitated by using only CONUS bases.

The CONUS F4D/E bases were further limited to those bases with only F-4D/Es. This avoided the problem of people working on more than one weapon system and possibly making errors in reporting completed work.

The analysis considers only 7, 5, and 3 level personnel. The 1 and 9 skill levels were not considered because their contribution, in the way of actual work on the aircraft and its parts, is extremely small in relation to the added computational complexity their inclusion would have entailed. These limitations were established as an aid to reaching the objective of the research.

Research Objective

Determine the productivity potential of each skill level (3, 5, 7) for aircraft maintenance personnel at the base level.

In order to achieve the objective, a number of other problems had to be solved first. These problems are stated below in the form of hypotheses that required testing. The combined solutions to these problems provided the knowledge necessary to achieve the objective.

Research Hypotheses and Questions

1. Productivity is a function of skill-level mix.
2. Productivity is a positive function of each of the three skill levels.

3. What amount of change of productivity is explained by a change in skill level mix?
4. What is the expected marginal productivity of each skill level?
5. How much confidence is there that the marginal productivities of the three skill levels are not the same?
6. What is the relative productivity of each skill level, using the 5-level as the referent skill level?

Summary

The research hypotheses and questions represent the specific problems that the thesis addresses. The successful solution of these problems allows the accomplishment of the thesis objective--to determine the productivity potential of maintenance personnel.

Chapter I indicated the necessity of such a measurement. Without it, manpower cannot be truly managed. Present manpower determination systems do not define the productivity of a person, nor do they measure it. The chapter concludes with a brief overview of how the research objective was pursued.

The specific methods of data collection and problem solution are discussed in Chapter II. This chapter also includes a discussion of the limitations of the chosen methodology.

Chapter III contains the results of the various tests and an analysis of each. The last section of the chapter is an analysis of the data used in the research.

The final chapter, Chapter IV, contains the conclusions drawn from the research and the recommendations of the researchers.

APPENDIX

The research hypotheses and questions presented in the preceding chapters are restated here for the convenience of the reader. The purpose of this appendix is to provide a summary of the research objectives and to present the data used in the analysis. The appendix is divided into two parts. The first part contains the research hypotheses and questions, and the second part contains the data used in the analysis. The appendix is intended to provide a complete and accurate record of the research process and to allow the reader to verify the results of the research.

CHAPTER II

METHODOLOGY

Overview

The objective of this research is to determine the potential productivities for the 3, 5, and 7 skill level personnel of a maintenance organization. This chapter details the methodology that was applied to the research problems posed in Chapter I. In the first section of the chapter, the data requirements and data availability are covered. The next section contains a discussion of the two basic methods of analysis used in this research, multiple linear regression (MLR) and correlation analysis. Following this general discussion are presented the specific methods that were applied to the research problems. The chapter concludes with a discussion of the limitations of the chosen methodology of this research.

Data Requirements

The type and source of data used was dictated by the intended use of the results of the analysis. As mentioned in the previous chapter, the results of this research are needed at the base level, possibly on a weekly or monthly basis. The manager must be able to analyze the capability of assigned manpower as often and as fast

as manning changes. Thus, the data used in determining productivity factors must be readily available at the base level.

Three basic methods exist that can be used to collect the data required for analysis: (1) direct measurement at the work location, (2) opinion survey of knowledgeable people (NCOs, supervisors, etc.), and (3) use existing data collection systems which, in this case, would be the Maintenance Data Collection system (MDC). Because of the requirements already placed on the data, i.e., data have to be readily available at the base level, the first two sources of data are not feasible. Therefore, MDC was chosen as the source.

As mentioned in Chapter I, data were collected for the 431X1 AFSC at CONUS bases having only the F-4D/E aircraft. The four bases meeting these limitations were Seymour-Johnson, MacDill, Homestead, and Moody AFB.

The ideal data to collect would indicate exactly what a person's skill or productivity potential was. To determine what information must be collected, it is first necessary to have a definition of *productivity*. This thesis uses the following definition:

Productivity of a person(s) is measured in terms of three things: (1) the different kinds of tasks a person can do; (2) the time it takes to complete each kind of task; and (3) the quality with which the tasks are accomplished.

This is based on Sutermeister's definition that productivity is the "output per man per hour, quality considered [12:2]."

Each of these factors is important. Obviously, a worker who can do ten or twelve separate maintenance tasks will probably be more productive than a person who can only do two or three tasks. Likewise, two workers who can do the same tasks will differ in productivity if their times to do the tasks are different. The quality factor is the most often omitted factor in the discussion of productivity. This is a serious fault, for it is quite clear that, while two people may do a job in the same time, such as preflighting an aircraft, the person who does a higher quality inspection is being more productive. In the long run, the higher quality will result in better maintenance and, therefore, higher productivity.

Ideally, data collected would reflect these three factors of a person's productivity (the kinds of tasks, the task times, and task quality). Such data could be analyzed to give the manager the information needed about the productivity potential of people. However, these data are not available in the Maintenance Data Collection system or in any other data system.

Only limited data were available for analysis. Reports of completed tasks and the task times are recorded by work center, rather than by individual identifiers or skill levels. Quality is evaluated, but the Quality

Control (QC) reports normally are not kept for more than thirty days. Reports of the actual manning of work centers (broken down by skill level) is not formally recorded in any data system. Manning data is necessary to investigate interrelationships among skill levels and their respective productivity potentials. Thus, the data that were available were limited to monthly work center reports of man-hours expended, the kinds and number of tasks accomplished, and the actual manning (see Table 2-1). Due to limitations on data availability, data were requested for a six-month period from all four bases (November 1, 1978 to May 31, 1979). This amount of data was considered large enough to provide well over 100 cases (data points) for analysis.

For analytical purposes, the assumption was made that the number of man-hours is a measurement of the productivity of the work center. From experience, the more time that people work, the more they produce. This does not satisfy the full definition of productivity used, but does take advantage of existing data.

The balance of this chapter explains how the data were analyzed. The types of data available caused the researchers to choose multiple linear regression and correlation analysis as the basic statistical methods to treat the data. The next section briefly discusses these two types of statistical investigation.

TABLE 2-1
SUMMARY OF DATA COLLECTION

Base Unique Data	Period of Collection	Personnel Data	MDC Data
<ul style="list-style-type: none"> • Type Maintenance Concept (66-1, POMO, etc.) • Weapon System 	<ul style="list-style-type: none"> • Month • Year 	<ul style="list-style-type: none"> • Number of Assigned Personnel by Work Center and Skill Level • AFSC 	<ul style="list-style-type: none"> • Manhours/Month by Work Center and AFSC • Work Unit Codes • Number Units Complete

Regression and Correlation

Regression

This is the primary statistical method employed in this research. Regression analysis enables the researcher to examine the relationship that exists between a dependent variable and one or more independent variables. In this research, *productivity* is the dependent variable and a person's skill, as reflected by his skill level, is the independent variable. The result of regression analysis is a linear equation of the following form:

$$\hat{Y} = \alpha + \beta X$$

This equation predicts the value of the dependent variable (\hat{Y}) for each value of the independent variable (X). Regression analysis finds the equation that is the best predictor, or minimizes the differences between the actual dependent variables (Y) and the predicted variables (\hat{Y}). The predictive accuracy of the equation can then be evaluated.

Regression analysis can include more than one independent variable. In this research, there are at least three such variables and they are the actual skill of each of the three skill levels. The multiple regression equation takes the following form:

$$\hat{Y} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

where:

α = a constant value,

β_i = the amount of change in \hat{Y} that a one unit change in β_i will cause; and

X_i = the number of units of independent variable X_i .

Another use of this technique is that it allows the researcher to control "other confounding factors [2:321]" and examine the importance of one specific variable or set of variables. Regression can also be used to examine and explain complex multivariate relationships (2:321). However, multiple linear regression (MLR) is subject to several assumptions which must be considered when using MLR for analysis. The assumptions involve an error term (ϵ).

The actual values of the independent variables are applied to the regression equation to produce a predicted value for the dependent variable (\hat{Y}). This value can be compared with the *actual* value of the dependent value (Y) that resulted from the influence of the independent variables. The difference between \hat{Y} and Y (the variance-VAR) is the error term (ϵ), the amount of the dependent variable that is not explained by the regression equation.

$$Y - \hat{Y} = \epsilon$$

The assumptions are as follows:

1. In regression analysis, each error term is assumed to be independent from all other error terms. Essentially this means that the values of the variables of each sampled case were independent of the values of other cases.

2. The expected value of the error term $[E(\epsilon)]$ equals zero.

3. The variance of the error term $[\text{var}(\epsilon)]$ equals the variance of the population. Implicit in this assumption is that the $\text{Var}(\epsilon)$ remains constant for the full range of variable values. Failure to remain constant could be an indication that the linear regression equation does not fully model the relationship among the variables.

4. The error terms are normally distributed. This assumption implies that the error terms are a result of random chance rather than a specific cause. Normality also implies that the values of the error terms tend to cluster about a central value.

