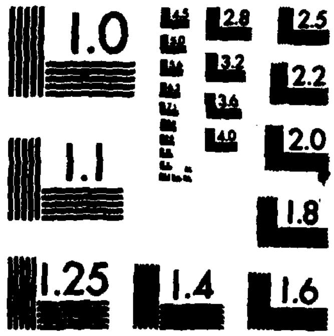
AD-A181 384 EVALUATING THE EFFICIENCY OF RPMA (REAL PROPERTY MAINTENANCE ACTIVITY) IN..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. W F BOWLIN 1/1

UNCLASSIFIED NOV 84 AU-AFIT-LSQ-84-1 F/G 5/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

EVALUATING THE EFFICIENCY OF RPMA IN THE AIR TRAINING COMMAND

TECHNICAL REPORT

Major William F. Bowlin
Asst. Professor of Quantitative Methods

November 1984

AU-AFIT-LSQ-84-1

The views expressed herein are those of the author and do not necessarily reflect the views of the Air University, the United States Air Force, or the Department of Defense.

Approved for release as requested in accordance with AFR 190-1

ABSTRACT

This research evaluates the operational efficiency of the in-house real property maintenance activity of the Air Training Command using a methodology called Data Envelopment Analysis (DEA). Evaluations are undertaken in a variety of ways -- reviewing annual data; checking for trends, stability, and seasonal behavior using window type analyses; and accomplishing a joint analysis with Tactical Air Command data. Results include identifying sources and amounts of inefficiencies for each base, command-wide trends, and special operational characteristics of different bases.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION AND BACKGROUND

SECTION I - INTRODUCTION

The purpose of this research was to evaluate or measure the operational efficiency of the in-house real property maintenance activity of the Air Training Command. Here efficiency is defined as the ratio of benefits achieved (outputs) to resources used (inputs).[1]

Often, as in commercial accounting, efficiency is measured by comparing an actually attained output to a standard or predetermined output. In engineering, outputs and inputs are customarily measured in terms of energy, so that a natural unit is thereby provided. Also the law of conservation of energy requires that the energy produced (output) must not exceed the energy consumed (input). Since all units of measurement are the same, a dimensionless ratio results with $0 \leq$ Efficiency ≤ 1 in this ratio form.

Unfortunately these concepts are not normally applicable to Air Force organizations. If we were able to specify a single output like the maximum achievable production of flying hours of a wing, given specified levels of resources, then wing efficiency could be determined by comparing the actual production of flying hours to the predetermined maximum achievable flying hour production. _No_ production function has been developed which can forecast the maximum number of flying hours achievable given the multitude of resource combinations and environmental conditions. Thus, Air Force organizations must rely on relative measures of efficiency from empirically based comparisons of input and output measures.

In economics, efficiency is usually assumed to have been achieved by the force of market competition. In our case, we are dealing with not-for-profit military operations where the assumption of perfect competition is not tenable. Hence, for this research we cannot make such an assumption and are therefore forced to turn to an efficiency measurement methodology called Data Envelopment Analysis (DEA) to ascertain whether technical efficiency has been achieved.

Our research will proceed as follows. In the remainder of this chapter we will briefly describe DEA and then identify and define the different input and output measures used in this research. Chapter 2 reports and interprets the results of applying DEA to the Air Training Command's in-house real property maintenance data. Our summary and conclusions are contained in Chapter 3.

SECTION II - DATA ENVELOPMENT ANALYSIS

We now turn to a description of Data Envelopment Analysis (DEA) as the method we will use to approach our research. Charnes, Cooper, and Rhodes (CCR) [6] and [7] developed DEA to measure and evaluate the relative efficiency of operations in not-for-profit programs. In order to keep this paper from becoming too technical, we only summarize the DEA model and its properties and characteristics.

Fractional Model

The following DEA model and its associated extremal principals extend the normal single output to single input efficiency definitions employed in the natural sciences to the multiple output and multiple input case we need.

$$\text{Maximize:} \quad h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

(1)

$$\text{Subject to:} \quad 1 \geq \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \; ; \; j = 1, \ldots, n$$

$$u_r, \; v_i \geq \epsilon > 0$$

where the terms represent:

h_0 = The measure of efficiency for decision making unit (DMU)[2] "0", the member of the set of j=1,...,n DMUs that is to be rated relative to the others. The ratio on which h_0 depends is represented in the functional for optimization as well as in the constraints. This DMU preserves its original subscript identification in the constraints but is distinguished by a "0" subscript in the functional.

u_r = The variable for each type of output "r", which will be optimally determined by the solution of the model and assigned as a weight[3] to the observed output value, y_r.

v_i = The variable for each type of input "i", which will be determined by the solution of the model and assigned as a "virtual multiplier" to the observed input value, x_i.

y_{ro} = The known amount of output "r" produced by DMU "0" during the period of observation.

x_{io} = The known amount of input "i" used by DMU "0" during the period of observation.

y_{rj} = The known amount of output "r" produced by DMU "j" during the evaluation period.

x_{ij} = The known amount of input "i" used by DMU "j" during the period of observation.

$\epsilon > 0$ = A small "non-Archimedean" constant.

All of the organizations are assumed to have common inputs and outputs in positive amounts. Execution of the model requires repeated computations which, in principle, must be done for each DMU in the universe of organizations under evaluation. In each case, the efficiency of each DMU is calculated in relation to all other DMUs.

The resulting efficiency value, h_0^*, does not depend on the units of measure in which the inputs and outputs are stated. That is, if any input and output is measured in different units then the value of h_0^* will not alter provided this same change is made in the units of measure for all DMUs.

Evidently the maximum value of h_0 is unity since the constraints require $h_0^* \leq 1$. Indeed if $h_0^* < 1$, then some convex combination of other DMUs could have done better and DMU "0" is not efficient. Conversely, DMU "0" is efficient if and only if $h_0^* = 1$.

We can relate this to the concept of Pareto optimality by saying that a decision making unit is efficient if and only if it is not possible to augment any output without either (a) decreasing some other outputs or (b) augmenting some inputs. Alternatively, it is inefficient if some input can be decremented without worsening any output or without increasing some other input. This does not preclude making tradeoffs after the "efficiency frontier" is attained but it does require setting them aside until after this frontier is identified.

Reference to Figure 1 will help to show what is involved. The solid line connecting points A, B, and C represent a section of the unit isoquant, i.e., the level of the production surface, for one unit of a single output. For simplicity we restrict ourselves to the case of one output (produced at unit level) and two inputs, x_1 and x_2. The x_1 and x_2 coordinates of points A, B, C, D, E, and F represent observed inputs used to produce the one unit of output attained by each of the six DMUs associated with these points.

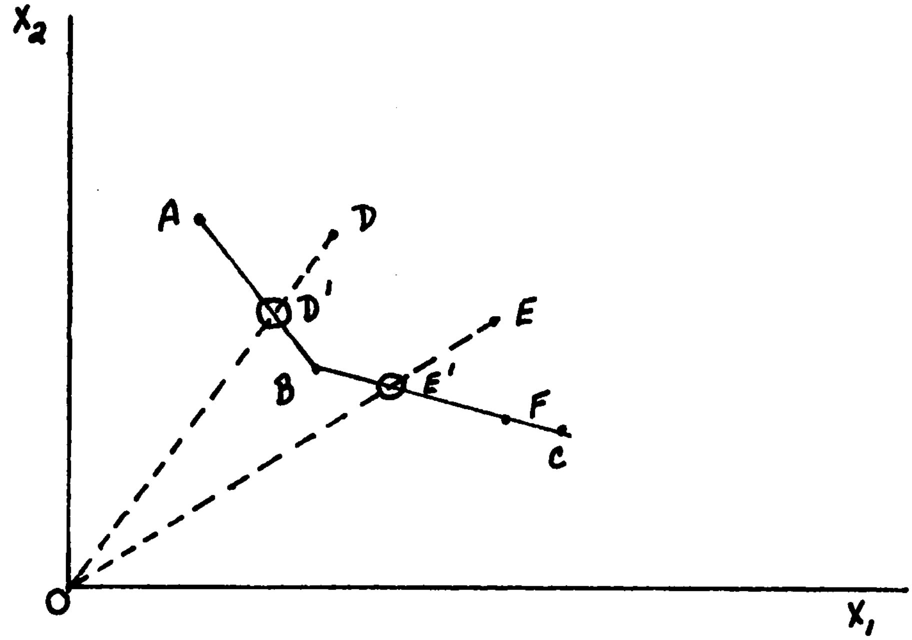


Figure 1: DEA Efficiency In The Single Output - Two Input Case

Both D and E are inefficient since they are dominated by D' and E', respectively.[4] The latter are not actually observed values but are obtained as convex combinations of A and B and B and C, respectively, which represent elements of the efficient frontier production possibility set. In fact, the values of h_0^* for points D and E correspond to the ratios of the ray segments d(O-D')/d(O-D) and d(O-E')/d(O-E) which are clearly less than unity.[5]

The points A,B, and C from which these convex combinations are obtained are all efficient and form an efficiency frontier. There is no point that can be generated from convex combinations of members of the production possibility set that will dominate them. Conversely, any movement along this frontier requires tradeoffs between x_1 and x_2 in order to stay on the frontier.

The DEA model evidently provides only relative evaluations by creating an "efficient frontier" such as the one depicted in Figure 1 that is generated from actual observations. It is relative in the sense that the efficiency rating depends on the DMUs used. Although DEA does depend on the DMUs used, it does not depend on prior theoretical knowledge or explicit assumptions about the value of the production process as in the model specifications used in statistical regression (and like) approaches.

The u_r and v_i values described in model (1) may be considered weights, but to avoid confusion with normal uses of *a priori* weights, we refer to the u_r and v_i variables as transformation ratios. This name refers to the fact that they transform real inputs (x_{i0}) to a "virtual" input (X_0) and real outputs (y_{r0}) to a "virtual" output (Y_0). In this way the DEA approach reduces the multiple outputs and the multiple inputs to a single scalar measure. Finally, the u_r and v_i choices made by the DEA model are optimal in that the mathematical procedure places the DMU that is being evaluated "in the best possible light"-- in the sense that no other u_r and v_i values can give a more favorable efficiency ratio from this set of data.

