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Data Envelopment Analysis as a Tool To Evaluate Efficiency of Army Real Property Management Activities (RPMA) Spending

by
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The U.S. Army is developing an Output Oriented Resource Management System (OORMS) to compare the value of resources expended with those received for all Army programs. One of the programs to be encompassed by OORMS is Real Property Management Activities (RPMA).

The RPMA program consists of a wide range of goals from which it is difficult to identify a single, quantifiable "entity" that represents the overall goal. Thus, to enable a realistic assessment in OORMS, a performance index is needed to evaluate the efficiency of RPMA at U.S. Army installations.

Three alternative modeling techniques were considered for potential use in developing such an index. Data Envelopment Analysis (DEA) was selected because of its ability to accommodate multiple inputs and outputs simultaneously without requiring that weight and functional relationships be specified.

The performance index was applied to RPMA and its use in several stages of the resource management process was analyzed. Results were distributed to managers at the Major Command (MACOM) headquarters and installation levels for review. In general, DEA appears to be a feasible modeling technique for RPMA performance; however, the method needs refinement to enable better discrimination among efficient installations and to optimize features of the index. A prototype should be developed and implemented at the installations to test different input and output measures. (5)

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FOREWORD

This work was performed for the Office of the Chief of Engineers (OCE), as an Operations and Maintenance, Army (OMA) reimbursable project. The OCE Technical Monitor was Richard Nelson, DAEN-ZCP-B.

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DATA ENVELOPMENT ANALYSIS AS A TOOL TO EVALUATE EFFICIENCY OF ARMY REAL PROPERTY MANAGEMENT ACTIVITIES (RPMA) SPENDING

1 INTRODUCTION

Background

The U.S. Army is developing an Output Oriented Resource Management System (OORMS) to compare the value of resources expended with services received for all Army programs. According to the Army Comptroller, OORMS is intended to meet a functional requirement of Army resource management: feedback on execution in terms of outputs achieved for inputs planned, programmed, budgeted, and then used. Without this essential feedback, it is difficult to make consistent, informed assessments as to how well the Army programs are being both planned and executed. The current resource management process is missing this vital link. Decisions about Army programs and alternatives can be improved measurably if feedback is made an integral part of the process.¹

Included in the OORMS assessments will be Real Property Management Activities (RPMA) at Army installations. The goal of RPMA is to develop, operate, and maintain the facilities necessary for the Army to accomplish its mission and provide a quality working and living environment for its personnel.² With such a broad, multi-objective goal, it is difficult to identify a single, quantifiable "entity" capable of representing the overall goal. In other words, to be able to quantify the degree of goal achieved by an installation, it is necessary to measure several different outputs--each accounting for a different objective--and to aggregate them properly so as to represent the amount of goal achieved. In addition, the aggregate measure of outputs has to be comparable to the amount of resources (input) deployed so that a single composite index can represent the efficiency of an installation. At present, no such index has been developed for RPMA.

Objective

The objective of this research was to develop an output-oriented performance measure index to evaluate the efficiency of RPMA at U.S. Army installations. This performance measure index should relate the outputs achieved by RPMA to the resource (input) deployed during operations; that is, it should be able to compare several types of output with several inputs simultaneously. In addition, the results of evaluations using this single index should assist in the decision-making process of resource management.

Approach

Three alternative methodologies were considered for index development: (1) data envelopment analysis (DEA), (2) ratio analysis, and (3) regression analysis. Mathematical

¹*Output Oriented Resource Management System, Handbook* (Office of the Comptroller of the Army, June 1986).

²*Real Property Management Activities (RPMA), Executive Summary, Vol 1* (Department of the Army Study Group, March 1978).

features of all three methods were compared and the method found most appropriate for dealing with RPMA was selected.

Input and output measures of RPMA operations were defined and selected to model performance. The performance model was applied to 21 U.S. Army Forces Command (FORSCOM) installations and the results were presented to the prospective users for evaluation. Feedback from the field was analyzed and used to revise the performance model.

2 DEVELOPMENT OF AN EFFICIENCY INDEX

Alternative Methodologies

Three different methodologies for establishing a performance index were evaluated for potential application to RPMA. Each method has already been used in some organizations to evaluate different programs.

Data Envelopment Analysis (DEA)

DEA was introduced by Charnes, et al.,³ for measuring the efficiency of not-for-profit entities. The method has been used to measure the efficiency of several organizations such as school systems,⁴ health care organizations,⁵ Navy District recruiting offices,⁶ fighter wings of the U.S. Air Force,⁷ and RPMA in the air training commands.⁸

DEA is designed to measure relative efficiency among similar organizations, called Decision-Making Units (DMU), that share the same technology to gain similar achievements (outputs) by using similar resources (inputs). In this study, the DMUs are Army

³A. Charnes, W. W. Cooper, and E. Rhodes, "Measuring the Efficiency of Decision-Making Units," *European Journal of Operational Research*, Vol 2, No. 6 (November 1978), pp 429-444; A. Charnes, W. W. Cooper, and E. Rhodes, "Short Communication: Measuring the Efficiency of Decision-Making Units," *European Journal of Operational Research* (1979), p 331.

⁴A. Bessent and W. Bessent, "Determining the Comparative Efficiency of Schools Through Data Envelopment Analysis," *Educational Administrative Quarterly*, Vol 16, No. 2 (1980), pp 57-75; A. Charnes, W. W. Cooper, and E. Rhodes, "Evaluating Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through," *Management Science*, Vol 27, No. 6 (1981), pp 668-697; A. Bessent, W. Bessent, A. Charnes, W. W. Cooper, and N. Thorogood, "Evaluation of Educational Program Proposals by Means of DEA," *Educational Administration Quarterly*, Vol 19, No. 2 (Spring 1983), pp 82-107.

⁵H. D. Sherman, *Measurement of Hospital Efficiency Using Data Envelopment Analysis*, unpublished DBA thesis (Graduate School of Business, Harvard University, 1981).

⁶A. Lewis and R. C. Morey, "Measuring the Relative Efficiency and Output Potential of Public Sector Organizations: An Application of Data Envelopment Analysis," *International Journal of Policy Analysis and Information Systems*, Vol 5, No. 4 (December 1981).

⁷A. Bessent, W. Bessent, C. T. Clark, and J. Elam, "Constrained Facet Analysis, A New Method for Evaluating Local Frontiers of Efficiency and Performance," *Air Force Journal of Logistics* (Summer 1984), pp 2-8; C. T. Clark, *Data Envelopment Analysis and Extensions for Decision Support and Management Planning*, Ph.D. dissertation (The University of Texas at Austin, May 1983).

⁸W. F. Bowlin, *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, December 1984); W. F. Bowlin, *Report on Evaluating the Efficiency of Real Property Maintenance Activities in the Air Training Command* (Air Force Institute of Technology, Wright-Patterson AFB, OH, November 1984).

installations or, more specifically, the RPMA organization at the installation level. The notation used to formulate DEA is:

Let DMU_j ; $j = 1, \dots, n$ be the set of DMUs to be evaluated.

Let I_i ; $i = 1, \dots, m$ be the set of input measures to be used in the evaluation.

Let O_r ; $r = 1, \dots, s$ be the set of output measures to be used in the evaluation.

Let $\bar{O}_j$ represent the observed output vector for DMU_j , where:

$\bar{O}_j = (O_{1j}, \dots, O_{ij}, \dots, O_{sj})$; O_{ij} = the amount of output i used by DMU_j

Let $\bar{I}_j$ represent the observed input vector for DMU_j , where:

$\bar{I}_j = (I_{1j}, I_{rj}, \dots, I_{mj})$; I_{rj} = the amount of input r used by DMU_j

Using these definitions, DEA measures the efficiency of a DMU by evaluating the ratio of weighted outputs to weighted inputs as follows:

$$\text{Efficiency of } DMU_{jo}, h_{jo} = \frac{\sum_{r=1}^s U_r O_{rjo}}{\sum_{i=1}^m V_i I_{ijo}} \quad [\text{Eq 1}]$$

where I_{ijo} = the amount of input i used by DMU_{jo} and O_{rjo} = the amount of output r used by DMU_{jo} .