Correlation

The second basic method of statistical analysis is correlation. Basically, correlation is a measure of association. A correlation coefficient is a measure of the degree of association between variables, i.e., the amount of change in one variable that is associated with a change of another variable.

There are many different tests of correlation. The basic test used in this thesis is for the Pearson product-moment correlation coefficient. The basic assumption of this test is that the values of the two variables being tested are normally distributed (11:196).

Both regression and correlation analysis (Pearson's) require data to be measured at least in the interval scale. In the interval scale "the distances between any two numbers on the scale are of known size [11:26]." Since the data collected for analysis are measured in the ratio scale, a higher level of measurement, this requirement is met.

The foregoing has been a brief review of regression and correlation analysis. More detailed discussions will be included where necessary in the specific applications of these statistical methods of analysis. The next section describes the exact methods used to solve the research problems presented as hypotheses and questions in Chapter I.

Specific Methods of Analysis

This section outlines the statistical method and technique used to extract information from the data to either support or not support the research hypotheses and to answer the research questions. The hypotheses and questions are discussed in the order they appear in Chapter I.

Research Problem 1

Hypothesis: *Productivity is a function of skill-level mix.*

For statistical purposes, a review of the data was accomplished to identify cases with identical combinations of the three skill levels. If two or more cases had the same manning (example: two work centers were manned with 3 SL₇s, 10 SL₅s, 4 SL₃s) or had multiples of these manning levels (example: 6 SL₇s, 20 SL₅s, 8 SL₃s), then all but one of these cases with like manning had to be eliminated to avoid confounding the MLR analysis. The work center with the highest man-hour figure would be retained, based on the assumption that higher levels of activity better reflect the true contributions of the respective skill levels.

The data also had to be sorted so that it would best reflect the true relative contributions of the three skill levels to the maintenance effort during normal (peacetime) conditions. To do this, a range of productivity was established. A person is assumed to be available for work 22 days a month, 8 hours a day (176 hours/month). Based on the researchers' experience, the normal rate of activity consumes about 60 percent of the available man-hours.

The assumption was made that if everyone is working at the normal rate, then everyone is about equally busy and is making an equal effort to produce. Activity below the

60 percent rate may lead to a tendency for certain people to slack off while others are forced to do most of the work. Therefore, the 60 percent rate of productivity (105 hours/month) was established as the lower bound of the acceptable range. The upper boundary was established at 220 hours a month. This figure was calculated based on a person working 22 days a month, 10 hours a day. It was felt that this amount of hours was not unusual and it was still below the planning factor for sustained combat of 242 hours/month (5). The range of acceptable data was established at 105 hours/month to 220 hours/month for the average person.

The second sort was based on the above range of acceptance. The data were comprised of monthly reports, by work center and the number of man-hours expended. As mentioned earlier, the reported man-hours is considered in this study as a reflection of the productivity of the work center. Each monthly work center report was matched with its manning document. To sort these monthly reports, the work center man-hours for the month was divided by the total number of SL₇s, SL₅s, and SL₃s in the work center that month. The resulting "average productivity per person" was compared with the acceptable range of activity.

Once the data of each base were sorted (see Figure 2-1), it was desired to combine data from each base, if possible, in order to provide a larger sample. The larger the sample, the more powerful are the statistical tests.

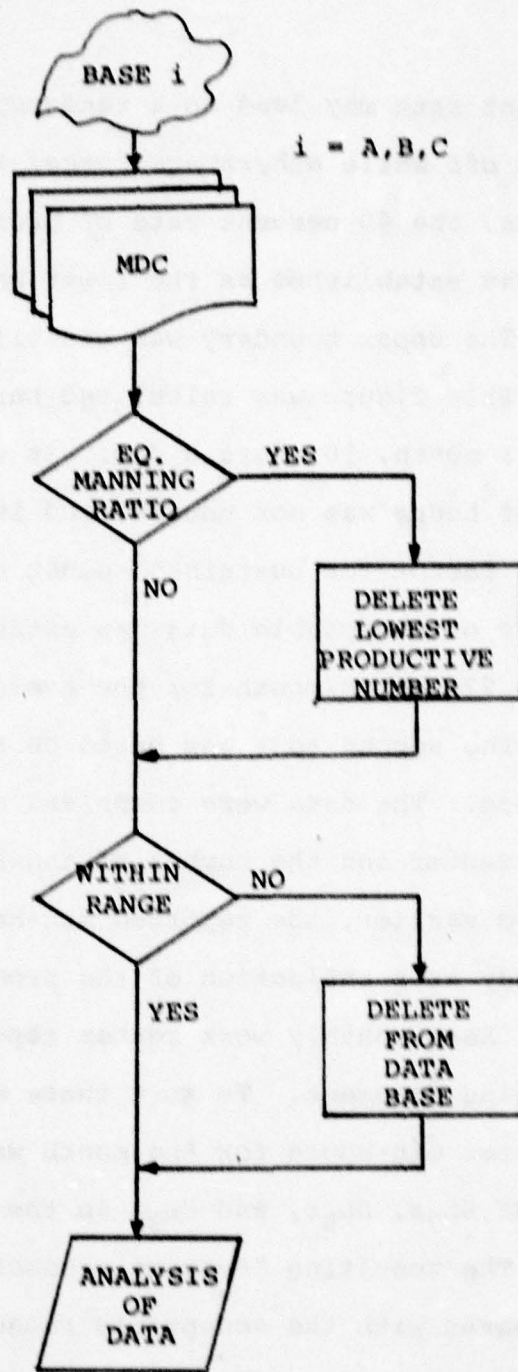


Fig. 2-1. Data Sort Process

However, in combining samples into a larger sample, one must insure that each sample is a sample from the same population. In this case the question is whether or not the 431X1 personnel at the different bases are generally the same (produce about the same) or whether the people are *different* (example: one base may have mostly SL₇s). Only if samples are from the same population will the statistical tests be more powerful than those performed for separate data.

The first step in testing for similarity of bases was to perform a regression analysis for the data from each base, thus producing a regression equation for each base (See Figure 2-2). Unless indicated otherwise, statistical analysis was accomplished using the Statistical Package for the Social Sciences (SPSS) (2). As mentioned in the discussion of regression, the regression equation can be tested for its predictive accuracy. To do this, SPSS tests the multiple correlation (R) between the dependent variable, productivity, and the independent variables, the skill level mix of the work center. Each base was tested for the hypothesis that there is a correlation between skill level mix and productivity. This is done by constructing a *null* hypothesis (H₀), that is, a hypothesis of no difference.