Reduction To Linear Programming Form

The model previously presented is a non-linear programming problem. It is, in fact, a fractional programming problem with a linear fractional objective and linear fractional constraints. As such it is both nonlinear and nonconvex. However, Charnes, Cooper, and Rhodes have shown that it in be transformed into an equivalent linear programming problem by means of the theory of linear fractional programming, developed by Charnes and Cooper. In order to simplify matters we are bypassing the development of the linear programming form and present it as follows:

$$\text{Minimize:} \quad h_0 = \theta - \epsilon\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^- \right)$$

(2)

$$\text{Subject to:} \quad \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{r0}; \quad r=1,\ldots,s$$

$$-\sum_{j=1}^{n} x_{ij}\lambda_j - s_i^- + \theta x_{i0} = 0; \quad i=1,\ldots,m$$

$$\lambda_j,\ s_r^+,\ s_i^- \geq 0; \ \theta \text{ unrestricted in sign}$$

where

θ =An intensity valuer or multiplier of the observed input x_{io}

S_r^+ = Output slack for output "r".

S_i^- = Input slack for input "i".

ϵ = A small positive valued non-Archimedian constant.

To enforce the non-Archimedean character of ϵ and avoid possible troubles from using "small" real numbers we revert to the procedure described in Charnes and Cooper [6] and first minimize θ with the constraints shown in (2) remaining unchanged. Then we maximize the slack variables in the objective function while constraining θ to the value it already attained in the first stage.

Model (2) is the form which is used in our research. For a unit to be rated 100% efficient θ^* must equal one and all slack variables, s_i^* and s_r^*, must equal zero. Hence $\theta^* < 1$ and/or $s_i^* > 0$ means that the observable inputs were excessive and efficiency was not achieved.

Comparison Sets

Also, from model (2), we have $\lambda_j^* > 0$ as a sufficient but not necessary condition for the j^{th} DMU to be a member of the comparison (=reference or neighborhood) set of the evaluated unit. Recall that the optimization employed in (1) ensures that the efficiency reference set provides the "best" (=highest) h_0

value available for each DMU. Knowing the DMUs from which the evaluation was made allows managers of inefficient units to check with those organizations on possible corrective actions.

Finally, a DMU rated 100% efficient which does not appear in the efficiency reference set of other DMUs which are rated inefficient is a candidate for additional review. Since a comparison set cannot contain any inefficient DMUs, failure to appear in such a set is an indication that this DMU may be a "self evaluator" and should not be considered efficient without further investigation. The DMU may be wholly efficient because it has special features distinguishing it from the others or it is possible that the DMU is operating inefficiently.

SECTION III - SPECIFICATION OF DEA INPUT/OUTPUT MEASURES

Specification of the input and output measures to be used in the DEA model was done in conjunction with major air command (MAJCOM) civil engineering officials. The specific measures chosen were based on the operational expertise of these individuals and certain characteristics that the input and output measures should have in order to take advantage of the capabilities of the DEA model.

There are four guidelines pertinent to the selection of the inputs and outputs.

First, the inputs and outputs should be comprehensive. That is, they should fully and properly measure the in-house real property maintenance activity.

Second, there should be some basis for believing that the relationship between inputs and outputs should be such that an increase in an input can reasonably be expected to increase one or more of the outputs.

Third, all input and output measures should exist in positive amounts for each DMU.

Finally, the variables should be identifiable and defined and controlled so that they cannot be manipulated in reports or at least the resulting data should be reviewed in order to remove these effects which might otherwise influence the results of the DEA model.

A number of possible input and output measures were reviewed and discussed for possible inclusion in the Data Envelopment Analysis phase of this research. The potentially large number of possibilities was narrowed to ones which seem to best fulfill the requirements of this study.

Eight outputs were considered which comprehensively reflect the accomplishments of the base civil engineering activity in performing its in-house real property maintenance function. We label and number these outputs as: (1) number of completed job orders, (2) number of completed work orders, (3) number of completed recurring work actions, (4) number of delinquent job orders, (5) replacement value of structures and systems, (6) percent of job orders completed, (7) percent of work orders completed, and (8) percent of recurring work actions accomplished.

There are six inputs representing the resources consumed and effort expended in producing the outputs. They are: (1) funds available in terms of supply and equipment funding, (2) available direct labor hours, (3) number of passenger carrying vehicles assigned and available for use, and (4) three measures of the amount of work available for accomplishment -- number of work orders in the civil engineering system, number of job orders in the civil engineering system, and number of scheduled recurring work actions.

The results of our efforts to gather data on these variables was disappointing, in that an insufficient number of observations were available for a stable Data Envelopment Analysis of more than seven variables. Therefore, we reduced the number of actual measures used to Outputs 1,2,3, and 4 and Inputs 1,2, and 3. They are described in the following subsections.

Selected Outputs And InPuts

In the following subsections we explain the four output and three input measures which were finally settled on for inclusion in our research. First we specify the outputs which are: completed job orders, completed work orders, completed recurring work actions, and delinquent job orders. Then we follow with descriptions of the input measures which are labeled as: supply and equipment funding, available direct labor hours, and available passenger carrying vehicles.

Output 1: Completed Job Orders (CJO): The job order system was designed to be a fast way to authorize work that does not require detailed planning. Job orders are work that require little or no planning, involve only one craft shop (e.g., masonry, electrical, carpentry, plumbing, etc.), and materials are normally readily available in bench stock. They represent day-to-day maintenance and repair work such as repair of air conditioning units, broken windows, and minor street pot holes. The number of completed job orders measures the amount of day-to-day work accomplished.

Output 2: Completed Work Orders (CWO): Work orders represent activities that are more extensive and complex than that done under job orders and usually result in capitalization of real property records. Because of its complexity, preparation for work accomplished under a work order involves gathering data for review and analysis, detailed planning, coordination between many craft shops, and ordering large amounts of material. A work order is processed through production control, planning and engineering, material control, base supply, and procurement. A job order is normally only processed through production control. Examples of work orders would be the construction of a new room or the complete replacement of an electrical system.

Output 3: Completed Recurring Work Action (CRWA): Recurring work items include recurring (preventive) maintenance, operations, and services for which the scope and level of effort is known without an earlier visit to the job site each time the work is scheduled. The work is periodic in nature. It includes all recurring work needed to prevent breakdown of critical facilities, equipment, or utilities. Grass cutting and pavement cleaning (operations), refuse collection and entomology (services), and changing air conditioner filters and preventive generator maintenance (maintenance) are examples of recurring work.

Output 4: Delinquent Job Orders (DJO): The definition of a delinquent job order depends on the type of job order of which there are three: emergency, urgent, and routine. Thus, in defining DJO we first need to explain the three types of job orders.

(1) Emergency: An emergency job order is work which, if not accomplished, will be detrimental to mission accomplishment or reduce operational effectiveness. This type of job order must be accomplished within 48 hours of the identification of the requirement.

(2) Urgent: An urgent job order refers to work that impacts mission accomplishment or reduces operational effectiveness less severely than work categorized as emergency. An urgent job order is to completed within five work days of the identification of the requirement.

(3) Routine: Routine job orders include work that should be done within 30 days of identification of the requirement if no material is required or 30 days after receipt of material if material is required. In order to reduce time lost to travel, routine job orders are accumulated by geographic area and scheduled as work packages rather than individual job orders.

We also need a category for scheduled (authorized) work which was not completed in a timely manner. This work falls into a class called "delinquent job orders".

(4) Delinquent: A delinquent job order is one in any of the above categories that is not completed within the specified time by the end of the reporting month. Headquarters personnel monitor this measure to check the timeliness of work accomplishment which they feel is essential to maintaining customer (organization or individual) satisfaction. However, recognizing that delinquent job orders are not desired, we use its reciprocal as the measure of this output. It is almost never the case that there are no delinquencies so we do not anticipate a problem of dealing with a zero denominator.

Input 1: Supply and Equipment Funding (DOL): This is a supply support factor. The larger the supply and equipment funding, the greater the availability of supplies and equipment with which to accomplish work. This includes not only equipment purchases but also equipment rentals. The availablility of supplies and equipment should reasonably be expected to affect output production.

Input 2: Available Direct Labor Hours (LAB HR): Available direct labor hours measure the size of the available work force which generally varies proportionately with the level of real property maintenance activity at each base. This measure represents the amount of time the work force is available for accomplishing civil engineering work. LAB HR equals the total work hours available (number of employees times the work week length) less an appropriate number of hours for sick leave, vacation time, training, etc.

Input 3: Available Passenger Carrying Vehicles (VEH): Another input variable is the number of passenger carrying vehicles available to the base civil engineering function. Small vans, pick-up trucks, and station wagons are examples of passenger carrying vehicles. Vehicles such as road graders, back hoes, and other specialized equipment are not included in this category. The measure of this input amount was computed by taking the number of passenger carrying vehicles assigned to the base real property maintenance activity and reducing it by the average vehicle maintenance down time (VDP and VDM). Headquarters officials believe that the nonavailability of passenger carrying vehicles is a major factor hindering work completion. Without vehicles, personnel are not able to get to the work site.

CHAPTER 2

ANALYSIS AND INTERPRETATION

SECTION I - INTRODUCTION

In this section we turn to the analysis of the Air Training Command's in-house real property maintenance activities operational efficiency. We propose to undertake these evaluations in a variety of ways and will proceed to do this in the following manner.

First, we describe our data collection procedures and some of the problems encountered such as the nonavailability of a sufficient number of bases for the number of inputs and outputs to be used in the analyses. We also describe how we overcome these problems through expanding our data base via (1) "window type" analyses and (2) combining the data from two separate major air commands into a single joint efficiency evaluation.

Next we report the results of our evaluation of the efficiency of Air Training Command's operations. Our evaluation of ATC begins with an analysis of its annual data. As might be expected from the few degrees of freedom available, most bases were rated 100% efficient. Therefore, in order to validate these annual efficiency ratings and to test for stability, trends, and other behavior over time, we proceeded to window type analyses. Generally, these window analyses supported the annual ratings. At the same time, however, they provided additional information on trends and seasonal behavior which are not available from the annual data.

Next, we proceed to combine the data points for ATC with data from a Tactical Air Command (TAC) for a series of joint analyses which again consists of an analysis of annual data and window type analyses. This is done to further review the results obtained from analyzing each command separately. In general, the joint analysis of annual data supports our earlier findings for ATC while the joint window analyses provided new information which was not evident in the preceding evaluations.