In the above ratio, I_{ijo} and O_{rjo} are observed values and therefore are constants. The variables U_r (one for each output measure) and V_i (one for each input measure) are called "virtual multipliers," and their values are computed relative to all DMU_j ; $j=1, \dots, jo, \dots, n$ by solving the following mathematical formulation (Eq 2):

$$\begin{aligned} \text{Maximize: } h_{jo} &= \frac{\sum_{r=1}^s U_r O_{rjo}}{\sum_{i=1}^m V_i I_{ijo}} \\ \text{Subject to: } \frac{\sum_{r=1}^s U_r O_{rj}}{\sum_{i=1}^m V_i I_{ij}} &\leq 1 \quad j = 1, \dots, n \\ U_r &\geq \epsilon > 0 \\ V_i &\geq \epsilon > 0 \end{aligned} \quad [\text{Eq 2}]$$

where ϵ is a non-Archimedean constant that constrains U_r and V_i to positive values.

Observe that every DMU in the set $DMU_j, j=1, \dots, n$ is represented by a constraint in the above formulation. Hence, there are s plus m variables and n constraints, with n being the number of units compared.

The above problem has to be formulated for each DMU in the set $DMU_j; j=1, \dots, n$. For each formulation, the set of constraints is the same, whereas the objective function represents the DMU being evaluated.

Since the DMU being evaluated, DMU_{j_0} , is also represented in the constraints with less than or equal to one right-hand side, the value of the objective function is $h_{j_0} = h_{j_0}^* \leq 1$ with $h_{j_0}^* = 1$ if DMU_{j_0} is efficient relative to the other DMUs present in the constraints of Equation 3.

Note that in the above formulation (Eq 2), the optimal U s and V s are associated with the DMU being evaluated; hence, the optimal U s and V s vary for each DMU. Furthermore, they represent the virtual multipliers that provide the highest possible rating for the DMU being evaluated while ensuring that such multipliers are also feasible for the other $n-1$ DMUs. In other words, the formulation ensures that the efficiency rating assigned to a DMU is the best one possible, and that no other set of weights (U s and V s) will assign a higher efficiency rate.

Therefore, when the efficiency of DMU_{j_0} is less than 1, it follows that the j_0^{th} unit is strictly inefficient compared with some other DMUs in the set. The subset of DMUs against which the j_0^{th} unit is compared is called the " j_0^{th} unit reference set"; this subset consists of DMUs for which the constraint is equal to 1 at optimality. In addition, DEA results provide ways to project the inefficient unit into its reference set so that it becomes efficient.

The formulation given in Equation 2 is an extended nonlinear programming formulation of an ordinary fractional programming problem. However, Charnes, et al.⁹ have shown that it can be transformed into an equivalent linear programming problem using the linear fractional programming theory developed by Charnes and Cooper.¹⁰ Appendix A explains the linear programming formulation and its solution.

Ratio Analysis

This approach has been used widely to measure performance in almost every type of organization. The performance measure is determined by evaluating the ratio between a weighted sum of inputs and a weighted sum of outputs. To do this, the weights are predetermined--not calculated as in DEA. This method is well suited for rating among units in which inputs and outputs can be quantified using the same measuring unit (e.g., U.S. dollars).

⁹A. Charnes, W. W. Cooper, and E. Rhodes (1978); A. Charnes, W. W. Cooper, and E. Rhodes (1979).

¹⁰A. Charnes and W. W. Cooper, "Programming With Linear Fractional Functionals," *Naval Research Logistics Quarterly*, Vol 9 (1962).

When inputs and outputs do not share the same measuring units, it can become difficult to find a meaningful performance ratio. Furthermore, the complexity of the problem increases when the relationships between input and output are unknown.

Several relatively simple ratios might be used to model single relationships between different sets of inputs and outputs. However, the separate ratios do not explicitly recognize the joint use of these inputs to produce a combination of outputs. Therefore, a unit may be rated highly efficient based on one of these ratios, while the same unit may be rated inefficient with respect to a different ratio. This situation leads to some ambiguity as to whether a unit is efficient or inefficient, and calls for a method of establishing different priorities (weights) among the separate ratios to generate an overall efficiency ratio.

However, when dealing with a few relevant outputs and the priorities among them are clear, ratio analysis allows management to stress the goals of the organization more effectively than with DEA. Furthermore, ratio analysis provides a way to penalize deviation in the inputs or in the outputs from some preestablished targets. Also, it permits management to change the priorities of the goal from time to time when the needs of the organization call for it.

The weaknesses of ratio analysis are that: (1) when aggregating many inputs and outputs, the index loses meaning, (2) goals that do not show in the index are disregarded by lower level management, and (3) the design of the ratio may need to be rather complex to avoid ambiguity.

Regression Analysis

This approach, although not as widely used as ratio analysis, is very popular among many organizations for estimating relationships between one input and one output (linear regression). Regression analysis usually performs well when used to evaluate systems of one input and a few outputs or vice versa--one output and several inputs. The approach can be viewed as a technique to design a *ratio*, in which case regression analysis simplifies the modeling of unknown relationships among inputs and outputs. On the other hand, regression analysis does not allow managers to emphasize selected goals and targets over the others.

Methodology Selection

Upon analyzing features of the three methods, it became clear that DEA offered several advantages over the other two methods for evaluating the efficiency of RPMA. These advantages are summarized here; for a more extensive comparison, refer to Bowlin, et al.¹¹ and Banker, et al.¹²

¹¹W. F. Bowlin, A. Charnes, W. W. Cooper, and H. D. Sherman, *A Comparative Study of Data Envelopment Analysis and Other Approaches to Efficiency Estimation*, Research Report CCS 451 (Center for Cybernetic Studies, The University of Texas at Austin, September 1983).

¹²R. D. Banker, R. F. Conrad, and R. P. Strauss, "A Comparative Application of Data Envelopment Analysis and Translog Methods: An Illustrative Study of Hospital Production," *Management Science*, Vol 32, No. 1 (January 1986), pp 30-44.

DEA differs from ratio analysis in that it handles multiple inputs and outputs simultaneously without requiring *a priori* specification of weights. Moreover, the production function, i.e., efficient input-output relationship, need not be known to evaluate efficiency with DEA.

DEA differs from regression analysis and related statistical techniques in that it is nonparametric and thus does not require specification of the functional forms and relations to be used. In addition, DEA evaluates the efficiency of a DMU against the most efficient DMUs (i.e., the efficiency "frontier") and not against interior DMUs (average).

There are, however, two limitations to DEA that should be mentioned:

- DEA will not necessarily locate all inefficient units; in other words, DEA measures only relative inefficiency.
- DEA is capable of addressing efficiency only and does not attempt to evaluate the effectiveness of the inputs used and/or the outputs obtained.

DEA Application Process

The DEA method is implemented in three steps: (1) identification of units to be evaluated, (2) identification of input and output measures, and (3) application of DEA and analysis of results.

Step 1: Identification of Units To Be Evaluated

Managers should identify the organizational units for which a DEA efficiency evaluation would be of interest. Generally, this parameter would be a set of units that provide similar services and whose performance management wants to evaluate to improve efficiency. For this study, the units to be evaluated are the RPMA organizations at the installation level.