$$H_0: R = 0$$

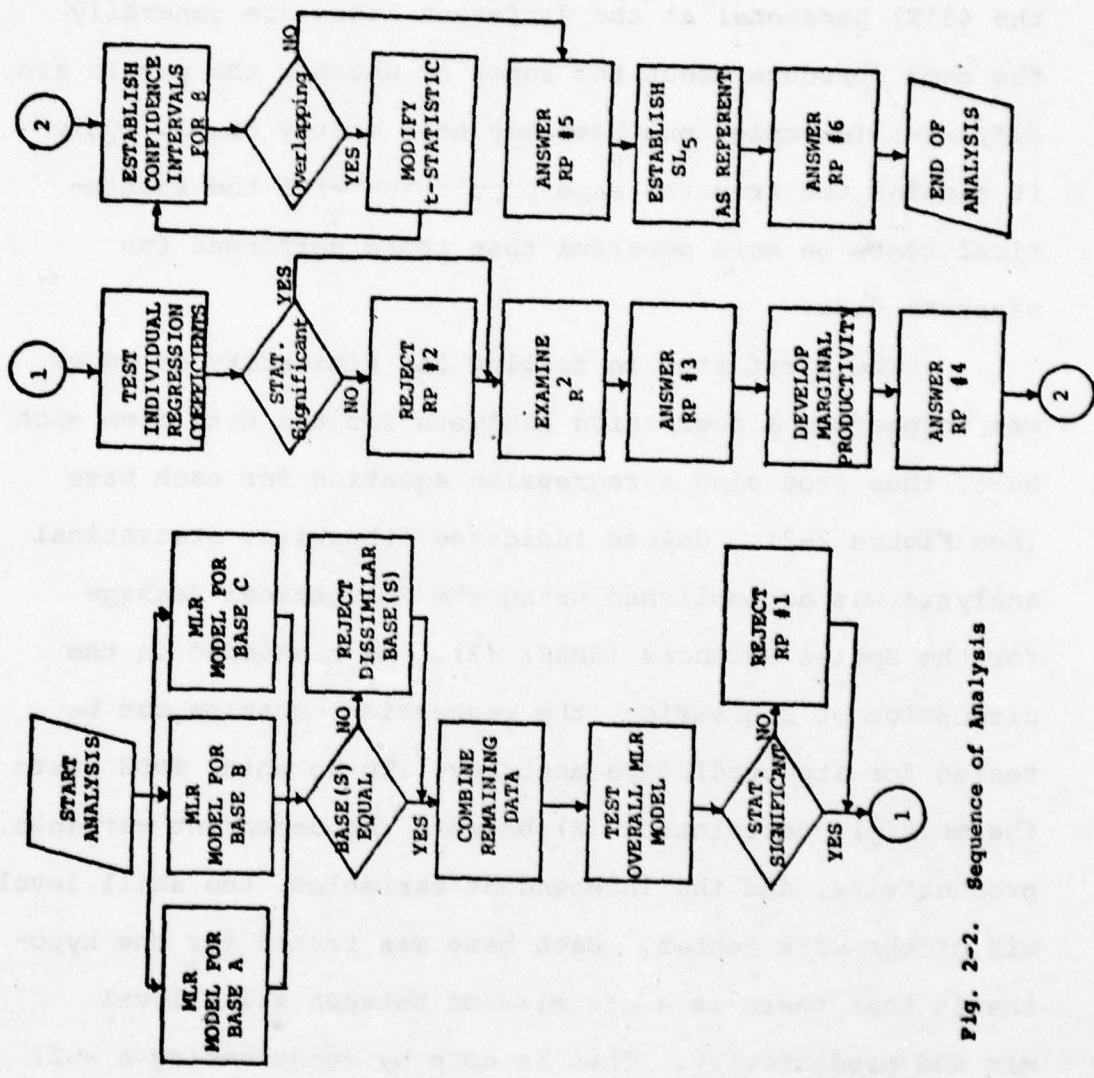


Fig. 2-2. Sequence of Analysis

This hypothesis is then tested statistically. If H_0 is rejected, then an *alternative* hypothesis (H_1) is accepted. In this case H_1 is that there is a correlation between skill level mix and productivity.

$$H_1: R \neq 0$$

If H_0 is not statistically rejected, then the research is left with the *weak* assumption H_0 . H_0 is a weak assumption because it has not been statistically proven. What has happened is that the data have failed to provide sufficient statistical information to reject the hypothesis.

The null hypothesis is tested by statistically measuring the probability that the sample being analyzed could have come from a population where H_0 is true. Two types of errors can occur in testing H_0 and these are called Type I and Type II. A Type I error could occur if the test rejected a sample when it in fact was from the population. A Type II error would occur if the test failed to reject the sample when in fact it was not from the population (11:8-11). The probability of making a Type I error is expressed as α . The nature of the errors is such that the minimization of one causes the other to increase. Thus, the researcher minimizes one or the other depending upon the design of his experiment.

The F-test was used for the test of $H_0: R = 0$. For this test the value of F is determined for the sample. F

is equal to the variance of the dependent variable explained by the regression equation divided by the unexplained variance (2:335).

$$F = \frac{\text{Explained variance}}{\text{Unexplained variance}}$$

The value of F for multiple samples of the same size (taken from the same population) has a particular distribution, the F-distribution. For a F-test, the value of F for the researchers' sample (F_{TEST} --designated as F_T in this thesis) is compared to the value of F that could be expected for such a sample size (F_{CRITICAL} --designated F_C). The particular value of F_C is directly related to the probability of making a Type I or II error, depending upon the researcher's requirements. If F_T is larger than F_C , then H_0 is rejected. This is the method used to test many of the hypotheses posed in this research.

The hypothesis, $H_0: R = 0$, was tested for each base. If the null hypothesis were not rejected at a high enough level of significance (a low value of α), using the F-test, then continued analysis would be pointless.

Bases indicating significant correlation (R) between skill level mix and productivity were then examined to see if they were samples from the same population. To do this, the regression equations were compared to see if they were statistically the same. The equations for each

base would take the form shown below. Only three bases are shown because additional bases would be depicted and analyzed in the same manner.

$$\text{Base A } \hat{Y}_A = \alpha_A + \beta_{A,SL_7} X_{SL_7} + \beta_{A,SL_5} X_{SL_5} + \beta_{A,SL_3} X_{SL_3}$$

$$\text{Base B } \hat{Y}_B = \alpha_B + \beta_{B,SL_7} X_{SL_7} + \beta_{B,SL_5} X_{SL_5} + \beta_{B,SL_3} X_{SL_3}$$

$$\text{Base C } \hat{Y}_C = \alpha_C + \beta_{C,SL_7} X_{SL_7} + \beta_{C,SL_5} X_{SL_5} + \beta_{C,SL_3} X_{SL_3}$$

where:

β_{A,SL_7} = the productive contribution of SL_7 at Base A, and

X_{SL_7} = number of SL_7 s.

To test if the bases are samples of the same population, a null hypothesis is constructed and tested, again using a F-test. The null hypothesis is that there is no difference among the maintenance personnel of the bases.

$$H_0: \beta_{A,SL_7} = \beta_{B,SL_7} = \beta_{C,SL_7} \text{ and}$$

$$\beta_{A,SL_5} = \beta_{B,SL_5} = \beta_{C,SL_5} \text{ and}$$

$$\beta_{A,SL_3} = \beta_{B,SL_3} = \beta_{C,SL_3}$$

A F-test of significance was accomplished using a procedure from the Neter & Wasserman text to construct the F-test statistic (F_T) (10:163). F_T was developed by comparing the error sum of squares (SSE), that portion of

If, on the other hand, the null hypothesis was rejected, then it would be concluded that at least one base was not the same as the others. This would raise the question as to which base(s) were not alike. To find this answer, a series of null hypotheses would be constructed and tested comparing two bases at a time. The same procedures used to compare three or four bases could be used to compare two bases. The null hypotheses would be similar to this example:

$$H_0: \beta_{A,SL_7} = \beta_{B,SL_7} \text{ and } \beta_{A,SL_5} = \beta_{B,SL_5} \text{ and} \\ \beta_{A,SL_3} = \beta_{B,SL_3}$$

As a result of this analysis, data from similar bases would be combined.

Once the data were combined, the initial research hypothesis, *Productivity is a function of skill level mix*, was tested. First a regression analysis was completed on the combined data. The resulting regression equation was of the form--

$$\hat{Y} = \alpha + \beta_{SL_7} X_{SL_7} + \beta_{SL_5} X_{SL_5} + \beta_{SL_3} X_{SL_3}$$

The multiple correlation (R) was determined and the following null hypothesis constructed to test the research hypothesis.

$$H_0: R = 0$$

variance not explained by the regression equation, for the "full model [10:164]" (SSE(F)), and for the "reduced model [10:164]" (SSE(R)). By combining the SSE and comparing this to the SSE(R), it can be determined if the amount of variance explained by the combined sum of squares (SSE(F)) is statistically the same as the variance explained by the SSE(R). If it is statistically the same then the data can be combined to yield a regression equation "containing greater precision than two different regressions [10:160]." The error sum of squares for the full model consists of the sum of the error sum of squares for each base, as computed by SPSS.

$$SSE(F) = SSE(A) + SSE(B) + SSE(C)$$

The error sum of squares for the reduced model was calculated by combining the data for all bases and then computing a single regression equation. F_T was then determined using Neter & Wasserman's equation (10:164).

$$F_T = \frac{SSE(R) - SSE(F)}{3} \div \frac{SSE(F)}{N_A + N_B + N_C - 15}$$

where N_i = number of cases from base i .

F_T is tested against an F_C ($F_3, N_1 + N_2 + N_3 - 15$) for statistical significance.

If the null hypothesis was not rejected, the *weak* assumption that the bases were the same would be accepted.

The null hypothesis that the multiple correlation is zero "is equivalent to the null hypothesis that all k regression coefficients [β_i] are equal to zero in the population, . . . [2:336]."

$$H_0: \beta_{SL_7} = \beta_{SL_5} = \beta_{SL_3} = 0$$

The test was made using the F_T -statistic provided by the SPSS program.

Research Problem 2

Hypothesis: Productivity is a positive function of each of the three skill levels.

This hypothesis can be stated in terms of three alternative hypotheses as follows:

$$H_1: \beta_{SL_7} > 0$$

$$H_1: \beta_{SL_5} > 0$$

$$H_1: \beta_{SL_3} > 0$$

The research hypothesis was tested using the null hypothesis ($H_0: \beta_i = 0$) of these equations. The F_T -statistic provided by SPSS was converted to a t_T -statistic and a one-tailed t-test was conducted. A t-test is based on the Students-t distribution which is related to a F-distribution by $F=t^2$. The t-test was used because for sample sizes less than 200 "the β_i estimates follow the

t-distribution [2:3]." The researchers determined the lowest α that would permit H_0 to be rejected in order to establish the amount of confidence in the alternative hypotheses.

Research Problem 3

Question: What amount of change in productivity is explained by a change in skill level mix?

Correlation analysis was used for this problem. SPSS provided the multiple correlation (R) for the regression equation. R, as a number, is difficult to translate. However, R^2 provides an easily understood number. R^2 , expressed as a percent, indicates the amount of change in Y (productivity) that is explained by the regression equation (regression of X_1 on Y). Thus, the value of R^2 was used to answer the research question.

Research Problem 4

Question: What is the expected marginal productivity of each skill level?