During the data collection stage of our research we found it necessary to reduce the number of inputs and outputs in order to conform with the number of bases available for the study. Therefore, we were interested in the effect on the efficiency ratings of augmenting our study with the deleted inputs and outputs. This, along with an examination of the sensitivity of the ratings to how the windows for the window analyses are formed, are other subjects covered in this chapter.

SECTION II - DATA COLLECTION

Our initial step was to gather fiscal year 1983 annual data, 1 October 1982 through September 1983, for each base within the the two MAJCOMs. The ATC data were obtained from reports available at ATC headquarters, as supplemented and modified by direct communication with the bases which had filed the reports or, in some cases, following up to secure reports which they had failed to file.

Unfortunately these efforts produced complete input and output information on only seven bases for ATC. A rule of thumb for maintaining an adequate number of degrees of freedom when using DEA is to obtain at least two DMUs for each input or output measure. Note, for instance, that an insufficient number of DMUs for the variables being used, would tend to produce a result in which all of the DMUs would be rated as 100% efficient simply because of an inadequate number of degrees of freedom.

For this research we would need a minimum of 14 bases (two DMUs for each of 7 input and output measures) for each MAJCOM to avoid possibly meaningless results. We used a variety of techniques to overcome the problem of having an insufficient number of DMUs. The number of DMUs was increased through "window analysis" techniques and/or combining the data points from ATC with those of a second MAJCOM into one overall analysis.

A "window analysis" is a way to increase the number of DMUs, and thereby, introduce more degrees of freedom into an analysis.[5a] The procedures for a window analysis involve subdividing each DMU's data and identifying each new unit as a differently <u>dated</u> DMU in order to create a new analysis set or "window" from these subunits. For example, annual data might be broken down into monthly or quarterly data, then each DMU (= Air Force base) could be represented as 12 or four different DMUs. A moving "window" is then constructed in a way that provides overlaps and checks on DMU behavior over a period of time. Such a moving window could be three successive months, for example, in which case the first window would consist of data on each DMU for the first, second, and third months. The second window would consist of data on each DMU for the second, third, and fourth months, and so on.

Note that the data for month two is used twice, once in the first window (months one, two, and three) and again in the second window (months two, three, and four). This provides a two way comparison for each DMU relative to its efficiency ratings (and sources of inefficiencies) from two different sets of data. Thus, moving over time one can check for stability, trends, seasonal behavior, or other properties of potential interest. Moreover, further insight can be supplied by additional comparisons with annual data or other ways of forming the windows, and so on.

Observed Inputs and Outputs

Tables A.1 and A.2 in Appendix A show the observed input and output values used in this study for ATC and MAJCOM #2. These tables contain annual and quarterly input and output values for Fiscal Year (= FY) 83.

In order to extend the window analysis, we also obtained data on the first quarter of FY 84 which are also shown in Tables A.1 and A.2. In a related attempt to extend the significance of the window analyses we also attempted to get data for FY 83 by month. But this information was unavailable for some of the bases and is therefore not included in our work.

SECTION III - ANALYSIS OF ATC

Analysis Using Annual Data

We initiate our efficiency evaluation of ATC by using annual data for the seven input and output measures previously discussed in a DEA. As expected, there was little discrimination between the bases on their relative efficiencies since there were so few DMUs relative to the number of inputs and outputs used. Using only annual data, all bases were either rated as 100% efficient or very close to 100% efficient. That is, they had values of $h_0^* = \theta^* = 1$ and slack variable values were zero.[5b]

Table 1 shows these results for ATC. Under the efficiency rating, h_0^* in column 1, the slack variables for the three inputs and four outputs used in our analyses are listed, while columns 2 through 8 display the optimal values obtained for each of those variables. The slack variables which appear under the efficiency rating in each column relate to the input or output measure with which the slack variable is associated. For example, the 3 in column 3 opposite VEH is the value of the slack variable (S_{VEH}^{-*}) in the constraint associated with the passenger carrying vehicle input measure for Lowry AFB. The value of $1,166,502 in column 4 represents the amount of slack (S_{DOL}^{-*}) in the constraint for the supply and equipment funding input measure for Mather AFB.

Note from Table 1 that Keesler, Reese, Sheppard, Vance, and Williams are rated 100% efficient. Their optimal solutions have $\theta^* = 1$ and all slack values are zero.

Table 1

Effeciency Measure Values - ATC

(1) Efficiency Measure Name	(2) Keesler	(3) Lowry	(4) Mather	(5) Reese	(6) Sheppard	(7) Vance	(8) Williams
			Efficiency Measure Values				
$h_0^* = \theta^*$	1.0	.915	.975	1.0	1.0	1.0	1.0
Slack Variables (s_i^{-*}, s_r^{+*})							
VEH	*	3	*	*	*	*	*
DOL	*	*	1166502	*	*	*	*
LAB HR	*	72461	*	*	*	*	*
CWO	*	6	105	*	*	*	*
CJO	*	129	*	*	*	*	*
CRWA	*	*	*	*	*	*	*
DJO	*	**	*	*	*	*	*

Note
1. * Indicates there was no positive slack.
2. ** Indicates there was positive slack values associated with delinquent job orders. We do not show the numerical value because it has no intuitive meaning since we are using a recipricol.

Legend
Inputs:
VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours
Outputs:
CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Also observe from this table that operational inefficiencies within an organization are identified in two parts via DEA. One part is the θ* values and the other part is the optimal slack variable values (s_i^{-*}, s_r^{+*}). The θ* indicates scale and technical inefficiencies while slack values represent mix inefficiencies (either input or output).

Lowry and Mather are rated less than 100% efficient by DEA on two grounds: first, they have θ* < 1 and second they also have non-zero slack variable values. I.e., Lowry has θ* = .915 and slack variables $s_{VEH}^{-*} = 3$, $s_{LAB\ HR}^{-*} = 72,461$, $s_{CWO}^{+*} = 6$ and $s_{CJO}^{+*} = 129$. This means that Lowry was, at best, only 91.5% efficient relative to the reference set data and thus should be able to reduce all of its inputs by 8.5% and still produce the same level of output. In addition, particular inputsw (VEH and LAB HR) can be further reduced by the input slack variable values without effecting a reduction in output. Finally, even with all input reductions made, the outputs can still be increased by their slack values. Only after all of these adjustments have been made will the base be efficient and at its Most Productive Scale Size (average productivity is maximized).

Continuing on, we note the large slack variable value for supply and equipment funding (DOL) for Mather. It is over one-third of the actual amount of supply expenses incurred by that base which implies that the .975 efficiency rating is too high.

As previously noted, Vance was rated 100% efficient. However, there is evidence that Vance's efficient rating may be due to special features in its operations. DEA provides a basis for relative efficiency evaluations in that efficient DMUs should generally appear in the reference set for other DMUs. DMUs rated efficient which do not appear in the efficiency set of other DMUs may not actually be comparable with any of the other DMUs. This is the case for Vance. It does not appear as a member of any inefficient unit's optimal basis set, and therefore, warrants further investigation before it should be considered 100% efficient. Williams, on the other hand, was in the optimal basis set for both inefficient units. This lends support to Williams efficient rating since it "dominates" each inefficient unit in one or more dimensions.

Window Analyses For ATC

The above analysis is only a start. By breaking annual information into quarterly data and undertaking window types of analyses, we can obtain a series of efficiency ratings for each base's quarterly operations. Recall from our previous discussion in this report that window analyses allow us to check the validity of the annual ratings while obtaining new information on trends, seasonal behavior, and stability within the data.

With five quarters of data, we are able to perform three separate three-quarter window analyses which we refer to as Analyses #1,#2, and #3. Analysis #1 consists of data from each base for the first, second, and third quarters while Analysis #2 has second, third, and fourth quarter data, and Analysis #3 used data from the third, fourth, and fifth quarters.

We display partial results from these analyses as in Table 2. Here in columns 3 through 5 we have the h_0^* (efficiency measure) value for each quarter in a particular analysis. For easy comparison, we show the h_0^* resulting from the analysis of annual data in column 2. For example, Lowry's quarterly operations in Analysis #1 received ratings of 87.4%, 78.9%, and 100% efficient for the first, second, and third quarters respectively. Also note that Lowry's second quarter is a DMU in Analysis #2. From this new reference set, Lowry's second quarter earned an efficiency rating of 69.0%. All of these quarterly ratings can be compared to Lowry's annual efficiency rating of 91.5%

We begin our review of the results of the window analyses reported in Table 2 with Keesler. The results of the three-quarter window analyses generally support Keesler's rating as efficient on the basis of its annual data. Table 2 shows Keesler with several ratings of less than one but all of these are at efficiency values of .95 or higher. One might reasonably expect some variation in ratings due to changes in time periods and reference sets, and the range of variations (5% or less) for Keesler all seem reasonable.

Lowry and Mather were generally inefficient across all window analyses. This conforms to the inefficiency ratings obtained when using solely annual data. Furthermore, the window analyses supplies additional details which indicate a downward trend in efficiency for Mather with consistently low values in the third quarter.

Table 2

ATC Efficiency Ratings
Window Analysis Using Three Quarters

(1) Base	(2) Annual	(3) 1st Qtr	(4) 2nd Qtr	(5) 3rd Qtr	(6) 4th Qtr	(7) 5th Qtr
Keesler	1.0					
Analysis #1		1.0	.963	1.0		
Analysis #2			.945	.994	1.0	
Analysis #3				.957	.961	1.0
Lowry	.915					
Analysis #1		.874	.789	1.0		
Analysis #2			.690	.968	.791	
Analysis #3				.828	.768	1.0
Mather	.975					
Analysis #1		1.0	.849	.640		
Analysis #2			.928	.645	.849	
Analysis #3				.645	.836	.838
Reese	1.0					
Analysis #1		1.0	.887	.875		
Analysis #2			1.0	.967	.827	
Analysis #3				1.0	.850	1.0
Sheppard	1.0					
Analysis #1		.919	.916	1.0		
Analysis #2			.893	1.0	1.0	
Analysis #3				1.0	1.0	1.0
Vance	1.0					
Analysis #1		1.0	1.0	1.0		
Analysis #2			1.0	1.0	1.0	
Analysis #3				1.0	1.0	1.0
Williams	1.0					
Analysis #1		1.0	.952	1.0		
Analysis #2			.899	1.0	1.0	
Analysis #3				1.0	1.0	1.0

RATINGS
1.0 = Efficiency
<1.0 = Inefficiency

Lowry's efficiency rating was significantly higher in the third quarter than in the other quarters. Turning to Table A.1 in Appendix A we see that Lowry's output during that period was significantly better that in the other periods. This may indicate a reporting error such as double counting of some work, i.e., the same job order was reported as being completed twice. We checked with base civil engineering personnel to see if such possibilities did occur. They responded that no reporting inconsistencies existed. Hence, other causes might need to be investigated such as reporting work being completed in this quarter which had been substantially completed in prior periods.