Step 2: Identification of Input and Output Measures

Managers should identify the relevant inputs and outputs of units to be evaluated as measured over a representative period of time (e.g., for 1 year, quarter, or month). Relevant outputs are those services and other activities for which the unit is responsible in achieving its mission (i.e., goals). Relevant inputs are the resources required to produce the designated outputs.

Field applications of DEA have indicated that this process of output and input identification often is by itself useful to managers, as outputs and inputs sometimes are not explicitly identified or understood. In addition, some of the relevant outputs and inputs may not have been measured or captured in the current information system. The absence of data on relevant outputs and inputs has raised questions about the adequacy of the information system, since this type of input/output data is needed to assess operating performance regardless of the techniques used.

Unless all relevant outputs and inputs are included in the DEA analysis, the DEA results will have to be reviewed for any bias that might result. There are four general guidelines for selecting the input and output measures:

1. The inputs and outputs should be comprehensive. That is, they should fully and properly measure the RPMAs.

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

3. All input and output measures should exist in positive amounts for each installation.

4. 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 to remove these effects which might otherwise influence the results of the performance model. As discussed earlier, DEA not only rates efficiency among installations, but also provides additional information regarding the efficiency of input usage and output achievement. Therefore, the choice of inputs and outputs will determine the value of information provided by the model. In other words, a choice of meaningless input and output measures will yield meaningless managerial information. Hence, to fully exploit the capabilities of DEA, two more guidelines were used for selecting input and output measures in this particular application:

5. The level of detail in defining inputs and outputs should be sufficient for Office of the Chief of Engineers (OCE)-level planning, programming, and budgeting activities.

6. Existing data sources should be used whenever possible, rather than generating new data.

Step 3: Application of DEA and Analysis of Results

At this point, the results of DEA may not be consistent with prior perceptions of the units evaluated. This outcome, in turn, may raise questions about how complete and representative the output and input measures are. In this way, the analysis may result in refinements to the set of inputs and outputs used in the model.

Identification of Input Measures

In general terms, there are two inputs: monetary funds and space used for supporting RPMA. Monetary funds, as a single input term, may not serve the purposes at the OCE level. Two alternative disaggregation schemes are possible:

1. According to the destination of the funds (labor, materials, utilities, and equipment), or

2. According to the current accounting system (J, K, L, and M accounts).

Furthermore, the level of disaggregation can be considered at different details (e.g., type of labor, or J_1 , J_2). Given that the main purpose of performance measurement is planning, programming, and budgeting at the OCE level, the following input list is recommended (Figure 1):

- I_1 : Cost of operation of utilities: J account.
- I_2 : Cost of M&R of real property: K account.
- I_3 : Cost of minor construction: L account.
- I_4 : Cost of engineering support: M account.
- I_5 : Square feet of maintenance and production buildings.

Identification of Output Measures

In general terms, the RPMA resources are used to:

1. Accommodate and provide services to Army personnel.
2. Maintain and repair facilities.

Therefore, outputs can be divided into two major groups: those related to personnel and those related to the physical plant. This division is shown in Figure 2 and is explained below.

Personnel Related Outputs

Quantity as well as quality of the service provided to persons living and working at the installations should be considered. Therefore, the following outputs are proposed:

- O_1 : population served; measures the quantitative aspect of serving people.
- O_2 : (population served)/(number of complaints + 1); measures the quality of service provided to the people.

Note that, as the number of complaints decreases, O_2 increases. Hence, O_2 can be perceived as a surrogate measure for the quality of life at an installation.

Facility (Physical Plant)-Related Outputs

An Army installation does not have an external output. Moreover, internal outputs are difficult to measure, as with any nonprofit organization.

In a resource management system, one way of determining the outputs is to answer this question: for what purposes are the resources used at an installation? The physical facilities use the inputs (resources) listed above in two ways:

1. As space and surface that require maintenance, repair, and upgrading.
2. As space that consumes energy.

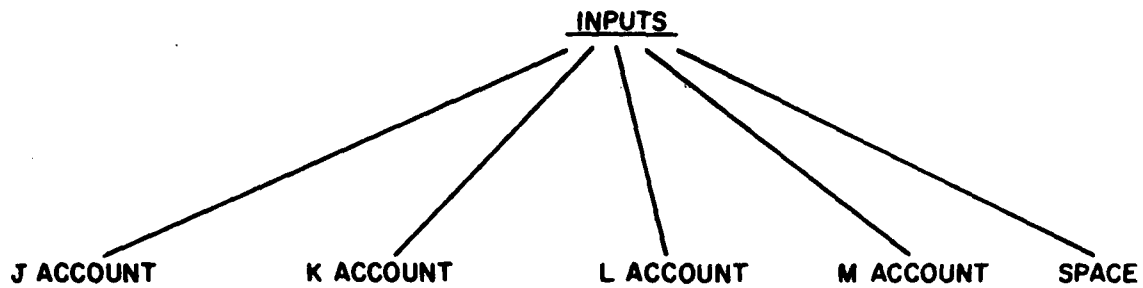


Figure 1. RPMA inputs.

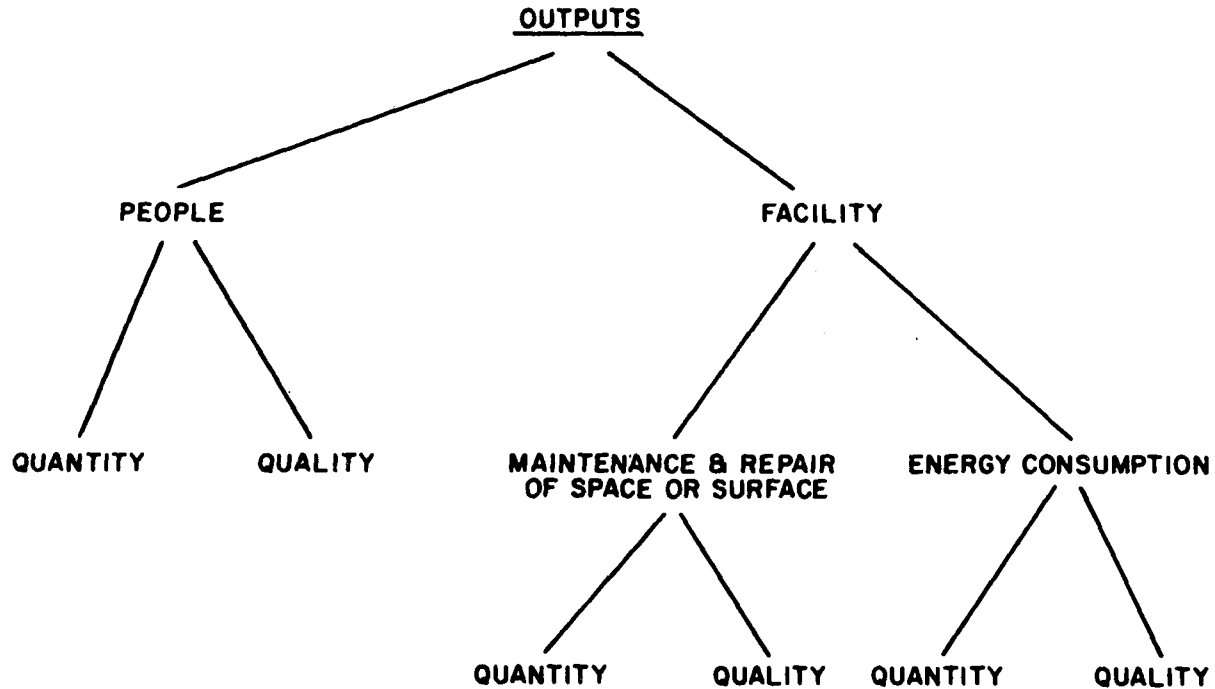


Figure 2. RPMA outputs.