The variable coefficients (β_{SL_7} , β_{SL_5} , β_{SL_3}) produced in the multiple regression analysis are taken to be the answers to this research question. The hierarchical method was used to bring the independent variables (skill levels) into the regression analysis, entering first the SL_7 , then the SL_5 , and then the SL_3 . Hierarchical strategy is recommended when the correlations among the variables

are believed to be results of causal relationships. The researchers assumed that there are causal relationships among the skill levels and their productivities (For example: an increase in the number of SL₇s will affect the productivity of the SL₃s in the work center). It was further assumed that the SL₇ has the most control over the "causal relationships." The SL₃ has the least control.

Research Problem 5

Question: How much confidence is there that the marginal productivities of the three skill levels are not the same?

The coefficients derived from the regression equation are the expected values, or the average values, as predicted by the sample data. This research question is concerned with how much confidence exists that these values are good predictors of the actual values found in the original population. The confidence in the coefficient increases if its value is stated as a range or interval of values. As this *confidence* interval is expanded, the confidence that it includes the actual population value increases. But as the interval increases, so does the range of values that the coefficient has.

This thesis considers three coefficients. A study of overlapping confidence intervals would be meaningless. Overlapping confidence intervals implies the possibility

that coefficients can have the same value, i.e., that there is no difference in the productivity of the skill levels. Therefore, primary interest is in the nonoverlapping confidence interval about each coefficient and the confidence attached to the intervals.

The confidence in the intervals is established by the α selected. The intervals can be tested using one-tailed t-tests that a value of β_i is less than a given value (b) and greater than another (a).

$$a < \beta_i < b$$

|Confidence Interval|

An iterative process was used, establishing an α and then determining the boundaries of the intervals about each coefficient.

$$\beta_i = \hat{\beta}_i \pm t \frac{s}{\sqrt{\sum \chi^2}}$$

where:

β = actual value of the coefficient in the population,

$\hat{\beta}$ = value of coefficient as determined by the data,

t = the value of t as dictated by the size of the sample,

s = estimated standard error, and

χ = variation of the dependent variable from its mean ($X - \bar{X}$).

The value of α was changed until nonoverlapping confidence intervals were found. The confidence in the intervals is represented by the final value of α .

Research Problem 6

Question: *What is the relative productivity of each skill level, using the 5-level as the referent skill level?*

By establishing the SL_5 as the reference, then the relative productivity of the SL_5 is one (1). The relative productivity factors for the SL_3 and SL_7 are determined by dividing the respective regression coefficients (marginal productivity factors found in Research Problem 4), by the SL_5 coefficient.

Marginal Productivity Factors:

$$SL_5 \text{ (referent skill level)} = 1$$

$$SL_7 = \frac{\text{Marginal Productivity } (SL_7)}{\text{Marginal Productivity } (SL_5)}$$

$$SL_3 = \frac{\text{Marginal Productivity } (SL_3)}{\text{Marginal Productivity } (SL_5)}$$

Limitations

The methodology of this research is designed to describe the productivity potential of persons of different skill levels in general terms. The available data did not lend itself to analysis of interrelationships among the skill

levels. It is possible to test for relationships with the right data. Such data would reflect changes in the productivity potentials of skill levels as the manning ratios of the skills change. This research produces only one value of productivity for each skill level. A large data base could be separated into subsets of work centers, each subset representing a particular manning ratio among skill levels. Each subset could be analyzed to determine the marginal productivity factors (β_i). These factors could then be compared to determine if they change as the ratio among skill levels changes.

Development of productivity factors is not an implication that, perhaps all the SL_7 s can be replaced by some ratio of SL_3 s. It is recognized that in many situations only a SL_7 can do certain tasks as a result of established law or regulations, or out of military necessity. There may also occasionally be a requirement for a minimum number of SL_5 s. It is in conjunction with these minimum requirements that productivity factors should be employed to better manage manpower.

Any conclusions drawn from the statistical analysis can only be applied to the participating bases, to a time frame closely approximating the period of data collection, and to the 431X1 AFSC. The productivity potential of various skill levels may vary widely from work center to work center, from AFSC to AFSC, and/or from base to base.

Equally important is the idea that productivity of a group of people can change with time due to such things as different training programs, different equipment to help do the work, different educational requirements for enlistment, and motivational factors that may change significantly from time to time.

Summary

This chapter has discussed the methods that were used to solve the research problems. The basic research tools were regression and correlation analysis. These methods were first explained in general terms and then in more specific terms as they were applied to specific research problems. The next chapter contains the results of the application of this methodology. The chapter includes an analysis of the results and a discussion of the assumptions and data of the research.

CHAPTER III

RESULTS AND ANALYSIS

Overview

This chapter contains the results of the application of the methodology explained in Chapter II. As a result of the sort process only 24 of 110 cases were used for analysis. However, even though the sample size was small, the statistical significance of the results has demonstrated the usefulness of the methodology and its ability to produce productivity factors for different skill levels of maintenance personnel.

Results and Analysis

Research Problem 1

Hypothesis: *Productivity is a function of skill-level mix.*

The eventual testing of the null hypothesis first required the sorting of data and the testing of the bases so that the data from the different bases might be combined. Once data were combined, the hypothesis was tested.

Data Sort No. 1. Data were sorted in order to remove cases with identical manning or exact multiples of

manning.¹ Three bases reported a total of 110 cases (each case included the work center's man-hours and manning-matrix). Of the 110 cases, 16 were rejected for this reason.

Data Sort No. 2. The remaining 94 cases were sorted for normal levels of productivity (105-220 man-hours/per month/per man). After the sort, 31 cases remained for further analysis.

The rejection of 63 of 94 cases because of abnormal levels of activity has some serious implications, particularly when one considers that only one of the rejected cases reflected higher than normal activity. These results lead to three possible conclusions: (1) the sampled work centers were overmanned for the work to be done, or (2) not all the work was reported in MDC, or (3) both of the above are true. If (1) is true, then manpower is being mismanaged. If (2) is true, then MDC does not accurately reflect the maintenance being done. This has the further implication that, if MDC is a questionable source of data, all Air Force programs that depend on MDC may be using inaccurate information to reach conclusions and solutions. While there may be some surplus in manpower in the sampled

¹Each case contained a number of man-hours worked by a work center in a month and the manning, by skill level, of the work center for that particular month (example: 1243 hrs, 4 SL₇s, 10 SL₅s, 3 SL₃s).

work centers, it is highly unlikely that this is the primary cause for the results of this analysis of levels of activity. The most likely explanation is that only a fraction of the work being done is documented accurately in the MDC system.

The next step in analysis was to determine if the three bases were samples of the same population. Similarity of bases would allow data to be combined, thus increasing the power of the analysis and generalizability of the findings.

$H_0: R_i = 0$ (i=base A, B, and C). A multiple regression analysis was run for each base. The multiple correlation (R) between skill-level mix and productivity was tested for significance for each base. See Table 3-1 for results.

TABLE 3-1
RESULTS OF REGRESSION OF BASE DATA

Base	R^2	F_T	d.f. m,n	F_C	α
A	.928	30.12	3,7	18.77	<.001
B	.912	30.91	3,9	13.90	<.001
C	.923	19.96	3,5	16.53	<.005

The null hypothesis was rejected in all three cases. The probability of drawing the data from a population where skill levels and productivity are unrelated is less than

0.005. In each of the samples actually tested, at least 91 percent of monthly change in productivity can be explained by a change in skill-level mix, as indicated by R^2 .

The results of these tests provide a degree of confidence that there is a relationship between skill levels and productivity. Since skill levels are surrogate measures of actual skill, it can be concluded that productivity is related strongly to skill. The correlation of skill to productivity was very high. The weakest correlation (Base B) indicated that, in the sampled work centers, 91 percent of a change in productivity was associated with a change in skill.

H_0 : All Bases are the Same: The regression of the three bases were compared and the hypothesis tested through the construction of a F-test. The test involved the comparison of error sum of squares as outlined in Chapter II (see Table 3-2).

TABLE 3-2
COMPARISON OF ALL BASES

F_T	F_C ($\alpha=.05$: d.f.=3,62)
10.08	3.15

Since the null hypothesis that the three bases are from the same population is rejected, it can be concluded that at least one base sample is different.

The bases were then compared, two at a time, in an effort to find the different base(s) (see Table 3-3).

TABLE 3-3
COMPARISON OF TWO BASES AT A TIME

Base X	vs.	Base Y	F_T	F_C ($\alpha=.05$)	d.f. m,n
A		B	0.39	3.49	2,20
A		C	8.98	3.63	2,16
B		C	2.47	3.55	2,18

H_0 : Base X = Base Y: The test failed to reject the hypothesis that Base A = Base B. Therefore, the conclusion is that they are from the same population and can be combined. The comparison of Base A and C early rejected the hypothesis of similarity. If A and B are the same, and A and C are different, C comes under suspicion of being the odd base. The third comparison of Base B and C shows again the *weak* assumption of equality. The test is very close at the $\alpha=.05$ level.

A further comparison of the regression lines of the slopes of the independent variable coefficients illustrates the comparison of the three bases (see Figure 3-1).