Table 2 provides evidence that Reese's efficiency rating is unstable and depends on the time period and reference set. It has several quarterly ratings which are significantly (more than 10%) below its annual rating of $h_0^* = 1$. Nevertheless, there are also several ratings which equal the annual efficient rating of $h_0^* = 1$. Each of these efficient ratings was checked for the presence of positive slack values which would imply a mix inefficiency that is not evident in the h_0^* value. However, all quarterly operations with $h_0^* = 1$ also had all slack variable values equal to zero. In addition, these quarterly operations appeared in the efficient reference set of inefficient operations. Thus, the efficient ratings received by Reese's quarterly operations appears valid.

The instability of the ratings for Reese is not only evident from the variation in ratings between quarters but also from the large variation in the ratings within each quarter. For example, see the third quarter.

Sheppard's efficient rating calculated from annual data appears to be influenced by its strong performance during the last two quarters of the fiscal year. As can be seen from Table 2, there was a marked improvement in Sheppard's performance between the second and third quarters. This suggested further inquiry and so we investigated, along with MAJCOM officials, whether there had been a change of command or civil engineer or some other action at this base which might account for the better performance. However, nothing was apparent from this headquarters-level inquiry and perhaps a further base-level inquiry should be undertaken.

Vance's efficient rating from using annual data is supported by the window analysis. This base was rated efficient regardless of the reference set and regularly appeared in the optimal basis sets of inefficient units. It is interesting to note that the real property maintenance activity (RPMA) at this base is contracted out by the Air Force, and the only Air Force personnel assigned to this base's RPMA are contract monitors.

ATC officials felt that there are two reasons for Vance's efficient rating. First, almost the entire contractor's work force consists of retired military civil engineering personnel which results in a highly skilled work force compared to the other bases which have several real property maintenance trainees. This finding indicates that we may have missed an important RPMA output -- the training of personnel.

The second advantage the contractor has is that he receives his supply and equipment funding at the beginning of the fiscal year while the other bases receive their funding sporadically throughout the year. This permits the contractor to better program and use his resource since he knows the amount of resources he will have on hand for the year while other base civil engineers operate under uncertainty.

Williams also appears to be performing well. Except for a slight aberration in the second quarter, it was consistently rated efficient. William's fourth quarter execution was especially strong. This DMU was in the comparison set for all inefficient units -- 12 out of 12 inefficient DMUs in Analysis #2 and seven out of seven inefficient units in Analysis #3.

Finally, note from Table 2 that there is a tendency for more efficient performance by the bases in the first quarter of the fiscal year. The first quarter shows five of seven bases rated efficient and the fifth quarter (= first quarter FY 84) has six of seven bases rated efficient. No other quarter has such a great percentage of efficient DMUs.

On the other hand, the second quarter has the worst performance. Only three of 14 DMUs were rated efficient.

We discussed with ATC officials possible reasons for this cyclical result such as seasonal variation due to weather or fluctuation in funding levels. It was their opinion that this could result from Congress' consistent failure to appropriate funds at the beginning of the fiscal year. During the first quarter of the fiscal year, the bases are not aware of what their programs will be for the year because they are operating under a Continuing Resolution Authority. Thus they order few new supplies and equipment and use what they have on hand. Since our input measure is supply and equipment expenses the above actions would result in lower expenses and hence possibly a higher efficiency rating.[7]

The effect of this inventory drawdown continues on into the second quarter but has the opposite impact. Normally by the second quarter bases know what funds are currently available to them for the year, and thus they begin to build their inventories back up. This results in higher than normal expenses and can contribute to a lower efficiency rating since the supply and equipment funding (expense) input would overstate the amount of supplies actually consumed.

This cyclical variation also reflects the programming advantage that Vance possibly has in receiving its supply and equipment finding at the beginning of the fiscal year which was previously discussed. Note that of the three decision making units which were rated 100% efficient for the second quarter, two of them were Vance's second quarter operations. Thus it appears that Vance is the only base that is unaffected by the lack of an appropriation at the beginning of the fiscal year and the corresponding impact on programming the use of its resources in an optimal (efficient) manner. Hence this particular advantage of Vance's contract operations is supported.

There is one other bit of information provided by DEA that is managerially useful and can aid further investigations. As discussed in Section II of Chapter 1, DEA identifies the efficient DMUs (=bases or quarterly operations) with which the inefficient base is compared in arriving at its efficiency rating.

To illustrate what we are referring to here, we will use the results of the analysis using annual data. Recall that Lowry and Mather were rated inefficient in this analysis while Keesler, Reese, Sheppard, Vance, and Williams were rated efficient. The comparison set for Lowry consisted of the efficient bases -- Keesler, Reese, Sheppard, and Williams -- while Mather was compared solely to Williams. Thus, the civil engineers at the inefficient bases and other interested individuals can look at the operations of the comparison set bases as a source of information for correcting their operation's inefficiencies. In Lowry's case this might not be meaningful or easily accomplished due to the large number of bases involved. However, the civil engineer at Mather might find it very beneficial since there is only one base in his comparison set.

The findings discussed in this section are indicators of operational efficiency (or inefficiency) in the real property maintenance function of the bases reviewed. These indicators are a means to an end, which is efficient operations, and not the end in themselves. As such, the information serves as guides to management for additional investigation.

As discussed for Lowry and Sheppard, we initiated some preliminary investigations from the headquarters level. However, these investigations generally proved to be inconclusive or tentative and hence further field (base) follow-up is required. Such field follow-up could be accomplished by base personnel, staff auditors, or headquarters staff assistance visits.

Summary of ATC Findings

We began our evaluation of ATC's base real property maintenance by analyzing base operations via annual data. As expected, all bases were rated 100% efficient or nearly 100% efficient due to having an insufficient number of bases in the analysis for the number of inputs and outputs used.

To test the stability and validity of the annual efficiency ratings and to search for any underlying trends, we performed a series of window analyses. We found that this type of analysis could be used not only to substantiate or question the results of the analysis of annual data but also to provide additional insight into the operation of the bases. For example, it indicated a downward trend in efficiency for Mather.

Finally, these results are indicators of efficiency or inefficiency and should be used as guides for further investigation at the headquarters and base level of operations.

SECTION IV - JOINT ANALYSIS OF ATC AND TAC

To further review and validate the results obtained for ATC from the previous analyses, we now bring in data of nine bases from a second major air command, TAC, and combine these data with ATC's data for joint analysis.[8] With this approach we are able to introduce more observations into an analysis which should provide better efficiency evaluations. Even if the two sets of data are not quite comparable this should show up in a consistent separation of their efficiency evaluations.

To further validate (and justify) our joint analyses, we investigated the real property maintenance activities of the two commands and could not find any real source of possible troubles for the kinds of analyses we are conducting. The dimensions we are looking at are the same across all major air commands. Maintenance of facilities, systems, and equipment are similar between the MAJCOMs. Both commands are required to follow the same Air Force regulations and directives regarding real property maintenance. Thus, base civil engineers from each MAJCOM should interpret the input and output measures similarly and follow the same procedures regardless of the primary mission of the base/

Joint Analysis Of Annual Data

Table 3 compares the efficiency ratings calculated from using annual data when the Major Air Commands were analyzed separately (columns 2 and 3) and when they are combined (column 4). In the following discussion we highlight ATC in order to maintain continuity with our earlier discussions. As can be seen from this table, several ATC bases had their efficiency ratings effected by this joint analysis.

Those bases that had their annual efficiency ratings unchanged or changed by less than 5% received strong support that the original ratings were valid since the introduction of

Table 3

Comparison Of Efficiency Ratings From Annual Data

(1) Base	(2) ATC	(3) MAJCOM #2	(4) ATC & #2
Keesler	1.0		.975
Lowry	.915		.915
Mather	.975		.728
Reese	1.0		1.0
Sheppard	1.0		.883
Vance	1.0		1.0
Williams	1.0		1.0
Luke		1.0	.949
Howard		.927	.927
Langley		.660	.645
George		1.0	1.0
Moody		1.0	.967
Shaw		1.0	.518
Myrtle Beach		1.0	1.0
Holloman		.624	.551
Bergstrom		1.0	.627

additional observations did little to change those rating. This would include Kessler, Lowry, Reese, Vance, and Williams.

However, Vance still seems to be an anomaly. Although it continues to be rated efficient, it again did not appear in any of the optimal basis sets for inefficient units which, as previously discussed, is an indication that the base is a self-evaluator and requires further review before it should be considered efficient. Although by this time in our study, possibly for special reasons which make it not quite comparable with other bases there are strong indications that Vance is operating efficiently, at least in its own special way.

Mather and Sheppard had their efficiency ratings (based on annual data) reduced by more than 10%. Note especially the results for Mather. The annual slack values and previous window analyses had already suggested that the .975 efficiency rating for Mather based on annual data was probably too high.[9] The .728 rating received in the joint analysis appears to be more in conformance with the results of the preceding window analyses. Sheppard's results indicated inefficiencies that were not identified in the previous analyses and thereby provide new information for study and analysis.