The amount of space and surface maintained, repaired, and upgraded is an output; likewise, the quality of these services is an output, as is the amount of space that consumes energy. However, the quality of energy consumption is not considered here, since it is an output of a different Army program--the Energy Conservation Improvement Program--(ECIP), not of RPMA.

The relationship between the outputs and inputs proposed can vary substantially from one facility to another. The following features of the facilities introduce this variance:

- Function (e.g., warehouse versus hospital),
- Structural characteristics (e.g., paved surface versus building),
- Geographic location.

Therefore, the specific definitions of the outputs should account for these features. In view of these considerations, the following outputs are proposed:

O_3 : Cost of duplicating the existing facility. This duplication cost (DC) can be computed as follows:¹³

$$DC = \text{Acquisition Cost} \times \text{Index (1)} + \text{Historical Renewal Costs} \times \text{Index (2)}.$$

Renewal includes improvements in the existing facility, but excludes maintenance and repair. Indexes 1 and 2 can be obtained from the Building Construction Index published by the *Engineering News Record*.

O_4 : Total of backlog maintenance and repair (BMAR) and deferred maintenance and repair (DMAR). This output is undesirable; therefore, the inverse, $1/(\text{BMAR} + \text{DMAR})$, should be used in the performance formula.

O_5 : Number of square feet of building space conditioned; modified by a building type energy use factor¹⁴ and by heating/cooling degree days.

The output O_3 represents the "quantity" of the physical facilities maintained and repaired; it accounts for the functional, structural, and locational differences between the facilities. Furthermore, O_3 is directly related to the inputs proposed under Identification of Input Measures. Therefore, it is a more useful measure than square feet of the facilities maintained and repaired.

The BMAR and DMAR values in output O_4 are commonly used as surrogate measures of the facilities' physical condition. They also account for the functional, structural, and locational differences among facilities. Therefore, in the absence of a more direct measure for the condition of the facilities, O_4 can be used as a surrogate measure for the quality of maintenance and repair consumption.

¹³O. Coskunoglu, "Appraisal of Army's Facilities," RPMA Information Paper No. 37 (U.S. Army Construction Engineering Research Laboratory, November 1985).

¹⁴Developed by the U.S. Army Construction Engineering Research Laboratory (USACERL); see *Design Criteria*, Architectural and Engineering Instructions (OCE, Engineering Division, 13 March 1987). Available through PAXMAIL.

Finally, O_5 is a measure of output pertaining to energy consumption. Again, it accounts for the functional, structural, and locational differences among facility types.

Data Availability

To avoid having to generate new data, a compromise was reached between desirable data and data on-hand. As a result, the list of inputs and outputs used in this study can be summarized as:

O_1 : Number of people living and working at the installation.

O_2 : Not used.

O_3 : Redefined as millions of square feet of building area.

O_4 : $10^9/\text{BMAR}$; only BMAR is used.

O_5 : (building area in sq ft) x (USA-CERL energy factor for building type and location).

I_1, I_2, I_3, I_4 : Total J, K, L, and M accounts, respectively.

I_5 : Total area of the buildings (sq ft) used for maintenance and repair purposes.

3 DEA COMPUTATIONS AND RESULTS

Computations

A portable personal computer (Compaq 286) with an off-the-shelf linear programming package (Vino) was used to solve the DEA computations. Vino was chosen because it reads data from Lotus 1-2-3, which is the most popular spreadsheet program.

Results were computed for two major commands (MACOMs) over 3 fiscal years as follows:

1. MACOM #1, FY85
2. MACOM #1, FY84
3. MACOM #1, FY83
4. MACOM #2, FY85
5. MACOMs #1 and #2, FY85; joint analysis.

The results for each computation are explained in Appendix B. Table 1 summarizes the results of MACOM #1 for FY85.

Table 1
Summary of Results for MACOM #1 in FY85

Installation	Efficiency Rate (%)	Reference Set*	No. of Times in Reference Set**
1	100.00	1	2
2	100.00	2	0
3	100.00	3	4
4	100.00	4	0
5	95.13	10,15,20,21	-
6	93.74	1,12,14,21	-
7	87.86	3,10,14,20	-
8	99.11	1,14,21	-
9	100.00	9	2
10	100.00	10	7
11	100.00	11	1
12	100.00	12	1
13	69.67	10,15,20,21	-
14	100.00	14	3
15	100.00	15	5
16	75.15	3,9,10,15,20	-
17	55.11	10,15,20	-
18	89.37	3,9,10,15,20	-
19	65.89	3,10,11	-
20	100.00	20	6
21	100.00	21	4

*The set of 100 percent efficient installations against which the inefficient installation is compared. Also see the section Alternative Methodologies and Appendix A.

**The more times an installation is in a reference set, the more indisputable its efficiency. Furthermore, when an installation is rated 100 percent and it is not in any reference set, its efficiency can be questioned.

Installations within MACOM #1 that were rated 100 percent efficient in each of the 3 years examined were numbers 3, 9, 10, 11, 12, 15, and 20. In contrast, the set of installations rated as less than 100 percent efficient in each of those same 3 years included numbers 6, 13, 16, and 18.

To further review and validate the results obtained for MACOM #1 from this analysis, data were gathered for FY85 from 21 installations in MACOM #2 and combined with those of MACOM #1 for a joint analysis. With this approach, more observations could be included in the analysis which should provide better overall efficiency in the evaluations. Even if the two sets of installations are not quite comparable, it should appear in the results as a consistent separation of their efficiency evaluations.

Tables 2 and 3 compare the efficiency rating calculated using FY85 annual data when the MACOMs were analyzed separately (column 2) and when they were analyzed together (column 3).

Table 2
Comparison of Efficiency Ratings—MACOM #1 and
Joint Analysis (FY85)

Installation	MACOM #1	MACOMs #1 & #2
1	100.00	100.00
2	100.00	98.38
3	100.00	98.69
4	100.00	100.00
5	95.13	95.13
6	93.75	88.35
7	87.75	83.33
8	99.12	93.57
9	100.00	100.00
10	100.00	100.00
11	100.00	93.44
12	100.00	100.00
13	69.67	69.67
14	100.00	100.00
15	100.00	100.00
16	75.15	71.07
17	55.11	48.20
18	89.38	80.83
19	65.90	47.28
20	100.00	100.00
21	100.00	100.00

Table 3
Comparison of Efficiency Ratings—MACOM #2
and Joint Analysis (FY85)

Installation	MACOM #2	MACOMs #1 & #2
1	100.00	100.00
2	99.89	97.42
3	91.02	87.48
4	100.00	100.00
5	100.00	100.00
6	100.00	100.00
7	79.17	78.66
8	100.00	100.00
9	100.00	100.00
10	79.04	71.97
11	100.00	100.00
12	100.00	100.00
13	100.00	95.91
14	100.00	100.00
15	100.00	100.00
16	90.48	89.65
17	78.17	70.11
18	100.00	100.00
19	62.60	61.87
20	87.74	85.10
21	100.00	100.00

Validation of Results

The results were submitted to prospective users of RPMA resources for validation at two different levels: (1) OCE and (2) the installations. At the headquarters level, the managers agreed that, in the case of MACOM #1, the installations identified by DEA as inefficient were likely to be relatively inefficient, although values of the slacks* associated with the inputs and outputs in some of the cases were viewed as out of range. In addition, the managers thought that the efficiency rate assigned to installation #17 (55.11 percent) was too low and might be due to the geographic location of the installation (Alaska).