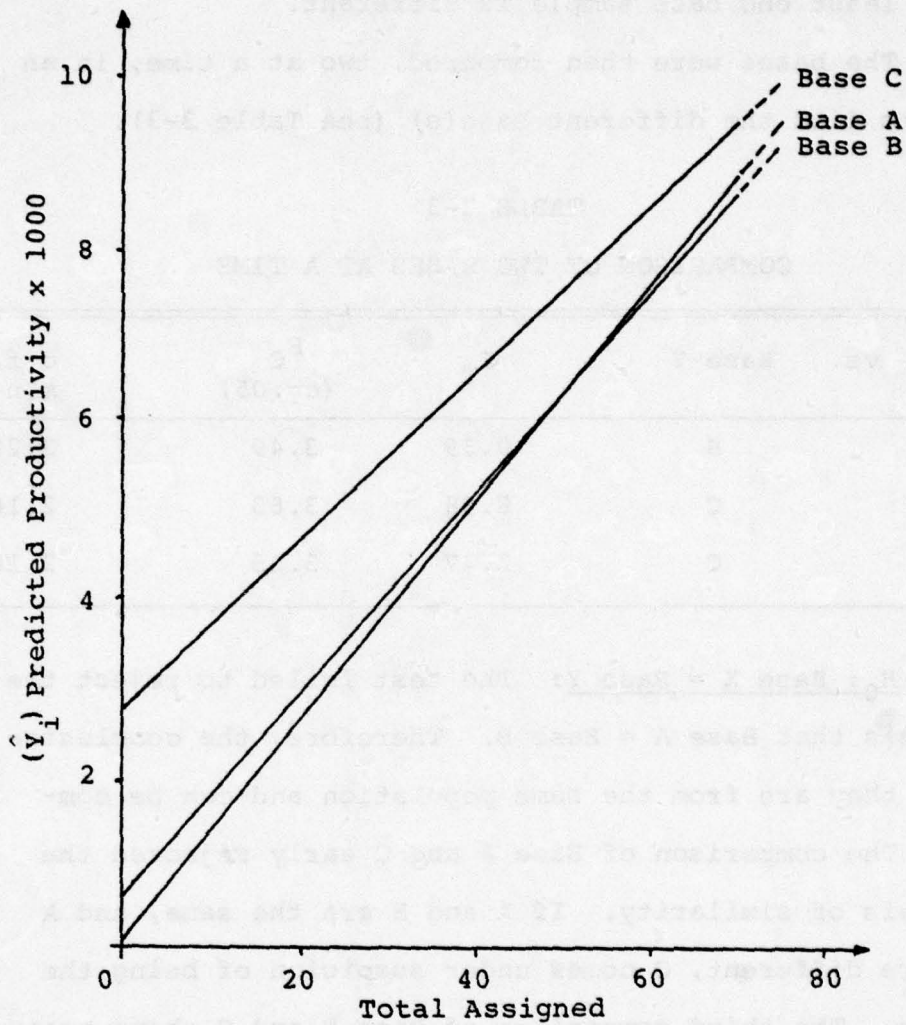


Fig. 3-1. Plot of Regression Lines for Bases A, B, and C
(not to be used to predict total manning)

If the personnel of different bases are about the same in terms of productivity, then the regression equations will be similar. If the manning of a particular work center was used as an input to the regression equations of similar bases, the predicted productivities (\hat{Y}) of the bases should be about the same. However, different bases will produce dissimilar equations. The same work center manning applied to dissimilar equations will result in different predictions of productivity (\hat{Y}). Figure 3-1 is a plot of the results of inputting identical work center manning combinations into the three base regression equations. The equation from Base C is depicted as being different from the others. The actual equations are shown in Figure 3-2.

$$\begin{aligned} \text{Base A} \quad Y_A &= 6.78 + 129.42 X_{SL_7} + 125.28 X_{SL_5} + 85.77 X_{SL_3} \\ \text{Base B} \quad Y_B &= 411.42 + 148.10 X_{SL_7} + 106.25 X_{SL_5} + 101.15 X_{SL_3} \\ \text{Base C} \quad Y_C &= 2801.7 - 65.23 X_{SL_7} + 131.17 X_{SL_5} + 18.00 X_{SL_3} \end{aligned}$$

Fig. 3-2. Base Regression Equations

The different values of corresponding coefficients are graphically depicted in Figures 3-3, 3-4, and 3-5. Figure 3-3 compares the contribution of the SL_7 at the three bases. The graph of Base C shows that as you increase the number of SL_7 s, the total productivity of the work center will decrease. Since such a relationship is highly unlikely,

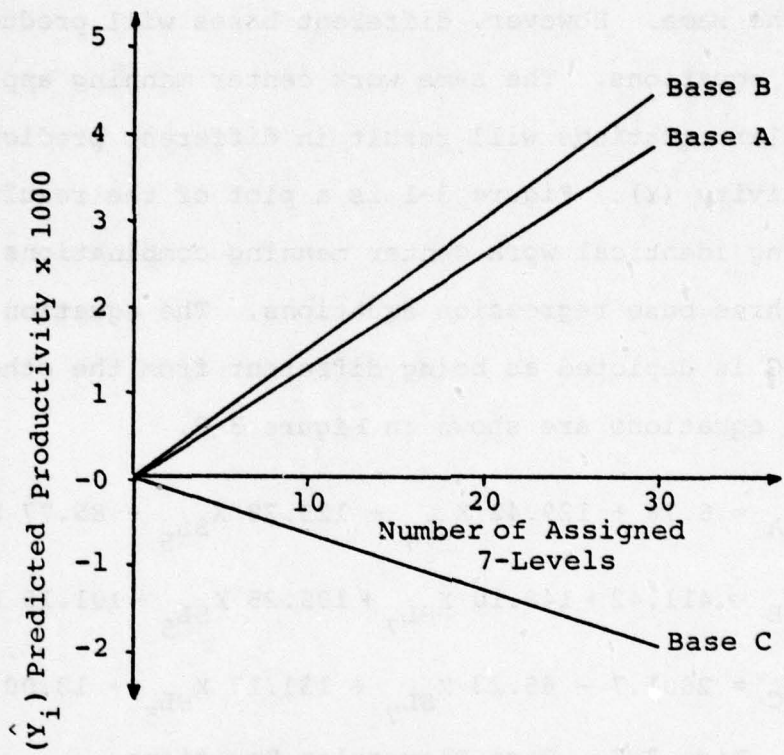


Fig. 3-3. Plot of Assigned 7-Levels Vs. Predicted \hat{Y}

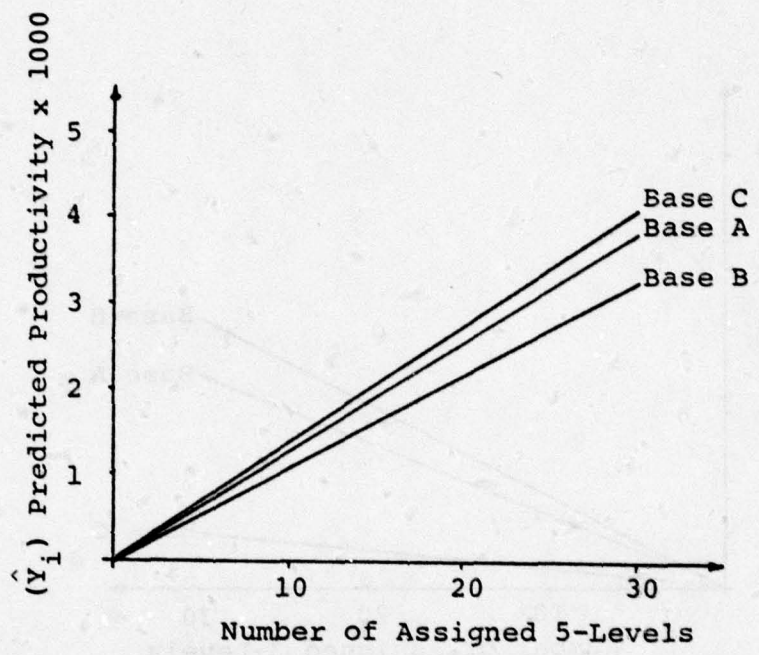


Fig. 3-4. Plot of Assigned 5-Levels Vs. Predicted \hat{Y}

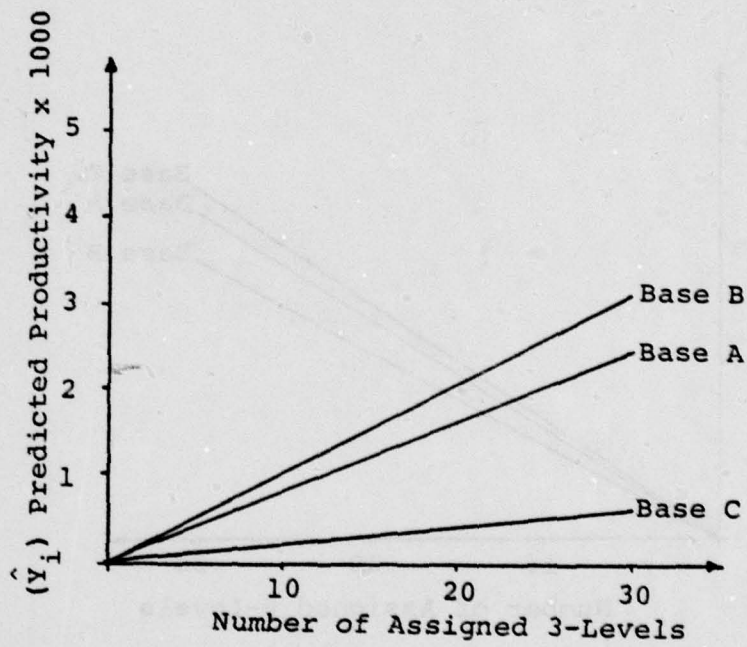


Fig. 3-5. Plot of Assigned 3-Levels Vs. Predicted \hat{Y}

this information is a further indication of serious defects in the MDC system. Figure 3-4 indicates that the SL_5 s at the bases are about the same. The SL_3 s are shown in Figure 3-5. Again Base C is depicted as being different from the other two.