Window Analyses Combining ATC and TAC

To further test the results obtained from this expanded analysis of annual data, we turn to the window analysis technique used in the previous sections. Take 4 presents partial results

Table 4

ATC Efficiency Ratings -Combined Data
Window Analysis Using Three Quarters

(1) Base	(2) Annual	(3) 1st Qtr	(4) 2nd Qtr	(5) 3rd Qtr	(6) 4th Qtr	(7) 5th Qtr
Keesler	.975					
Analysis #4		.847	.821	.863		
Analysis #5			.769	.825	.829	
Analysis #6				.761	.769	.955
Lowry	.915					
Analysis #4		.670	.656	.999		
Analysis #5			.636	.955	.753	
Analysis #6				.696	.614	1.0
Mather	.728					
Analysis #4		.892	.650	.466		
Analysis #5			.672	.459	.567	
Analysis #6				.445	.571	.776
Reese	1.0					
Analysis #4		1.0	.838	.740		
Analysis #5			1.0	.897	.757	
Analysis #6				.579	.547	.926
Sheppard	.883					
Analysis #4		.741	.742	.918		
Analysis #5			.651	.819	.825	
Analysis #6				.832	.797	.777
Vance	1.0					
Analysis #4		.855	.883	.824		
Analysis #5			1.0	.966	1.0	
Analysis #6				.893	.873	1.0
Williams	1.0					
Analysis #4		.960	.790	1.0		
Analysis #5			.794	1.0	1.0	
Analysis #6				.847	.826	.972

(h_0^* values) from this series of analyses in the same format as Table 2.[10] This series of window analyses are referred to as Analysis #4 (first, second, and third quarters), Analysis #5 (second, third, and fourth quarters) and Analysis #6 (third, fourth, and fifth quarters).

Reviewing Table 4 we see that the results reported in Table 3 are substantiated for some of the bases. The ratings for Mather and Williams show some fluctuation but generally support the annual rating as a reflection of the organization's overall performance for the year. A few additional findings concerning these units also are noteworthy.

Through the third quarter, Mather again shows a definite downward trend in the efficiency of its operations with the third quarter being extremely poor. The fourth quarter and fifth quarter (=first quarter FY 84) show some improvement but the base does not recover to its performance in the first quarter of FY 83. This same trend was reflected in Table 2, but it was not as pronounced.

The second quarter efficiency diminution for Williams evident in Table 2 is also present here but it is even more pronounced.

The results for Vance are inconclusive and require further investigation. Reviewing the h_0^* values listed in Table 4 we see that these values for Vance are generally .87 and higher and the mean for all of these values is .91.[11] From this information we might conclude that the relatively efficient rating resulting from annual data is valid.

However, as was true with previous analyses, we again have indications that Vance's operations might be less efficient than suggested by the ratings. Out of eight possible FY 83 quarterly ratings in the window analyses, Vance had only two which were $h_0^* = 1$. Both of these ratings, second and fourth quarter in Analysis #2, are suspect since they are in only one optimal basis set which happens to be Vance's own third quarter. Thus Vance must continue to be regarded as a self-evaluator. If we disregard (eliminate) the second and fourth quarter ratings in Analysis #2, we would have a mean rating of.88 for Vance. This is 12% below the annual rating of 100% efficient and is probably a greater variation than reasonably could be expected from changes in time periods and reference sets.

For the remaining bases, Keesler, Lowry, Reese, and Sheppard, there is evidence that the annual efficiency rating may be overstated and the window analyses have uncovered additional inefficiencies. The ratings computed via the window analyses are consistently lower than the annual measures by significant amounts. For example, Lowry's average quarterly efficiency ratings from Table 4 of .67 for the first quarter, .646 for the second quarter, .883 for third quarter, and .684 for the fourth quarter are well below the rating of .915 for the year.

Other findings discussed in analyzing ATC separately are also evident here. Lowry's abnormally high third quarter productivity is again evident. Sheppard's trend to improved performance beginning with the third quarter is also reflected.

The joint window analyses also provides new information on Reese's real property maintenance function. It highlights a trend that was not apparent from the previous analyses. There is a definite downward trend in Reese's operational efficiency as can be seen from the following average quarterly efficiency ratings: 1st - 1.0, 2nd - .919, 3rd - .79, and 4th - .652.

Contribution Of The Joint Analysis

The purpose of combining the data from two separate major air commands into a single analysis was to introduce more observations into our research and thereby obtain additional insight into our DEA evaluations. Additional light is also shed on the evaluations obtained from the annual data or window analyses for each separate command. We can confirm some of the previous findings and raise doubts about others in ways that provide additional ways of identifying possible inefficiencies and trends that were concealed or not uncovered in the preceding analyses.

In our research, the joint analyses conformed to the previous findings for ATC in several cases. In both the joint analyses and the individual analyses, Lowry received the same efficiency rating based on annual data. Also, the window type analyses from both approaches highlighted Lowry's greater than normal third quarter efficiency.

For Mather, the combined analysis of annual data supported the implication from ATC's window analyses that Mather's annual analyses also identified the same downward trend in efficiency for Mather that was identified in the ATC window analyses.

The combined-data analyses (both annual and window analyses) also uncovered inefficiencies that were apparent when using solely ATC data. Keesler and Sheppard were assigned diminished efficiency ratings. In addition, these combined-data analyses brought forth the downward trend in efficiency for Reese.

Although we combined the data from two different major air commands for our research, this type of analysis is not readily implementable in the Air Force without a change in current real property maintenance management procedures. The Air Force delegates operational oversight of the real property maintenance function to the major air command while the base has operational control. Hq Air Force directorates are not involved with the operations of base-level, in-house real property maintenance activities and as a result, there are no procedures for aggregating real property maintenance work-load data at Air Force headquarters. At the same time, currently there are no procedures for exchanging this type of information between major air commands. Thus, for this kind of joint evaluations to be possible, major air command officials must be willing to share work-load and resource consumption information between commands and establish procedures which will permit this exchange.

SECTION V - SENSITIVITY OF ATC EVALUATIONS

In this section we test the sensitivity of our program evaluations for ATC bases to changes in the categories of inputs and outputs used in the analyses. Recall that during our data collection phase we found it necessary to reduce the number of inputs and outputs included in our analysis due to having an insufficient number of DMUs. Here we will check the effect on the preceding efficiency ratings of augmenting our study with some of the inputs and outputs that were previously deleted.

We will also review the sensitivity of our evaluations to how we form the windows for the window analyses.

Changes In Inputs And Outputs

In accomplishing this research we found it necessary to eliminate some inputs and outputs from our analyses. The primary reason for making these reductions was due to an insufficient number of DMUs.

Recourse to a window analysis increased the number of DMUs and allowed us to check the stability of the efficiency ratings. This same technique also enables us to test the sensitivity of the efficiency rating, h_0^*, to changes in the inputs and outputs used to effect these evaluations.

Since we have 21 DMUs with the three-quarter window analysis, we are able to provide an adequate number of degrees of freedom to accommodate a Data Envelopment Analysis with ten inputs and outputs. Therefore we generated two more analyses which we refer as Augmented Study #1 (AS1) and Augmented Study #2 (AS2). AS1 used the same inputs and outputs as Analysis #2 but augmented them[12] with three additional outputs: percentage of job orders completed (%CJO), percentage of work orders completed (%CWO), and percent of recurring work actions completed (%CRWA). AS2 had the same inputs and outputs as Analysis #2 plus three additional inputs: number of available job orders (AJO), number of available work orders (AWO), and the number of scheduled recurring work actions (SRWA).

The observed values for the additional input and output measures used in these augmented studies are listed in Table 5. Values are presented for the second, third, and fourth quarters so to be comparable to Analysis #2. Using Keesler as an example, the table shows that in the second quarter it had 925 work orders and 9,069 job orders available for completion and 4,757 recurring work actions scheduled for accomplishment. This resulted in Keesler completing 8.76% of its available work orders, 69.5% of its available job orders, and 75.2% of scheduled recurring work actions.[13]

Table 6 compares the efficiency ratings from Analysis #2 and Augmented Studies #1 and #2. Note that in general the h_0^* values for each base do not vary much between the analyses as illustrated by the results for Keesler. Augmenting Analysis #2 with three additional inputs (AS1) or three additional outputs (AS2) did not vary Keesler's efficiency rating. It's second quarter ratings were .945 (Analysis #2), .946 (AS1), and .943

Table 5

Additional Observed Values For Augmented Studies

Base	Input & Output	2nd Qtr	3rd Qtr	4th Qtr
Keesler	AWO	925	743	703
	AJO	9069	8644	9238
	SRWA	4757	5251	4910
	%CWO	8.76	10.36	9.82
	%CJO	69.[illegible]	75.5	71.8
	%CRWA	75.2	79.7	84.0
Lowry	AWO	117	1261	1318
	AJO	6074	6064	6229
	SRWA	3113	4317	3898
	%CWO	4.42	6.03	5.84
	%CJO	62.6	65.7	62.0
	%CRWA	80.6	107.5	92.1
Mather	AWO	725	697	683
	AJO	6173	4867	6054
	SRWA	1578	1584	2401
	%CWO	9.38	9.04	7.61
	%CJO	74.6	68.7	75.3
	%CRWA	57.0	62.2	61.8
Reese	AWO	616	578	737
	AJO	2907	3194	3324
	SRWA	1691	1539	14335
	%CWO	8.11	9.34	7.73
	%CJO	78.9	79.0	77.7
	%CRWA	81.7	101.2	96.2
Sheppard	AWO	1737	1569	1608
	AJO	7449	8970	8697
	SRWA	2403	867	2596
	%CWO	7.77	7.65	8.58
	%CJO	79.4	86.3	84.4
	%CRWA	57.9	103.1	97.3
Vance	AWO	1014	1174	1085
	AJO	2283	3161	2472
	SRWA	983	1323	1801
	%CWO	13.02	12.01	12.72
	%CJO	66.6	53.8	72.8
	%CRWA	68.0	82.7	70.9

Table 5 Continued

Base	Input & Output	2nd Qtr	3rd Qtr	4th Qtr
Williams	AWO	523	468	421
	AJO	3986	3908	4741
	SRWA	2711	3337	4035
	%CWO	11.85	12.82	13.78
	%CJO	72.6	73.4	75.7
	%CRWA	61.4	92.3	83.6

LEGEND
AWO - Available Work Orders
AJO - Available Job Orders
SRWA - Scheduled Recurring Work Actions
%CWO - Percent of Work Orders Completed
%CJO - Percent of Job Orders Completed
%CRWA - Percent of Recurring Work Actions Completed

Table 6

Comparison Of Efficiency Ratings

Base	Analysis	2nd Qtr	3rd Qtr	4th Qtr
Keesler	2	.945	.994	1.0
	AS1	.946	.993	.999
	AS2	.943	1.0	1.0
Lowry	2	.690	.968	.791
	AS1	.713	.968	.791
	AS2	.809	1.0	.881
Mather	2	.928	.645	.849
	AS1	.938	.725	.894
	AS2	1.0	.898	.972
Reese	2	1.0	.967	.827
	AS1	1.0	1.0	1.0
	AS2	1.0	1.0	.968
Sheppard	2	.893	1.0	1.0
	AS1	.893	1.0	1.0
	AS2	.943	1.0	1.0
Vance	2	1.0	1.0	1.0
	AS1	1.0	1.0	1.0
	AS2	1.0	1.0	1.0
Williams	2	.899	1.0	1.0
	AS1	.966	1.0	1.0
	AS2	.971	1.0	1.0

(AS2). Mather probably could be considered the lone exception to these "invariance" findings. Hence, it would appear from this comparison that the introduction of these additional inputs or outputs would not significantly alter the results of our analyses.