Regarding the results for MACOM #2, managers at the headquarters level strongly agreed that installation #19, which was rated at 62.6 percent in FY85, is one of the most efficient installations. In both cases (i.e., MACOM #1 and MACOM #2), the managers agreed that not all of the installations rated as 100 percent efficient could be perceived as equally efficient. In other words, the managers held that the model should be able to differentiate better among efficient installations.

*A geometrical interpretation of the slacks variables, along with their suggested usage by managers, is given in Appendix A.

At the installation level, as might be expected, managers were less receptive of the model's capabilities. From their viewpoint, the model suggests budget reductions since the level of outputs is not under their control. However, the installation managers offered valuable suggestions toward improving the model.

Analysis of the user feedback from both levels reveals that the model should produce better results with the following adjustments:

1. The replacement value, as defined earlier, should be used as O_3 , instead of square feet of building, to help account for the variety of building types.
2. Instead of using the inverse of BMAR as an output, BMAR should be considered an input.
3. I_1 , I_2 , I_3 , and I_4 should be aggregated into only one input, $I_1 = \$(J+K+L+M)$.

The advantage of the first recommendation was explained in Chapter 2. To understand how the second recommendation will benefit the model, consider installation #19 and its reference set for the analysis of MACOM #2 in FY85. Table 4 shows the results of evaluating those installations under 10 different criteria. Clearly, installation #19 is less efficient for 9 of the 10 criteria. Only under the criterion BMAR/Ksq ft is installation #19 the most efficient. Note also that the seven criteria under which installation #19 is inefficient are all included in the performance model, whereas BMAR/Ksq ft is not. For this criterion to be included in the performance model, BMAR has to be considered an input. As such, the model would rate installation #19 as 100 percent efficient since no other installation is more efficient under this criterion.

Finally, the third recommendation will improve the quality of the results because the number of 100 percent efficient installations will decrease as aggregation reduces the number of degrees of freedom for the model. In addition, aggregation of the four accounts into only one input (I_1) will avoid the difficulties in explaining the value of the slacks associated with each account.

Table 4
Comparison of Installation #19 With Its Reference Set

Installation	Criteria		
	\$K/Ksq ft	\$L/Ksq ft	\$M/Ksq ft
5	\$576.85	\$94.6	\$248.10
11	\$2,432.00	\$318.00	\$953.33
12	\$1,314.19	\$200.27	\$827.72
18	\$1,074.79	\$67.55	\$424.31
19	\$2,075.79	\$445.05	\$1,478.54
	\$(J+K+L+M)/Pop.	\$(J+K+L+M)/Ksq ft	\$BMAR/Ksq ft
5	\$3,061.84	\$1,066.90	\$2,388.61
11	\$268.13	\$4,048.67	\$800.73
12	\$1,577.86	\$3,659.35	\$679.21
18	\$2,204.70	\$2,010.55	\$1,355.82
19	\$2,108.26	\$5,152.20	\$201.19
	\$M/Pop.	\$J/Pop.	
5	\$712.01	\$422.85	
11	\$56.07	\$20.31	
12	\$388.77	\$477.75	
18	\$465.28	\$486.77	
19	\$605.01	\$471.73	
	O_3/I_5	\$J/Btu	
5	5.3432	\$0.0023	
11	13.0435	\$0.0058	
12	36.1590	\$0.0145	
18	9.2885	\$0.0081	
19	9.2667	\$0.0179	

O_3 = Replacement value

I_5 = Sq ft of shops

4 IMPLICATIONS FOR MANAGEMENT

DEA was next evaluated for use in the following managerial tasks: audit and review of operations, planning, and budgeting, and resources determination and prediction. Results from the previous analysis were applied to this evaluation to study the model from a practical standpoint.

DEA as a Management Audit Tool

The most straightforward use of the DEA results is for auditing to distinguish between relatively efficient and inefficient installations. By doing so, managers can concentrate on those inefficient installations most likely to profit from further analysis.¹⁵ In addition, since the efficient installations are in the reference set of inefficient installations, managers can make comparisons to better understand the source of inefficiency. In comparing an inefficient installation with its reference set, the values of the slacks for inputs and outputs show where the comparison is weaker and by how much. Therefore, by analyzing these values, managers should be able to understand the particulars of the inefficient installation and whether those properties are admissible.

Efficient installations also have to be analyzed since DEA results measure only relative efficiency. The values of the "virtual multipliers" (U_0, V_1), provide information about the input and output mixture that rates these installations as 100 percent efficient. Thus, managers have to decide if that mixture is the appropriate one.

Planning and Budgeting With DEA

For managers at installations rated less than 100 percent efficient, there is an immediate way to profit from the performance model results: by planning in such a way as to become more like the units in their reference set (hence, more efficient).

Another possible use of the performance model is in the budgeting process. At the MACOM level, the performance model can be used to simulate the budgets submitted by each installation as if they were real data. For the installations whose budgets are rated as less than 100 percent efficient, MACOM management can "negotiate" an alternative budget based on the budgets of the other installations in their reference set. For the installations whose budgets are rated as 100 percent efficient, MACOM managers should ensure that (1) the budget is appropriate and (2) the installations follow it as closely as possible.

As an example of using the performance model in budgeting, suppose that the requested budget of each installation in MACOM #2 is that shown in Table 5. Table 6

¹⁵H. D. Sherman, "Data Envelopment Analysis as a New Managerial Audit Methodology--Test and Evaluation," *Auditing: A Journal of Practice and Theory* Vol 4, No. 1 (Fall 1984), pp 35-53.

Table 5

Example Requested Budgets for MACOM #2 Installations

Instal- lation	Population Served	Replacement		Energy Budget	\$(J+K+L+M)	BMAR	Msq ft
		Value D.C.					
1	8.904	1.750433	0.693742	54.135	15.19642	0.596	
2	46.049	2.893076	1.525868	74.879	14.95708	1.426	
3	42.212	2.257709	1.310005	56.891	17.57870	1.575	
4	2.265	1.979978	0.099975	6.37	1.141	0.025	
5	1.698	0.358625	0.316338	5.199	11.6397	0.912	
6	46.233	1.430648	0.716229	61.64	5.3088	0.302	
7	15.765	1.62362	0.495335	32.464	11.991	0.449	
8	23.874	1.073542	0.615065	35.712	5.517	0.366	
9	2.784	0.965905	0.254581	13.458	0.89	0.157	
10	12.656	0.695382	0.378755	29.659	3.809	0.362	
11	25.503	0.091396	0.08973	6.073	1.2011	0.115	
12	25.174	1.251925	0.827437	39.721	8.031	0.327	
13	40.012	2.61558	1.346354	60.181	28.54462	1.392	
14	15.499	0.753619	0.46455	23.434	9.509921	0.257	
15	15.822	0.756672	0.473115	40.136	26.898	0.207	
16	19.015	1.08138	0.36737	29.833	1.321	0.242	
17	3.807	0.493099	0.132355	12.258	2.29	0.096	
18	3.024	1.549681	0.18198	6.667	4.495892	0.357	
19	19.702	0.959136	0.519221	41.537	1.622	0.87	
20	35.387	2.815029	0.95207	52.144	5.288	1.121	
21	47.023	2.796394	0.842773	36.66	2.281	0.651	

lists the results of applying the performance model to these requested budgets. The results in terms of installation #1 can be interpreted as follows:

- The budget requested by Installation #1 is only 60.07 percent efficient compared with the budgets requested by the rest of the installations in MACOM #2.
- Installations that had the most influence on installation #1's efficiency rate are 4, 12, and 21 (reference set).