The conclusion of this analysis is that Base C is probably not similar to the other two bases. The inclusion of Base C data with that of A and B would increase the amount of variation of \hat{Y} and would cause the level of statistical significance of the results to decrease. The results of this analysis also indicate that inclusion of Base C data may introduce a degree of Type II error (discussed in Chapter II) while doing little to decrease the Type I error. Therefore, Base C data was excluded from further consideration.

$H_0: R = 0$. H_1 : Productivity is a function of skill level mix. Though this hypothesis has already been rejected for each of the bases, the combined data are tested to answer the research problem.

A regression analysis was completed on the combined data of Bases A and B. The resulting regression equation is shown in Figure 3-6.

$$Y = 79.51 + 135 X_{SL_7} + 116.99 X_{SL_5} + 101.78 X_{SL_3}$$

Fig. 3-6. Regression Equation for the Combined Data

The mutiple correlation of the equation was tested for significance (see Table 3-4).

TABLE 3-4
SIGNIFICANCE OF CORRELATION

F_T	d.f. m,n	F_C	α
212.94	3,20	8.10	<.001

The null hypothesis is rejected. The probability that the data are from a population where productivity and skill are unrelated is less than .001. The conclusion, therefore, is that productivity is indeed a function of skill. This indicates that the relationship expressed by the regression equation, that productivity is a function of the total skill of the workers, is valid.

Research Problem 2

Hypothesis: Productivity is a positive function of each of the three skill levels.

The multiple correlation of the entire equation was just tested. The test was whether or not the independent variable coefficients of the sampled population were greater than zero. See Figure 3-6 for the estimates of the coefficients provided by the sampled data.

$$H_0: \beta_i = 0 \quad (e = SL_7, SL_5, SL_3)$$

$$H_1: \beta_i > 0$$

A one-tailed t-test was performed for each β_i .
Results are found in Table 3-5.

TABLE 3-5
SIGNIFICANCE OF PARTIAL CORRELATION COEFFICIENTS

Skill Level	t_T	$t_C (n=20)$	α
β_7	3.43	2.845	.005
β_5	11.05	3.850	.0005
β_3	2.67	2.528	.01

The null hypotheses were all rejected with very high levels of statistical significance. It is highly probable (at least 99 percent) that the data tested came from a population where the three skill levels each makes a positive contribution to productivity. This means that each skill level does make a positive contribution to productivity. Each person adds something to the productivity of the work center. This also means that skill can be used to predict productivity potential. How well it can predict was the subject of the next problem.

Research Problem 3

Question: *What is the amount of change in the productivity explained by a change in skill level mix?*

Another way to word the question is "How well can a skill level mix (an amount of skill) be used to predict productivity?" It has already been established, with a high degree of statistical significance, that skill is related to productivity. Now the question is about how much are they related. The multiple correlation (R) for the regression equation for the combined data is shown in Table 3-6.

TABLE 3-6

MULTIPLE CORRELATION OF SKILL TO PRODUCTIVITY

R	R ²
.9844	.9690

The multiple correlation coefficient confirms that, statistically, skill-level is a very good predictor of productivity. The square of the multiple correlation (R²) is interpreted as indicating that 96.9 percent of a change in productivity was associated with a change in the skill-level mix. This means that the regression equation in Figure 3-3 could have been used in the sampled work centers to determine their productivity potentials, and only

4 percent of a change in productivity would not have been predicted by a change in the total skill of the work center. The next research question investigates the productivity of each separate skill level.

Research Problem 4

Question: *What is the expected marginal productivity of each skill level?*

How productive is a new worker in an organization? The variable coefficients in the regression equation (see Figure 3-6) provide this information (see Table 3-7).

TABLE 3-7
MARGINAL PRODUCTIVITY FACTORS

β_{SL_7}	=	135.18
β_{SL_5}	=	116.99
β_{SL_3}	=	101.78

The analyzed data indicate that the addition of a SL_7 to an average work center (SL_7s, SL_5s, SL_3s), can be expected to increase the productivity by 135.18 man-hours/month. For a SL_5 , the contribution is 116.99 man-hours/month. The SL_3 can be expected to add 101.78 man-hours/month. These numbers do not mean, for example, that a SL_3 can be expected to produce 102 hours of work on his own.

These numbers reflect each person's contribution as a member of a work center. Quite often a person's contribution will be made as a member of a team. It is possible that a person working entirely by himself would be either more or less productive than the factors in Table 3-7. But these factors reflect the result of the interaction of the people in the work center.

These numbers cannot be interpreted as the productivity *potential* of the new worker. The numbers only represent the normal, every-day contribution. However, if the researcher can establish enough confidence in the marginal productivity factors (the subject of the next research problem), then the factors can be used to establish a comparison of each skill level's productivity potential to the other skill levels (Research Problem 6).

Research Problem 5

Question: How much confidence is there that marginal productivities of the three skill levels are not the same?

So far, this research has rejected the hypothesis that the marginal productivity factors (β_i) equal zero (Research Problem 2). This research then determined the expected values of the β_i for the sample data. The next problem was to determine the probability that the sample was not taken from a population where the three skill levels are equally productive: $\beta_{SL_7} = \beta_{SL_5} = \beta_{SL_3}$. This

problem was approached by constructing nonoverlapping confidence intervals about the three independent variable coefficients in Figure 3-6. The results are shown in Table 3-8.

TABLE 3-8
CONFIDENCE INTERVALS OF REGRESSION COEFFICIENTS

High	β	Low	Standard Error	t(n=22; $\alpha = .62$)
123.16	$\leq SL_7$	≤ 147.19	39.39	.305
113.76	$\leq SL_5$	≤ 120.22	10.59	.305
90.14	$\leq SL_3$	≤ 113.42	38.17	.305

Statistically, this means that about 38 percent certainty exists that, in the larger population from which the sample data was taken, the productivity of the skill levels are different. In more practical terms, this means that for such a small sample size, the evidence was not strong enough to support a stronger conclusion. In light of the questionable validity of the data in MDC, as indicated by the results of both this research and that of a civilian research institute (see last section of this chapter), the conclusion is that 38 percent confidence is good evidence that the skill levels have different productivity potentials. The conclusion is that the marginal productivity

factors are the best estimate of the contributions of the skill levels sampled.

Based on these results, Research Problem 6 develops a measure of the comparative productivity potentials of each skill level.

Research Problem 6

Question: *What is the relative productivity of each skill level, using the 5-level as the referent skill level?*

Results are found in Table 3-9.

TABLE 3-9

RELATIVE PRODUCTIVITY FACTORS

SL ₇	=	1.155
SL ₅	=	1.000
SL ₃	=	0.869

The relative productivity factors (RPF) are, in this research, the best way to compare the productivity potentials of the skill levels. The results in Table 3-9 indicate that, in the work centers sampled, the SL₃ is about 13 percent less productive than the SL₅, and the SL₅ is about 15.5 percent less productive than the SL₇. In a comparison of the SL₇ to the SL₃, the SL₇ is about 33 percent more productive than the SL₃. The implication of these numbers is significant.

For a manager who has jobs that could be done by either a SL₅ or SL₃, the RPF indicates that the loss of a SL₅ is not going to be corrected by adding a SL₃, by a factor of about 13 percent. The RFPs for skill levels in different AFLCs or work centers can be compared to see where increases in different skill levels will have the greatest effect. Ideas such as increasing the skill of people and decreasing the number of people can be explored with the RPF. For instance, in the 431X1 AFSC sampled in this research, replacing or upgrading a SL₃ position to a SL₅ will increase the productivity of that position by 13 percent. To be feasible, the upgrading of the position should save at least 13 percent over the previous costs. There is another useful interpretation of the RPF.