Two Quarter vs Three Quarter Window Analyses

In the preceding analyses, we turned to accomplishing a series of window type analyses using data from three fiscal quarters in order to increase the number of observations and thereby attain a more reliable efficiency rating. Thus, we are also interested in the sensitivity of the results of the window analyses to how we form the windows used in the analysis, and hence we accomplished a second series of window analyses using two quarters of data for each window.

Table 7 shows the h_0^* values for this new series of window analyses. It can be compared with Table 2 which contains the h_0^* values for the three-quarter window analyses. As can be seen from reviewing these tables, the ratings and trends in both analyses are very similar.

For example, both series of analyses have similar efficiency ratings for Keesler. Both gave a 100% efficient rating for the first and fifth quarters. The other quarters were also very similar. Note the fourth quarter where the two-quarter window analyses computed ratings of 1.0 and .963 which are very close (indeed almost identical) with the ratings of 1.0 and .961 for the three-quarter window analyses shown in Table 2.

Table 7

Efficiency Ratings

Window Analysis Using Two Quarters

Base	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Keesler	1.0	1.0			
		.963	1.0		
			.990	1.0	
				.963	1.0
Lowry	.935	.859			
		.789	1.0		
			.968	.792	
				.768	1.0
Mather	1.0	.854			
		.931	.685		
			.645	.847	
				.857	.838
Reese	1.0	.907			
		1.0	.983		
			1.0	.895	
				.919	1.0
Sheppard	1.0	1.0			
		.917	1.0		
			1.0	1.0	
				1.0	1.0
Vance	1.0	1.0			
		1.0	1.0		
			1.0	1.0	
				1.0	1.0
Williams	1.0	1.0			
		.964	1.0		
			1.0	1.0	
				1.0	1.0

In Mather's case both series of analyses show its performance becoming progressively worse through the third quarter of FY 83 and then showing some improvement. This is in addition to having very similar ratings from the two types of analyses.

Ratings Sensitivity Summary

To further check the stability of our evaluations, we tested their sensitivity to the addition of different inputs and outputs and changes in the number of DMUs used in the analysis. We found that, in general, the ratings were unaffected by the introduction of the inputs and outputs we eliminated in the first part of this chapter. The results also indicated that using a two-quarter window analysis versus a three-quarter window analysis will not significantly alter the efficiency ratings. Hence the results from our previous analyses continue to stand with these additional validations -- i.e., stability of results not affected by variations either in the number of inputs and outputs or in the number of DMUs.

CHAPTER 3

SUMMARY AND CONCLUSIONS

In this research we reviewed and discussed efficiency ratings and trends for Air Force bases in the Air Training Command. The research is built around an efficiency measurement methodology developed by Charnes, Cooper, and Rhodes [6] and others called Data Envelopment Analysis (DEA). DEA provides a relative measure of efficiency for organizations that have multiple inputs and multiple outputs and for which an a priori production function is not available.

We initiated this study by applying DEA to annual data from ATC bases. As expected, almost all bases were rated 100% efficient. This was due to having an insufficient number of observations to effect a Data Envelopment Analysis which would discriminate between efficient and less efficient bases.

We increased the available number of observations via a three-quarter window analysis and a joint analysis using data from two commands. This allowed us to test the stability and validity of the measures obtained from evaluating the bases using solely annual data. It also provided supplemental information on trends and cycles.

Using the three-quarter window analysis in conjunction with the analysis of annual data we can come to the following conclusions on the operational efficiency of the bases included in our analysis:

(1) Keesler, Sheppard, Vance, and Williams, seem to be operating efficiently.

(2) Lowry and Mather clearly have the most inefficient operations.

(3) Reese's results are not quite as clear cut but they do indicate that Reese has some operational inefficiencies. However, it does not appear to be as inefficient as either Lowry or Mather.

(4) Our analysis also provided indications that Vance was rated efficient because of special operational characteristics which are different from the civil engineering operations of the other bases -- possibly its contract operations.

(5) Finally, we noted that there was a concentration of efficient operations in the first quarter of the fiscal year while a majority of the second quarter operations were inefficient. This supports the hypothesis that a lack of an appropriations causes significant planning problems in the use of resources.

Recall that these ratings are relative and dependent on the DMUs and inputs/outputs included in the analysis. Thus, we also tested the sensitivity of our findings to the addition of new inputs and outputs and to how we formed the windows for the window analysis. We found that these changes had little effect on the efficiency ratings.

Finally, it is important to note that these findings are not to be used solely as an end in themselves but also as a means to an end. That end being efficient operations. This information should be used as guides for further investigation into how an organization can become operationally efficient. Information supplied via the identification of the amount of inefficiency in each input and output and the bases in the inefficient unit's comparison set can be used for this purpose.

APPENDIX A

SUPPLEMENTAL TABLES

This appendix contains supplemental tables reporting the data used in and the results of the efficiency evaluations for Air Training Command and MAJCOM #2.

TABLES A.1 AND A.2

Tables A.1 and A.2 report the observed input and output values for ATC and MAJCOM #2 used in this research. They are the actual amount of resources consumed by a base in producing its output over the time period shown.

The annual values shown in column 3 of Table A.1 are for Fiscal Year (=FY) 83. For example, Keesler used inputs of 38 passenger carrying vehicles (VEH), $3,247,600 worth of supplies and equipment (DOL), and 453,951 direct labor hours (LAB HR) in FY 83 to produce 308 completed work orders (CWO), 25,451 completed job orders (CJO), 15,962 completed recurring work actions (CRWA), and 3,629 delinquent job orders (DJO) as outputs for the year. Replacing the annual accomplishments and efforts with their reported quarterly values we have, for example, Keesler using 38 vehicles, $779,240 and 106,022 direct labor hours to complete 81 work orders, 5,983 job orders, and 4,072 recurring work actions with 913 job orders being delinquent in the first quarter of FY 83.

The other cells are similarly interpreted but, of course, some treatment of these data may be needed for DEA. For example, recall from our earlier discussion in Chapter 1 that we need to use the reciprocal of the number of delinquent job orders as our measure to reflect the fact that increases in delinquent job orders are not desirable. Thus, the 913 delinquent job orders reported by Keesler for the first quarter in column 4 of Table A.1 would be replaced by 1/913 or .00110 in DEA development.

Table A.1

Observed Inputs and Outputs for ATC
Fiscal Year 1983 Data

(1) Base	(2) Input/ Output	(3) Annual	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Keesler	VEH	38	38	38	38	38	38
	DOL	3,247,600	779,240	810,450	830,250	827,750	616,015
	LAB HR	453,951	106,022	115,083	117,901	114,945	98,247
	CWO	308	81	81	77	69	71
	CJO	25,451	5,983	6,307	6,530	6,631	6,882
	CRWA	15,962	4,072	3,578	4,186	4,126	4,443
	DJO	3,629	913	977	912	827	283
Lowry	VEH	33	33	33	33	33	33
	DOL	2,507,700	576,242	640,971	640,000	650,500	536,997
	LAB HR	250,169	57,304	62,821	62,878	67,166	57,731
	CWO	294	89	52	76	77	56
	CJO	14,697	3,045	3,804	3,986	3,862	4,136
	CRWA	13,517	2,780	2,508	4,639	3,590	9,028
	DJO	2,705	982	599	355	769	1,038

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.1 Continued

(1) Base	(2) Input/ Output	(3) Annual	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Mather	VEH	29	29	29	29	29	29
	DOL	3,491,000	910,270	875,762	780,0000	925,000	501,000
	LAB HR	265,344	62,219	66,201	65,845	71,079	68,623
	CWO	251	68	68	63	52	28
	CJO	18,940	6,434	4,608	3,341	4,557	4,223
	CRWA	5,222	1,851	900	986	1,485	3,294
	DJO	2,306	590	246	601	869	538
Reese	VEH	24	24	24	24	24	24
	DOL	1,846,700	450,250	396,450	525,000	475,000	237,511
	LAB HR	150,677	31,322	34,315	41,269	43,772	34,243
	CWO	215	54	50	54	57	58
	CJO	9,341	1,943	2,293	2,522	2,583	2,515
	CRWA	5,672	1,352	1,382	1,558	1,380	1,596
	DJO	394	52	82	99	161	224

LEGEND

Inputs
- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Funding
- LAB HR - Available Direct Labor Hours

Outputs
- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Actions
- DJO - Delinquent Job Orders

Table A.1 Continued

(1) Base	(2) Input/ Output	(3) Annual	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Sheppard	VEH	40	40	40	40	40	40
	DOL	3,153,300	810,070	791,683	775,000	776,550	575,368
	LAB HR	368,356	85,692	91,261	96,540	94,864	85,552
	CWO	513	120	135	120	138	121
	CJO	27,141	6,147	5,913	7,743	7,338	6,039
	CRWA	6,748	1,936	1,391	894	2,527	2,207
	DJO	1,860	495	468	537	360	364
Vance	VEH	23	23	23	23	23	23
	DOL	1,691,700	402,964	391,242	456,270	441,250	329,206
	LAB HR	197,939	45,675	47,141	51,552	53,572	47,515
	CWO	539	128	132	141	138	134
	CJO	6,790	1,770	1,520	1,700	1,800	1,708
	CRWA	4,267	1,228	668	1,094	1,277	1,536
	DJO	941	253	297	246	145	110

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.1 Continued

(1) Base	(2) Input/ Output	(3) Annual	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Williams	VEH	22	22	22	22	22	22
	DOL	1,848,600	471,983	461,298	465,070	450,291	376,362
	LAB HR	126,060	28,484	35,013	29,453	33,110	31,414
	CWO	242	62	62	60	58	30
	CJO	11,940	2,589	2,893	2,869	3,589	3,214
	CRWA	10,686	2,767	1,665	3,081	3,373	3,650
	DJO	1,323	431	302	304	286	346