To increase the efficiency of installation #1's budget, management should try to decrease the amount of inputs budgeted. As an example, there are three possible ways of making this installation's requested budget 100 percent efficient:

1. Reduce (J+K+L+M) by 47 percent, or
2. Reduce BMAR by 88 percent, or
3. Reduce (J+K+L+M) and BMAR by 46 percent each.

Table 6

Example Results of Applying Performance Model to Requested Budgets

O3 = Reple Value; I1 = J + K + L + M; I2 = BMR																
Unit	u1	u2	u3	u4	u5	v1	v2	v3	v4	v5	Efficiency					
Evaluated	S01	S02	S03	S04	S05	S11	S12	S13	S14	S15						
1	0.0001 8.904 17.87525	0 0 0	0 1.161984 0 1.750433 0	0.0001 0 0	83.65928 0 0.693742	1.578363 54.135 0	0.0001 15.19642 3.967739	0.0001 0 0	0.0001 0 0	24.41909 0.596 0	60.07					
REF. SET LAMBDA			21 0.271032		12 0.543307		4 0.157749									
2	0.0001 46.049 16.87386	0 0 0	0 2.893076 0 0.783687	0.0001 0 0	57.17797 0 1.525868	1.075741 74.879 0	0.027004 14.95708 0	0.0001 0 0	0.0001 0 0	13.35599 1.426 0	87.25					
REF. SET LAMBDA			21 0.933828		12 0.725492		5 0.437499									
3	0.0001 42.212 6.059178	0 0 0	0 2.257709 0 0.707511	0.0001 0 0	69.13114 0 1.310005	1.300607 56.891 0	0.302707 17.57870 0	0.0001 0 0	0.0001 0 0	16.14742 1.575 0	90.57					
REF. SET LAMBDA			21 0.714590		12 0.524291		5 0.866000									
4	0.0001 2.265 0	0 0 0	0 10.89597 0 1.975978 0	0.0001 0 0	784.4559 0 0.099975	14.80019 6037 0	0.0001 1.141 0	0.0001 0 0	0.0001 0 0	228.9046 0.025 0	100.00					
REF. SET LAMBDA			0		0		4 1									
5	0.0001 1.698 0	0 0 0	0 5.268001 0 0.358625 0	0.0001 0 0	310.1448 0 0.316338	6.213773 5.199 0	0.0001 11.6397 0	0.0001 0 0	0.0001 0 0	74.22525 0.912 0	100.00					
REF. SET LAMBDA			5 1		5 1		0									
6	0.542710 46.233 0	0 0 0	0 0.208507 0 1.430648 0	0.0001 0 0	104.1713 0 0.716229	0.656740 61.64 0	4.199604 5.3088 0	0.0001 0 0	0.0001 0 0	123.2570 0.302 0	100.00					
REF. SET LAMBDA			0		0		6 1									
7	0.0001 15.765 7.206334	0 0 0	0 1.86048 0 1.62362 0	0.0001 0 0	134.4921 0 0.495335	2.537420 32.464 0	0.0001 11.991 5.731581	0.0001 0 0	0.0001 0 0	39.5162 0.449 0	69.65					
REF. SET LAMBDA			21 0.375535		12 0.196130		4 0.165625									

Table 6 (Cont'd)

TRADOC FY85 O3 = Reple Value; I1 = J + K + L + M; I2 = BMAR											
Unit Evaluated	u1 O1 S01	u2 O2 S02	u3 O3 S03	u4 O4 S04	u5 O5 S05	v1 I1 S11	v2 I2 S12	v3 I3 S13	v4 I4 S14	v5 I5 S15	Efficiency
8	0.257102 23.874 0	0 0 0	0 0 0	0.0001 1.073542 0.199341	127.3092 0.615065 0	0.498094 35.712 0	5.988697 5.517 0	0.0001 0 0	0.0001 0 0	134.3508 0.366 0	84.44
REF. SET LAMBDA			21 0.196586		12 0.487196		9 0.045502		6 0.048422		
9	0.776121 2.784 0	0 0 0	0 0 0	0.0001 0.965905 0	384.3145 0.254581 0	1.503616 13.458 0	18.07839 0.89 0	0.0001 0 0	0.0001 0 0	405.5704 0.157 0	100.00
REF. SET					9 1						
10	0.0001 12.656 1.349792	0 0 0	0 0 0	0.0001 0.695382 0.276506	158.6812 0.378755 0	1.396629 29.659 0	4.991440 3.809 0	0.0001 0 0	0.0001 0 0	109.2955 0.362 0	60.10
REF. SET LAMBDA			21 0.171320		12 0.210027		9 0.237983				
11	2.333557 25.503 0	0 0 0	0 0 0	0.0001 0.091396 0	451.2126 0.08973 0	2.825315 6.073 0	18.26630 1.2011 0	0.0001 0 0	0.0001 0 0	529.5844 0.115 0	100.00
REF. SET LAMBDA					11 1						
12	0.0001 25.174 0	0 0 0	0 0 0	0.0001 1.251925 0	120.8519 0.827437 0	2.273590 39.721 0	0.057384 8.031 0	0.0001 0 0	0.0001 0 0	28.22579 0.327 0	100.00
REF. SET LAMBDA					12 1						
13	0.0001 40.012 4.276235	0 0 0	0 0 0	0.0001 0.192206 2.61558	67.83176 1.346354 0	1.285122 60.181 0	0.0001 28.54462 93148678	0.0001 0 0	0.0001 0 0	16.27669 1.392 0	91.83
REF. SET LAMBDA			21 0.441035		12 0.883524		5 0.770062				
14	0.036164 15.499 0	0 0 0	0 0 0	0.0001 0.756619 0.062790	197.5519 0.46455 0	3.749458 23.434 0	0.0001 9.509921 4.413071	0.0001 0 0	0.0001 0 0	47.21495 0.257 0	92.33
REF. SET LAMBDA			21 0.077546		12 0.468334		5 0.036918				

Table 6 (Cont'd)

TRADOC FY85 O3 = Reple Value; I1 = J + K + L + M; I2 = BMAR											
Unit Evaluated	u1 01 S01	u2 02 S02	u3 03 S03	u4 04 S04	u5 05 S05	v1 11 S11	v2 12 S12	v3 13 S13	v4 14 S14	v5 15 S15	Efficiency
15	0.815016 15.822 0	0 0 0	0 0 0	0.0001 0.756672 0	0.0001 0.473115 0	1.454481 40.136 0	0.0001 26.898 14.02997	0.0001 0 0	0.0001 0 0	201.0639 0.207 0	71.79
REF. SET LAMBDA											
16	0.553984 19.015 0	0 0 0	0 0 0	0.0001 1.08138 0	0.0001 0.36737 0	0.329187 29.833 0	18.36124 1.321 0	0.0001 0 0	0.0001 0 0	272.4137 0.242 0	100.00
REF. SET LAMBDA											
17	0.787592 3.807 0	0 0 0	0 0 0	0.0001 0.493099 0	0.0001 0.132355 0	1.523901 12.258 0	18.28649 2.29 0	0.0001 0 0	0.0001 0 0	410.8745 0.096 0	54.52
REF. SET LAMBDA											
18	1.647673 3.024 0	0 0 0	0 0 0	0.0001 1.549681 0	0.0001 0.18198 0	11.36288 6.667 0	5.049233 4.495892 0	0.0001 0 0	0.0001 0 0	4.321458 0.357 0	100.00
REF. SET LAMBDA											
19	0.0001 19.702 9.268231	0 0 0	0 0 0	0.0001 0.959136 0.763684	0.0001 0.519221 0	61.64966 41.537 13.40173	0.0001 1.622 0	0.0001 0 0	0.0001 0 0	0.0001 0.87 0.352691	86.64
REF. SET LAMBDA											
20	0.0001 35.387 15.51216	0 0 0	0 0 0	0.0001 2.815029 0.247765	0.0001 0.95207 0	1.774876 52.144 0	1.408985 50288 0	0.0001 0 0	0.0001 0 0	0.0001 1.121 0.352691	77.13
REF. SET LAMBDA											
21	0.0001 47.023 0	0 0 0	0 0 0	0.0004 2.796394 0	0.0004 0.842773 0	2.599370 36.66 0	2.063581 2.281 0	0.0001 0 0	0.0001 0 0	0.0001 0.651 0	100.00
REF. SET LAMBDA											

Resource Determination With DEA

One of the most attractive features of DEA is its ability to identify the efficiency frontier, which allows managers to know if a "production possibility"* will be relatively efficient compared with the rest of the DMU. This property of DEA can be exploited further by managers when trying to predict the level of resources (inputs) needed to reach a specific level of outputs in the future.