This second interpretation is based on a different analysis of the regression coefficients. The initial measure of productivity was man-hours. If the regression is viewed in terms of man-hours instead of productivity, then the factors in Table 3-9 have a new significance. In terms of man-hours, the results indicate that a SL₇ works 33 percent more hours than a SL₃ and 16 percent more hours than a SL₅. The SL₅ works about 13 percent more hours than a SL₃. This could also mean that the higher skill levels *record* more time for themselves or more of their reports get into the MDC system. The idea that, for instance, a SL₇ puts in an average of one-third more time working than

a SL_3 is rejected. The SL_7 may produce more, but he probably does not work many more hours. The implication is that MDC system data reflect a disproportionate input from the high skill levels. This has a direct bearing on the validity of MDC system data.

Analysis of Variance

One of the assumptions of regression analysis is that all the error components have the same variance ($\text{Var}(\epsilon) = \sigma^2$) for the entire range of Y values. Without this assumption, the value of the regression equation becomes somewhat limited. An examination of the plot of residuals (error terms) against \hat{Y} indicates that $\text{Var}(\epsilon) = \sigma^2$ is not true statistically (see Figure 3-7).

An analysis of the variance indicates that, for the collected data, the regression equation is less accurate in predicting productivity as the amount of work (\hat{Y}) increases (note that the variance increases as \hat{Y} increases (Figure 3-7)). It is not possible to say whether it is a larger work center, with its greater amount of work, or any work center that is overwhelmed with work that would experience an increasing variance in ϵ .

The plot of residuals shows that as productivity increases, the data are plotted further away from the horizontal axis, i.e., $Y - \hat{Y}$ (variance) gets greater. But the rate at which the variance increases is not abrupt,

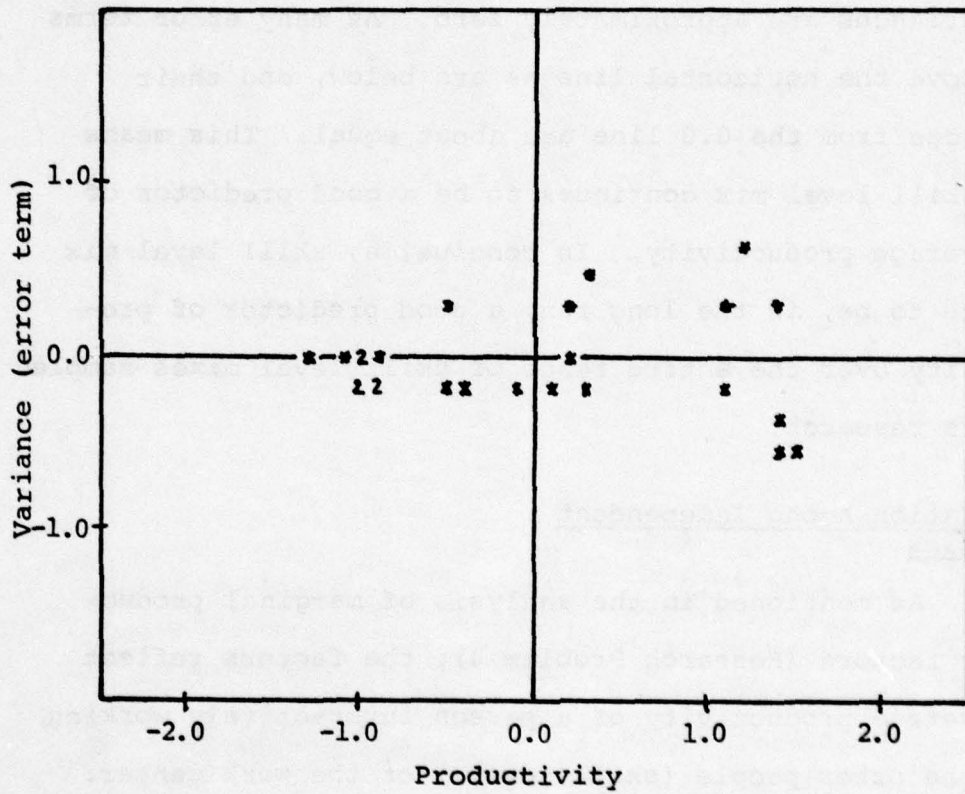


Fig. 3-7. Plot of Standardized Residuals

reflecting a relatively slow increase. This means that as the number of people in a work center increases, the less accurate is skill level mix in predicting the actual productivity. The implication is that some new factor(s) starts to cause productivity to vary. Another examination of the plot of residuals shows that, even though the variance increases with productivity, the sum of the values of the variances are approximately zero. As many error terms are above the horizontal line as are below, and their distances from the 0.0 line are about equal. This means that skill level mix continues to be a good predictor of the average productivity. In conclusion, skill level mix appears to be, in the long run, a good predictor of productivity over the entire range of skill level mixes sampled in this research.

Correlation Among Independent Variables

As mentioned in the analysis of marginal productivity factors (Research Problem 4), the factors reflect the average productivity of a person interactively working with the other people (skill levels) of the work center. If the interrelationships among the skill levels have a significant effect upon their individual productivities, the manager must be able to deal with these effects in the management of manpower. For these reasons the relationships among the skill levels were investigated.

The investigation started with the calculation of the correlation between pairs of skill levels. The Pearson product-moment correlation coefficient (r) was computed as part of the regression analysis by SPSS (2:279-281). The results are shown in Table 3-10.

TABLE 3-10
PARTIAL CORRELATION COEFFICIENTS

$r_{i,j}$	SL ₅		SL ₇	
	r	r^2	r	r^2
SL ₃	0.5097	0.26	0.4171	0.17
SL ₅	-	-	0.07870	0.62

The interpretation of Table 3-10 is that 26 percent of the change in the number of SL₃s in a work center is associated with a change in the number of SL₅s. The other correlations are explained the same way. The important point is that the only relationship among the skill levels that can be explored with the sample data base is the relationship between *numbers* of people in each skill level.

The values of r in Table 3-10 have additional meaning. If the values of r are extreme, then the condition of multicollinearity exists. The existence of multicollinearity means that values of the independent variable coefficients are not very reliable (2:340). SPSS defines

"extreme values" of r to be between .8 and 1.0 (2:340). Chou considers values of .95 or greater as extreme (4:763). Since neither of these extremes is exceeded, the β_i coefficients are considered reliable.

Validity of Data

Only 36.2 percent of the monthly man-hours reported reflected what could be considered to be normal levels of activity. Another study has found that reported man-hours are about double the actual time used on maintenance jobs (9:32). The same report found that "over half of the observed tasks could not be matched with any reported account of work performed, . . . [MDC][9:i]." The ramifications of this evidence on the results of this thesis, on LCOM, and on other programs that depend on the MDC system are profound.

"Normal activity" for a work center is defined as the level of activities such that the average person has a reported number of man-hours between 105 and 220 hours per month. These bounds were selected based on a work-month of 22 days and an 8-hour work-day (=176 hrs/mo). Of this time, a certain amount is spent at meetings, sick call, etc. The assumption was made that, under normal conditions, not more than 40 percent of the 176 hrs/mo would be lost to such activities. The minimum normal work-month thus became 60 percent of 176 hrs/mo (=105 hrs/mo). This became

the lower boundary of the normal range of activity. The upper boundary, 220 hrs/mo represents a work-day of 10 hours and a work-month of 22 days. The researchers considered this amount of work to not be unusual. This number is still below the planning factor for combat activity of 242 hours per man per month. Thus, the normal activity range was established as 105 to 220 hrs/mo. The total average man-hours (direct and indirect labor) of each work center were compared with this range.

Only 36.2 percent of the total data points fell in this range. Of the rejected data, only 2.1 percent were above the "normal" range, and 61.7 percent were below (see Figure 3-8). One month a work center reported that its manpower (22 SL₅s and 10 SL₇s) did 410.6 man-hours of work. This equates to 12.8 hours/month per person, or 0.6 hours a day (22 workdays/month). On the other extreme, a work center of 13 people (8 SL₅s and 5 SL₇s) did 4947.5 man-hours of work. This comes to 380.6 hours/month per person, or 17.3 hours a day (22 workdays/month).

The low levels of reported work activity can be accounted for several ways:

1. People are underdocumenting. A lot of work may not be reported or the actual hours are underdocumented.
2. People are underemployed. The units may be manned properly but there is not enough work to keep everyone busy.