LEGEND

Inputs
- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Funding
- LAB HR - Available Direct Labor Hours

Outputs
- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Actions
- DJO - Delinquent Job Orders

Table A.2 Continued

Observed Inputs and Outputs for TAC
Fiscal Year 1983 Data

Base	Input/ Output	Annual	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Luke	VEH	44	44	44	44	44	44
	DOL	2,444,700	461,100	684,600	474,000	825,000	437,600
	LAB HR	265,866	57,645	70,334	69,028	68,859	61,913
	CWO	197	52	53	61	31	36
	CJO	16,878	3,811	4,180	4,191	4,696	3,880
	CRWA	12,860	2,554	2,277	4,756	3,273	2,863
	DJO	2,405	627	612	649	517	592
Howard	VEH	42	42	42	42	42	
	DOL	2,887,300	599,800	780,600	748,800	758,100	
	LAB HR	338,611	74,158	81,969	87,717	758,100	
	CWO	135	32	46	14	43	
	CJO	30,130	7,914	7,276	7,094	7,846	
	CRWA	3,492	873	873	873	873	
	DJO	4,951	1,694	791	993	1,473	

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.2 Continued

Base	Input/ Output	Annual	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Langley	VEH	105	105	105	105	105	
	DOL	4,304,100	934,500	1,387,300	1,155,500	826,800	
	LAB HR	526,896	123,463	127,217	141,237	134,979	
	CWO	162	40	42	34	44	
	CJO	29,690	8,130	6,870	6,910	7,780	
	CRWA	11,361	2,687	3,068	3,3390	2,486	
	DJO	21,806	5,698	5,604	6,441	4,063	
George	VEH	44	44	44	44	44	44
	DOL	2,302,400	693,200	667,300	554,600	387,300	850,500
	LAB HR	237,136	56,126	62,055	65,242	53,713	44,220
	CWO	327	65	74	72	116	97
	CJO	30,110	7,772	7,515	6,686	8,137	6,180
	CRWA	7,075	2,706	1,314	2,230	825	7,158
	DJO	3,523	1,104	943	780	696	1,323

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.2 Continued

Base	Input/ Output	Annual	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Moody	VEH	19	17	17	20	23	23
	DOL	1,787,800	401,500	432,800	520,000	433,500	339,300
	LAB HR	210,869	44,674	53,978	57,680	54,537	53,162
	CWO	193	15	71	35	72	74
	CJO	12,348	2,815	3,133	3,255	3,145	3,672
	CRWA	9,244	2,668	2,493	2,086	1,997	1,460
	DJO	2,465	739	658	396	672	673
Shaw	VEH	71	71	71	71	71	71
	DOL	3,823,800	957,300	927,400	774,700	1,164,400	783,200
	LAB HR	254,816	61,978	61,537	64,539	66,762	65,067
	CWO	122	21	31	26	44	38
	CJO	15,593	3,608	3,563	3,859	4,563	4,818
	CRWA	5,981	1,509	2,295	1,248	929	2,487
	DJO	1,387	316	423	444	204	7

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.2 Continued

Base	Input/ Output	Annual	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Myrtle	VEH	14	14	14	14	14	14
Beach	DOL	2,127,600	427,200	492,300	554,500	653,600	419,200
	LAB HR	176,146	40,209	40,205	46,132	49,600	46,734
	CWO	579	183	123	94	179	109
	CJO	17,060	3,160	4,408	4,501	4,991	3,437
	CRWA	9,756	2,692	837	3,171	3,056	2,705
	DJO	3,724	960	835	1,000	929	728
Holloman	VEH	35	39	37	32	32	32
	DOL	3,668,100	674,500	953,600	1,021,400	1,018,600	814,200
	LAB HR	306,498	77,339	81,422	74,216	73,520	63,788
	CWO	190	43	58	65	24	34
	CJO	14,800	3,012	3,961	3,588	4,239	3,588
	CRWA	10,546	3,162	1,584	3,121	2,679	2,854
	DJO	10,464	3,305	2,988	2,160	2,011	1,596

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.2 Continued

Base	Input/ Output	Annual	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Bergstrom	VEH	38	38	38	38	38	38
	DOL	2,406,900	382,200	619,700	593,500	811,500	665,400
	LAB HR	237,951	55,448	59,509	63,822	59,172	64,008
	CWO	171	60	36	39	36	58
	CJO	10,773	3,021	2,737	2,579	2,436	2,565
	CRWA	8,453	1,938	1,635	2,058	2,822	2,931
	DJO	1,928	473	415	439	601	1,028

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

NOTE: Recall from our earlier discussion that we need to use the reciprocal of the DJO measure. Therefore, the actual value used in effecting DEA would be, for example, 1/431 or .00232 for base G, first quarter.

Table A.3

Table A.3 displays the two factors, θ* and optimal slack variable values, which compose the efficiency rating for the three series of window analyses undertaken for ATC. Analysis #1 consists of data from the first, second, and third quarters for each base. Data from the second, third, and fourth quarters form the windows in Analysis #2 while Analysis #3 involves data from the third, fourth, and fifth quarters.

The θ* values listed for Analyses #1, #2, and #3 in columns 4 through 8 are the same as those reported in Table 2. They are repeated here so as to show both parts of the efficiency analysis in one place. Note that $\theta^* = h_0^*$ when the non-Archimedean conditions are fulfilled.

The slack variable values which appear under the efficiency ratings in each column correspond to the input or output measure with which the slack variable is associated for each analysis shown in column 3.

We will use Keesler to illustrate how to read this table. In Analysis #1, Keesler's second quarter received an efficiency rating, $\theta^* = h_0^*$, of .963 with zero values for all slack variables except for LAB HR which equaled 4,791 hours and DJO which equaled 3.3 Keesler's second quarter is also a DMU in Analysis #2. From this new reference set, Keesler, second quarter had θ* = .945 with positive slack variable values of DOL = $46,971, LAB HR = 41,339 hours, CWO = 19 work orders, and DJO = 30.4.

As discussed in Chapter 1 when we described the delinquent job order output measure, we use a reciprocal of the number of delinquent job orders as the actual DJO measure when effecting DEA. Hence, the DJO slack variable values shown in this table have little intuitive meaning. However, they do have value in that they are an important factor in determining Most Productive Scale Size.

Finally, the * in column indicates that the slack variable had a value of zero for that analysis.

Table A.3

Efficiency Measures For ATC

Window Analyses

(1) Base	(2) Measures	(3) Analysis	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Keesler	$\theta^* = h_0^*$	#1	1.0	.963	1.0		
		#2		.945	.994	1.0	
		#3			.957	.961	1.0
	Slack Values						
	VEH	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	DOL	#1	*	*	*		
		#2		46971	65486	*	
		#3			176566	198656	*
	LAB HR	#1	*	4791	*		
		#2		41339	49199	*	
		#3			23762	16303	*
	CWO	#1	*	*	*		
		#2		19	27	*	
		#3			*	1	*
	CJO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CRWA	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	DJO	#1	*	3.3	*		
		#2		30.4	35.3	*	
		#3			24.4	21.1	*

Table A.3 Continued

(1) Base	(2) Measures	(3) Analysis	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Lowry	$\theta^* = h_U^*$	#1	.874	.789	1.0		
		#2		.690	.968	.791	
		#3			.828	.768	1.0
	Slack Values						
	VEH	#1	2	1	*		
		#2		1	2	1	
		#3			*	*	*
	DOL	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	LAB HR	#1	*	*	*		
		#2		1599	15307	12524	
		#3			7039	7116	*
	CWU	#1	*	16	*		
		#2		14	4	*	
		#3			*	*	*
	CJU	#1	*	*	*		
		#2		*	950	16	
		#3			*	*	*
	CRWA	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	DJU	#1	20.4	5.7	*		
		#2		9.7	19.9	31.6	
		#3			11.3	24.4	*

Table A.3 Continued

(1) Base	(2) Measures	(3) Analysis	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Mather	$\theta^* = h_0^*$	#1	1.0	.849	.640		
		#2		.928	.645	.849	
		#3			.645	.836	.838
	Slack Values						
	VEH	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	DOL	#1	*	49166	*		
		#2		294258	138250	290304	
		#3			137983	331132	11777
	LAB HR	#1	*	5716	1295		
		#2		2940	*	*	
		#3			*	*	*
	CWO	#1	*	*	*		
		#2		7	*	14	
		#3			*	10	20
	CJO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CRWA	#1	*	602	25		
		#2		*	351	*	
		#3			361	*	*
	DJO	#1	*	*	*		
		#2		*	*	2.6	
		#3			*	4.7	4.8

Table A.3 Continued

(1) Base	(2) Measures	(3) Analysis	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Reese	$\theta^* = h_0^*$	#1	1.0	.887	.875		
		#2		1.0	.967	.827	
		#3			1.0	.850	1.0
	Slack Values						
	VEH	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	DOL	#1	*	*	23622		
		#2		*	67045	11997	
		#3			*	*	*
	LAB HR	#1	*	*	3800		
		#2		*	4368	281	
		#3			*	*	*
	CWO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CJO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CRWA	#1	*	93	*		
		#2		*	*	*	
		#3			*	531	*
	DJO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*

Table A.3 Continued

(1) Base	(2) Measures	(3) Analysis	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Sheppard	$\theta^* = h_0^*$	#1	.919	.916	1.0		
		#2		.893	1.0	1.0	
		#3			1.0	1.0	1.0
	Slack Values						
	VEH	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	DOL	#1	*	*	*		
		#2		8194	*	*	
		#3			*	*	*
	LAB HR	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CWO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CJO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CRWA	#1	*	*	*		
		#2		1046	*	*	
		#3			*	*	*
	DJO	#1	10.8	9.7	*		
		#2		11.7	*	*	
		#3			*	*	*
Vance	$\theta^* = h_0^*$	#1	1.0	1.0	1.0		
		#2		1.0	1.0	1.0	
		#3			1.0	1.0	1.0
	Slack Values						

All slack values equal zero for all windows.