The above problem can be approached using DEA as follows:

Let $\bar{O}_d = (O_{1d}, \dots, O_{sd})$ be the known level of outputs that installation d wants to produce next year.

Let $\bar{I}_d = (I_{1d}, \dots, I_{md})$ be the unknown input vector necessary for installation d to produce $\bar{O}_d$ next year.

Let $\bar{I}_g = (I_{1g}, \dots, I_{mg})$ be an estimated input vector for installation d . In other words, $\bar{I}_g$ is an input vector with which management "feels" confident to produce $\bar{O}_d$ next year in installation d . Then:

Let DMU_D be a dummy DMU with its input-output vector represented by $(\bar{O}_d, \bar{I}_g)$.

Now DMU_D can be added to the set of installations, DMU_j ; $j=1, \dots, n$, and the efficiency of DMU_D can be evaluated with respect to the extended set of installations, DMU_j ; $j=1, \dots, n, D$.

Suppose that DMU_D is rated as less than 100 percent efficient. Then, projecting $(\bar{O}_d, \bar{I}_g)$ into the efficiency frontier¹⁶ will make DMU_D 100 percent efficient. In other words, the input vector $\bar{I}_d = \theta \cdot \bar{I}_g - \bar{S}_i$ will be enough to produce $\bar{O}_d$ next year if DMU_D operates efficiently.

Observe that the production possibility represented by $(\bar{O}_d, \bar{I}_d)$ is the efficiency frontier point "closest" to $(\bar{O}_d, \bar{I}_g)$. Here, "close" means similar in production technology or input-mix. Thus, the problem being addressed has several different solutions, each depending on the input-mix (recipe) to be used to produce $\bar{O}_d$.

Since the value I_d , as determined above, depends on the value $\bar{I}_g$ seeded, the process can be repeated several times to explore the various alternatives in input-mix for DMU_D to produce $\bar{O}_d$. Managers will be responsible for deciding which $\bar{I}_d$ (input-mix) DMU_D should use the following year to produce $\bar{O}_d$.

*Feasible set of inputs and output values.

¹⁶A. Charnes and W. W. Cooper, "The Non-Archimedean CCR ratio for Efficiency Analysis: A Rejoinder to Boyd and Fare," *European Journal of Operational Research*, Vol 15 (1984), pp 333-334.

To continue the example, suppose now that the data in Table 5 are the real data corresponding to the installations in MACOM #2 for FY86. Then, Table 6 now contains the results of evaluating the installation's performance during FY86. In other words, now the interpretation of results regarding installation #1 is:

- The efficiency rate assigned to installation #1 in FY86 is 60.07 percent.
- Installations with the most influence on installation #1's efficiency rate are 4, 12, and 21.

Suppose also that the managers want to know how much $(J+K+L+M) - I_1$ will cost to operate installation #1 in 1990 assuming that: (1) O_1 , O_3 , O_5 , and I_5 will remain at the same level as that in 1986, (2) O_2 will increase 10 percent with respect to the 1986 level, and (3) I_2 (BMAR) will not exceed \$5 million. To solve this problem, the managers proceed as explained earlier:

1. Create a dummy DMU for installation #1 - with: $O_1 = 8.904$, $O_3 = 1.925476$, $O_5 = 0.693742$, $I_1 = \text{dummy} = 54.135$, $I_2 = 5$ and $I_5 = 0.596$.

2. Add the above dummy DMU to the set of installations in Table 5 and apply DEA to the new set. The efficiency rate of the dummy DMU is then 66.43 percent (Table 7).

3. Decrease the value of I_1 in dummy DMU until its efficiency rate equals 100 percent (Table 7). The value of I_1 that makes the dummy DMU's efficiency rate 100 percent is $I_1 = 29.31139$. This figure will be the cost to operate installation #1 efficiently in 1990 assuming 1986 prices do not change.

One more issue should be addressed under this discussion--the reallocation of resources among efficient DMUs. Here, the question is "Which DMU will have the greatest potential to use additional resources," or, "Which DMUs are underfunded, and by how much." The answer to these questions requires a deeper analysis of the efficiency frontier.

At first glance, the underfunded installations, if any, must be among the units rated 100 percent efficient by DEA. As a general rule of thumb, resources should be reallocated from inefficient units to relatively efficient ones. However, the efficiency frontier must be studied closely since DEA does not differentiate among relatively efficient installations. One way to further differentiate among relatively efficient installations using DEA is by seeding a small number of "utopian" installations into the set of DMUs (utopian in the context of efficiency). By doing so, only the fictitious installations will be rated relatively efficient, and the rest of the DMUs ($DMU = j; j = 1, \dots, n$) will be evaluated against them.

The main drawback to this approach is that the utopian installations do not belong to the production possibility set; hence, the new efficiency rate of the real installation may be unrealistic. However, this problem can be alleviated by selecting the utopian DMU to be as realistic as possible.

Table 7
Resource Determination With DEA

	U_1	U_3	U_5	V_1	V_2	V_5
	O_1	O_3	O_5	I_1	I_2	I_5
	S_1^-	S_3^-	S_5^-	S_1^+	S_2^+	S_5^+
	0.0001	0.0001	95.76124	0.842747	3.012537	65.96505
Dummy #1	8.904	1.925476	0.693742	54.135	5	0
	1.532	0.376766	0	0	0	0
REF.SET	21	12	9			
LAMBDA	0.000907	0.174583	2.154602			
Decreasing I_2						
	0.0001	0.351734	123.5046	2.339895	0.0001	29.63733
Dummy #1	8.904	1.925476	0.693767	35.18775	5	0.596
	24.07107	0	0	0	0.406969	0
REF.SET	21	12	5			
LAMBDA	0.581312	0.219265	0.07808			
Further Decreasing I_2						
	0.005986	0.323894	143.1764	2.713590	0.0001	34.32949
Dummy #2	8.904	1.925476	0.693742	29.31139	5	0.596
	0	0	0	0	0	0
REF.SET	Dummy #1					
LAMBDA	1					

O_1 = Population served
 O_3 = Replacement value
 O_5 = Btu/yr.
 I_1 = \$ (J+K+L+M)
 I_2 = \$B/MAR
 I_5 = Sq ft of shops

5 CONCLUSIONS AND RECOMMENDATIONS

Three modeling techniques have been studied for potential in providing an output-oriented performance index to evaluate the efficiency of RPMA programs at U.S. Army installations. The methodology chosen for further evaluation was DEA because of its ability to handle multiple inputs and outputs simultaneously and without requiring *a priori* specification of weight or functional relationships among these parameters. These features make DEA suitable for application to not-for-profit organizations such as Army installations.

The DEA process was analyzed, and it was concluded that:

1. DMUs identified as inefficient by DEA were strictly inefficient compared with other existing DMUs.
2. DEA can associate a narrow set of relatively efficient units (the reference set) with the inefficient unit under evaluation, which helps managers identify the source of inefficiency.
3. DEA identifies an efficiency frontier consisting of relatively efficient DMUs, which means this frontier is a practically attainable production possibility set.
4. DEA does not necessarily locate all inefficient units; thus, some units rated as relatively efficient may be strictly inefficient.
5. DEA identifies alternative paths for making inefficient DMUs become relatively efficient.
6. The choice of input and output measures used is critical to the inherent value of the results.