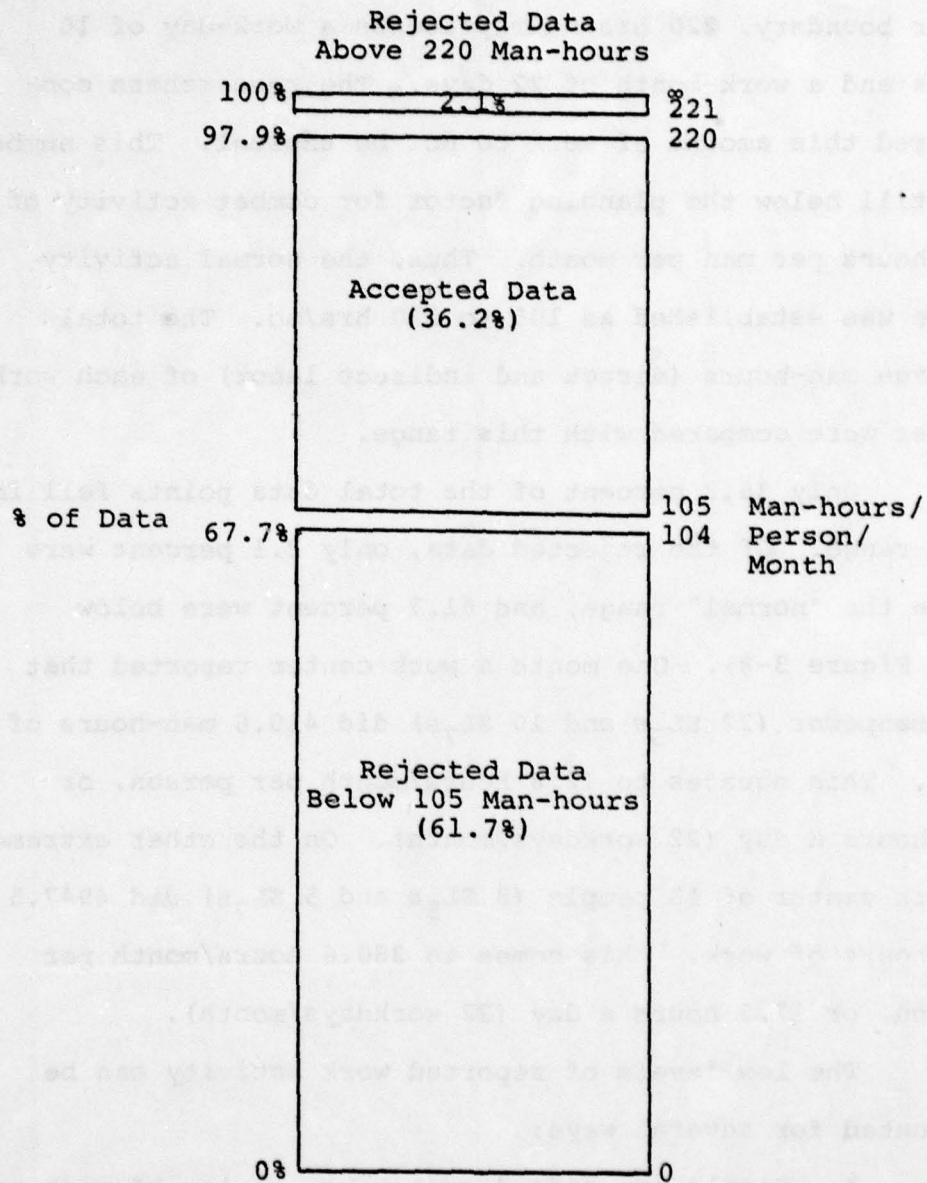


Fig. 3-8. Acceptance and Rejection Regions of Data

3. Units are overmanned. Flying activity is normal but units have very large numbers of personnel.

4. Information is reported but is "lost in the system" and never shows up in the MDC reports.

A study done by a private consulting firm, Desmatics, Inc., "quantified the accuracy of reported base-level maintenance direct labor hour data [9:i]." The study was completed under USAF contract in April, 1979. The firm's observers measured the time it took to do a sample number of aircraft maintenance tasks. They then tried to match the observed tasks with the tasks reported by MDC. At one base the match rate was about 39 percent (9:30). At the second base tested, 55 percent of the tasks were matched (9:30). For those tasks matched at the two bases, the Reporting Accuracy Factor (RAF) was 1.94 (9:3).

$$\text{RAF} = \frac{\text{Reported}}{\text{Observed}} \text{ hours} = 1.94$$

The amount of work reported was almost double the actual time of accomplishment.

Conclusions from the thesis and the Desmatics' report cannot be applied beyond the units established by the respective sampling plans. However, the results do pose serious questions. In the thesis, for example, if all of the reported man-hours were reduced by the factor of 1.94, only one case (out of 24 cases used for final

analysis) would have remained valid. Desmatics, Inc. could match less than 50 percent of their observed tasks. What happened to the data on the rest of the AFTO Forms 349 that were turned in? Did they enter the MDC system? If they did, there is a good chance they entered with errors, otherwise they probably would have been matched. How many entered in error? What kinds of errors were made?

Our analysis leads us to believe that serious errors are made in the reporting and recording of data that are reflected in the Maintenance Data Collection system.

The availability of data also appears to be a problem. Each base appears to have its own policies about what data are recorded, how data are stored, how long it is maintained, and who has access to it. Important information is often not recorded on the same document, but in several different mediums. Some bases appear to fear research. One base refused a TAC Headquarters request for assistance on this thesis, and another requested that their base be disassociated from their data. Sometimes records are incomplete. The validity of the data was partially affected by the fact that some of the monthly reports could not be found. For example, data may have been available for January and March, but February data were missing.

Together, the problems of data storage/retrieval and of data validity must present serious problems to

managers who may try to use the MDC system as a source of management information.

Summary

The analysis of the results of this research indicate that the proposed method of measuring the potential productivities of different skill levels is feasible and effective. The same research revealed that data collected by the Maintenance Data Collection system is probably incomplete and contains erroneous information.

The analysis began with a sort of the data. The data reflected a low manpower utilization rate. The comparison of bases indicated that all the bases could not be treated as being statistically the same (LCOM treats all bases as being the same (5)). The analysis indicated that productivity is a function of skill, that each skill level made a positive contribution to productivity, and that the skill levels most likely have different productivity potentials. The research then developed marginal productivity factors and relative productivity factors. The interrelationship among skill levels was investigated but the sample data did not permit any relationships to be identified.

The analysis of Chapter III has included specific conclusions as each research problem was addressed. Chapter IV contains a summary of the more significant conclusions, as well as recommendations.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Overview

In the preceding chapters the subject of manpower management of aircraft maintenance people was addressed. Some problems in present systems of management were identified and stated as research problems. The plan to research answers to the problems was then described. The results of the research plan were presented and analyzed. This chapter summarizes the findings and conclusions of this research and offers recommendations for future action.

Conclusions

The relative productivity of maintenance personnel can be measured using the techniques of this thesis. This measurement, in turn, can be used to predict the productivity (capability) of the personnel. The actual results of this particular study are not directly applicable for field use because of problems of data validity. The data reflected low levels of manpower utilization. Additionally, a private firm has found evidence that less than 50 percent of the actual maintenance jobs can be traced and identified in Maintenance Data Collection system reports. They also

found that, in those reports that they could match with jobs they had observed, the reported man-hours were almost double the actual time of work.

The productivity factors developed by the methods of this thesis would be most applicable to normal, day-to-day changes in work center manning and not to major changes in the manning. This limitation exists because the productivity factors reflect the interrelations among the people (the team work) as the work centers are presently structured. A new structure would cause a change in relationships. However, these methods of analysis are relatively simple, inexpensive, and could be easily used to establish new factors for a new organizational structure.

The skill, and therefore the productivity, of each skill level is different. Recognition of this difference is intuitive. As a precise measure of the difference, the measure can be a significant factor in the efficient management of manpower. This research illustrates how to develop such a measure for a given base or combination of bases.

The current Maintenance Data Collection system is questionable as a source of useful management information. The quality of the information contained is highly suspicious, as indicated by this research and an Air Force contracted study (9). If the data were accurate, its

availability in a form that is usable to the manager is much in doubt.

Management requires an effective and efficient management information system. The tool developed by this thesis is only as good as the data that provides the necessary information. The implications are profound. Manpower management information (and perhaps technical information) may be useless to managers. This information is widely employed in today's logistics systems.

Recommendations

A field test of the ideas presented in this thesis is recommended. Select a few work centers for the test. Establish the absolute minimum manning requirement for seven-levels and/or five-levels. Develop the rest of the manning matrix from productivity factors developed through the regression analysis of historical data for the work center.

A further recommendation is to design a better data collection system to support the goals specified in this thesis. Better productivity factors could be determined if MDC contained information about the workers' skill level, experience (in terms of time on station and time in skill level), and the quality of the work. We strongly recommend divorcing the responsibility for reporting the work-related data from the worker and his direct supervisor.

For a majority of the flightline maintenance, this could be done using equipment that is presently installed. Most Maintenance Job Controls have computer terminals (MMICS). We propose that Job Control keep track of the work being done on the flightline. When a man is sent to do a job, his identification number (ID) should be entered into the computer along with the job code and the time. The time of completion would also be reported. In the computer the ID would be related to the person's skill level, grade, time on station, and to quality control reports that apply to him. This information would allow much more precise measures of a person's productivity potential. It would also eliminate many of the problems inherent in self-reporting systems.

A third recommendation is to determine the information needs of "management" and redesign the system to provide the required information. Design the information system to collect only the data needed, and report it in a form that can be used.

Summary

This research has shown that it is possible to measure differences among people using relatively simple statistical analysis. Managers do not have to manage different people using standards based on some "average" person. But to do the analysis requires a quality management

information system. That is the next step. And once quality information is available, more modern methods of analysis can be used to improve the management of our increasingly scarce resources.

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