Table A.3 Continued

(1) Base	(2) Measures	(3) Analysis	(4) 1st Qtr	(5) 2nd Qtr	(6) 3rd Qtr	(7) 4th Qtr	(8) 5th Qtr
Williams	$\theta^* = h_0^*$	#1	1.0	.982	1.0		
		#2		.899	1.0	1.0	
		#3			1.0	1.0	1.0
	Slack Values						
	VEH	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	DOL	#1	*	*	*		
		#2		10585	*	*	
		#3					
	LAB HR	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CWO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CJO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*
	CRWA	#1	*	599	*		
		#2		1044	*	*	
		#3			*	*	*
	DJO	#1	*	*	*		
		#2		*	*	*	
		#3			*	*	*

Table A.4

Table A.4 exhibits the θ^* and optimum slack variable values resulting from the window analyses of the combined ATC and MAJCOM #2 data. It uses the same format as Table A.3 except that the three window analyses are referred to as Analyses #4, #5, and #6.

Table A.4

Efficiency Measures For ATC

Joint Window Analyses

Base	Measures	Analysis	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Keesler	$\theta^* = h_0^*$	#4	.847	.821	.863		
		#5		.769	.825	.829	
		#6			.761	.769	955
	Slack Values						
	VEH	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DOL	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	LAB HR	#4	22672	29295	31122		
		#5		26608	29094	27087	
		#6			28902	27071	31664
	CWO	#4	21	22	34		
		#5		33	43	58	
		#6			39	49	39
	CJO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	CRWA	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DJO	#4	3.4	3.4	4.0		
		#5		3.9	4.4	3.3	
		#6			2.5	1.6	*

Table A.4 Continued

Base	Measures	Analysis	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Lowry	$\theta^* = h_0^*$	#4	.670	.656	.999		
		#5		.636	.955	.753	
		#6			.696	.614	1.0
	Slack Values						
	VEH	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DOL	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	LAB HR	#4	*	*	*		
		#5		*	8136	1197	
		#6			*	2053	*
	CWO	#4	*	8	98		
		#5		18	6	*	
		#6			*	*	*
	CJO	#4	*	*	737		
		#5		*	*	*	
		#6			*	*	*
	CRWA	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DJO	#4					
		#5		*	10.2	3.3	*
		#6			*	*	*

Table A.4 Continued

Base	Measures	Analysis	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Mather	$\theta^* = h_0^*$	#4	.892	.650	.466		
		#5		.672	.459	.567	
		#6			.445	.571	.776
	Slack Values						
	VEH	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DOL	#4	131959	39917	*		
		#5		47417	3873	51455	
		#6			8939	49265	*
	LAB HR	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	12963
	CWO	#4	67	49	9		
		#5		53	25	73	
		#6			30	81	40
	CJO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	CRWA	#4	*	220	*		
		#5		179	*	*	
		#6			*	581	*
	DJO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*

Table A.4 Continued

Base	Measures	Analysis	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Reese	$\theta^* = h_0^*$	#4	1.0	.838	.740		
		#5		1.0	.897	.757	
		#6			.579	.547	.928
	Slack Values						
	VEH	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DOL	#4	*	14213	10107		
		#5		*	20671	2889	
		#6			*	*	*
	LAB HR	#4	*	*	*		
		#5		*	2423	*	
		#6			*	31	3475
	CWO	#4	*	*	3		
		#5		*	5	*	
		#6			3	*	*
	CJO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	CRWA	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DJO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*

Table A.4 Continued

Base	Measures	Analysis	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Sheppard	$\theta^* = h_0^*$	#4	.741	.742	.918		
		#5		.651	.819	.825	
		#6			.833	.797	.777
	Slack Values						
	VEH	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DOL	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	LAB HR	#4	981	5499	13587		
		#5		10645	17481	16041	
		#6			18250	15676	11515
	CWO	#4	*	*	*		
		#5		*	47	*	
		#6			62	22	*
	CJO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	CRWA	#4	*	708	703		
		#5		112	265	*	
		#6			1590	*	*
	DJO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*

Table A.4 Continued

Base	Measures	Analysis	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Vance	$\theta^* = h_0^*$	#4	.855	.883	.824		
		#5		1.0	.966	1.0	
		#6			.893	.873	1.0
	Slack Values						
	VEH	#4	7	7	5		
		#5		*	*	*	
		#6			1	*	*
	DOL	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	LAB HR	#4	7647	9947	8123		
		#5		*	69	*	
		#6			*	823	*
	CWO	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	CJO	#4	612	899	909		
		#5		*	330	*	
		#6			871	544	*
	CRWA	#4	750	1351	1076		
		#5		*	29	*	
		#6			809	522	*
	DJO	#4	*	*	*		
		#5		*	*	*	
		#6			23.3	.7	*

Table A.4 Continued

Base	Measures	Analysis	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	5th Qtr
Williams	$\theta^* = h_0^*$	#4	.961	.790	1.0		
		#5		.794	1.0	1.0	
		#6			.847	.826	.972
	Slack Values						
	VEH	#4	2	*	*		
		#5		*	*	*	
		#6			*	1	*
	DOL	#4	3422	*	*		
		#5		15320	*	*	
		#6			*	*	*
	LAB HR	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	CWO	#4	*	*	*		
		#5		4	*	*	
		#6			*	*	19
	CJO	#4	28	*	*		
		#5		*	*	*	
		#6			25	175	*
	CRWA	#4	*	*	*		
		#5		*	*	*	
		#6			*	*	*
	DJO	#4	5.2	*	*		
		#5		*	*	*	
		#6			*	*	*

NOTES

1. It is important not to confuse efficiency with effectiveness or propriety. Effectiveness is the ability to state and achieve objectives. Propriety issues ar concerned with whether objectives are legal, moral, or ethical and even when this is the case, propriety issues can arise around the methods used to attain the objectives. See Kohler's Dictionary For Accountants [8] p. 190 & 408.

2. This term is used to indicate a not-for-profit entity in which a manager has some freedom of decision making on its inputs and outputs.

3. These are referred to as "virtual multipliers" or "transformation rates" by Charnes, Cooper, and Rhodes [6].

4. Thus $h_0^* < 1$ for both of these DMUs.

5. The function d(O-D') are to be understood as measures of distance from the origin in a Euclidean metric.

5a. This technique was used in Charnes, Clark, Cooper, and Golany [3] after having been introduced in Charnes, Cooper, Divine, Klopp, and Stutz [5].

5b. See Charnes, Cooper, and Rhodes [6] p. 433 for a proof.

6. Complete results for the window analyses, including the slack variable values, are contained in Table A.3 in Appendex A.

7. In the Air Force, real property maintenance supplies are expensed to the civil engineering account when they are received by the civil engineer and not when they are actually used or consumed.

8. Refer to Table A.1 and A.2 in Appendix A for the observed input and output values in this joint analysis.

9. See the results of the anual analysis shown in Table 1 and the window analyses reported in Table 2.

10. Table A.4 reporting all efficiency measures (θ^* and slack variables) for all of the bases is located in Appendix A.

11. The mean was calculated by averaging the average ratin (h_0^*) for each quarter. So for Vance we have the following average rating for each quarter: 1st - .855, 2nd - .942, 3rd - .894, and 4th - [illegible]. These averages were determined from the h_0^* values presented in Table 4. The average of these averages is .91.

[illegible] that Analysis #2 consisted of data from the second, [illegible] fourth quarters of the fiscal year.

13. These figures were calculated by dividing the completed work type from Table A.1 by the available work type presented in Table 4. For example, Keesler's second quarter measure of the percentage of completed work orders was computed as follows: 81/925 = .0876 = 8.76%.

SELECTED REFERENCES

1. Air Force Regulation 85-1. "Resources and Work Force Management." Washington D.C.: Department of the Air Force, 21 May 1982 (and changes thereto).

2. Bowlin, W.F. "A Data Envelopment Analysis Approach To Performance Evaluation In Not-For-Profit Entities With An Illustrative Application To The U.S. Air Force." Ph.D. dissertation, The University of Texas at Austin, Texas (December 1984)

3. Charnes, A.; Clark, C.T.; Cooper, W.W.; and Golany, B. "A Developmental Study Of Data Envelopment Analysis In Measuring The Efficiency Of Maintenance Units In The U.S. Air Forces." Annals of Operations Research (forthcoming)

4. Charnes, A. and Cooper, W.W. Management Models and Industrial Applications of Linear Programming. New York: John Wiley and Sons, Inc., 1961.

5. Charnes, A.; Cooper, W.W.; Devine, D.; Klopp, G.A.; and Stutz, J. "An Application of Data Envelopment Analysis to U.S. Army Recruiting Districts." Applications of Management Science, A Research Annual, R.L. Schultz, ed. (Greenwich, Conn. JAI Press, Inc. forthcoming).

6. Charnes, A.; Cooper, W.W.; and Rhodes, E. "Measuring the Efficiency of Decision Making Units." European Journal of Operational Research 2,6 (November 1978): pp. 429-44

7. Charnes, A.: Cooper, W.W.; and Rhodes, E. "Short Communication: Measuring Efficiency of Decision Making Units." European Journal of Operational Research 3,4 (July 1979): p. 339

8. Cooper, W.W. and Ijiri, Y., ed. Kohler's Dictionary For Accountants. 6th ed. Englewood Cliffs, N.J.: Prentice-Hall Inc., 1983.

SECURITY CLASSIFICATION OF THIS PAGE

AD-A181384

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): AU-AFIT-LSQ-84-1	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Department of Cost Analysis and Pricing; 6b. OFFICE SYMBOL (If applicable): AFIT/LSQ	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Air Force Institute of Technology, School of Systems and Logistics, Wright-Patterson AFB, OH 45433-6583	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Evaluating the Efficiency of RPMA in the Air Training Command

12. PERSONAL AUTHOR(S)
Major William F. Bowlin

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical	FROM ____ TO ____	1984 November	85

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
05	01	
05	03	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Efficiency, Productivity, Efficiency Measurement, Real Property Maintenance, Data Envelopment Analysis

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This research evaluates the operational efficiency of the in-house real property maintenance activity of the Air Training Command using a methodology called Data Envelopment Analysis (DEA). Evaluations are undertaken in a variety of ways -- reviewing annual data; checking for trends, stability, and seasonal behavior using window type analyses; and accomplishing a joint analysis with Tactical Air Command data. Results include identifying sources and amounts of inefficiencies for each base, command-wide trends, and special operational characteristics of different bases.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: William F. Bowlin	22b. TELEPHONE (Include Area Code): (513) 255-4846; 22c. OFFICE SYMBOL: AFIT/LSY

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

END

7-87

DTIC