Input and output measures were selected to fully exploit the capabilities of DEA for the user. A compromise was reached between the desired data and that which was available. Numerical results of the analysis were presented to a panel of managers for validation. These managers suggested that the model should further differentiate between the installations rated as 100 percent efficient.

This study has shown that DEA is a theoretically sound technique capable of evaluating the performance of RPMA at Army installations. Optimal use of DEA will be possible once the method is "fine-tuned" by testing alternative input and output measures until its capabilities are fully exploited.

Based on these findings, it is recommended that a prototype of the performance model be implemented within OORMS to allow prospective users to test alternative input and output measures.

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APPENDIX A:

DATA ENVELOPMENT ANALYSIS—CONCEPT AND DERIVATION

This appendix describes the fundamentals of DEA. The first section focuses on mathematical formulation of the model, with the second part summarizing the model's strengths and weaknesses.

Linear Programming Formulation

The formulation in the text designated as Equation 2 is an extended nonlinear programming formulation of an ordinary fractional programming problem. However, studies¹⁷ have shown that it can be transformed into an equivalent linear programming problem using the theory of linear fractional programming developed by Charnes and Cooper as follows:¹⁸

$$\text{Maximize:} \quad h_{jo} = \sum_{r=1}^s U_r O_{rjo}$$

$$\text{Subject to:} \quad \sum_{i=1}^m V_i I_{ijo} = 1$$

$$\sum_{r=1}^s U_r O_{rj} - \sum_{i=1}^m V_i I_{ij} \leq 0; \quad j = 1, \dots, jo, \dots, n$$

$$U_r \geq \epsilon > 0 \quad r = 1, \dots, s$$

$$V_i \geq \epsilon > 0 \quad i = 1, \dots, m \quad [\text{Eq A1}]$$

The Equation A1 formulation constrains the weighted sum of the inputs to be equal to 1 and maximizes the outputs that can be obtained. The other constraints in Equation A1 transform the less-than-unity constraints of Equation 2 (Chapter 2) to a form in which the weighted output cannot exceed the weighted input for any DMU. Equation A1 is also called the "unit input" formulation.

¹⁷A. Charnes, W. W. Cooper, and E. Rhodes (1978); A. Charnes, W. W. Cooper, and E. Rhodes (1979).

¹⁸A. Charnes and W. W. Cooper.

The dual linear program of Equation A1 can be written as follows:

$$\begin{aligned}
 \text{Minimize:} \quad & [\theta - \epsilon (\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+)] \\
 \text{Subject to:} \quad & \sum_{j=1}^n \lambda_j O_{rj} - s_r^+ = O_{rjo} \quad r = 1, \dots, s \\
 & - \sum_{j=1}^n \lambda_j I_{ij} - s_i^- + \theta I_{ijo} = 0 \quad i = 1, \dots, m \\
 & \lambda_j, s_r^+, s_i^- \geq 0 \text{ and } \theta \text{ unrestricted in sign}
 \end{aligned}
 \tag{Eq A2}$$

Where:

- θ = An intensity value or multiplier of the observed input vector x_{jo}
- s_r^- = output slack for output "r"
- s_i^+ = input slack for input "i"
- ϵ = A small non-Archimedean constant.

In Equation A2, the variable θ is considered an "intensity" variable that reduces the value of all inputs to the smallest number permitted by the constraints. The variables λ_j ; $j=1, \dots, n$ are the dual variables associated with the constraints representing DMU_j; $j=1, \dots, n$ in Equation A1. For λ_j to be positive (>0), its corresponding DMU_j constraint in Equation A1 has to be equal to 0, which means that DMU_j is in the reference set of the DMU being evaluated, DMU_{jo}.

The name "data envelopment analysis" comes from the facts that, in Equation A2: (1) the linear combination of output vectors represented by the $\lambda_j O_{rj}$ envelops the observed output vector of the DMU being evaluated from above, and (2) the same linear combination, but with the input vectors, envelops the "minimum" vector of observed inputs from below.

The presence of the non-Archimedean constant in the objective function of Equation A2 is equivalent to a double optimization since ϵ is so small that $\epsilon (\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+)$ does not affect the value of θ . In other words, two optimizations occur at the same time: (1) minimize θ and (2) maximize $(\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+)$.

By virtue of the duality theory of linear programming:

$$\text{Maximize } h_{jo} = \sum_{r=1}^s U_r O_{rjo} = \text{Minimize } [\theta - \epsilon (\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+)]
 \tag{Eq A3}$$

Also note that s_r^+ and s_i^- are the dual variables associated with the constraints $U_r \geq \epsilon$, $V_i \geq \epsilon$ in Equation A2, respectively; therefore, at optimality, the only time the corresponding $U_r = \epsilon$ and/or $V_i = \epsilon$ is when $s_i^- \geq 0$ and/or $s_r^+ \geq 0$.

From the above discussion, it can be shown that a DMU is considered efficient if and only if $\theta^* = 1$, and all S_i^{-*} and S_r^{+*} are equal to zero in Equation A3. This reasoning is called the non-Archimedean efficiency theorem for which formal proof can be found elsewhere.¹⁹

Efficiency Adjustments and Projections

In addition to measuring the relative efficiency of a DMU, DEA provides additional information for the inefficient DMU to become efficient. Let θ^* , λ_j^* , S_i^{-*} , S_r^{+*} be an optimal solution of Equation A2 for DMU_{j0}. Then, Equation A2 can be rewritten as:

$$\theta^* I_{i0} - S_i^{-*} = \sum_{j=1}^n I_{ij} \lambda_j^* \quad i=1, \dots, m \quad [\text{Eq A4}]$$

$$O_{r0} + S_r^{+*} = \sum_{j=1}^m O_{rj} \lambda_j^* \quad r=1, \dots, s$$

If the left-hand side of Equation A4 is replaced with Equation A5:

$$I'_{i0} = \theta^* I_{i0} - S_i^{-*} \quad i=1, \dots, m$$

$$O'_{r0} = O_{r0} + S_r^{+*} \quad r=1, \dots, s$$

then a DMU with its production vector represented by the new values $(\bar{O}'_j, \bar{I}'_j)$ will be rated efficient, relative to the same set DMU_j; $j=1, \dots, n$, since $\theta'^* = 1$, $S'^{+*}_r = 0$ and $e'^*_i = 0$ will be an optimal solution of Equation A2. (Formal proof of this derivation is shown elsewhere.²⁰) Thus, the transformation (Eq A5) projects DMU_{j0} into its reference set, and the values S_i^{-*} , S_r^{+*} and θ^* represent the adjustments needed for DMU_{j0} to become efficient.

To better explain the Charnes, et al. formulation, it can be applied to a simple problem with a simple geometrical solution. Consider a set of four DMUs each with two inputs, I_1 and I_2 , and one output, O_1 . To simplify, assume that O_1 is equal to 1 for the four DMU's. Figure A1 represents the four DMUs by their coordinate values for I_1 and I_2 . For example, P_1 has $I_{11} = 2$, $I_{21} = 2$, $O_{11} = 1$; P_2 has $I_{12} = 3$, $I_{22} = 2$, $O_{12} = 1$; and so on.

¹⁹A. Charnes and W. W. Cooper, "Preface to Topics in Data Envelopment Analysis," *Annals of Operations Research*, Vol 2 (1985), pp 59-94.

²⁰A. Charnes and W. W. Cooper (1985).

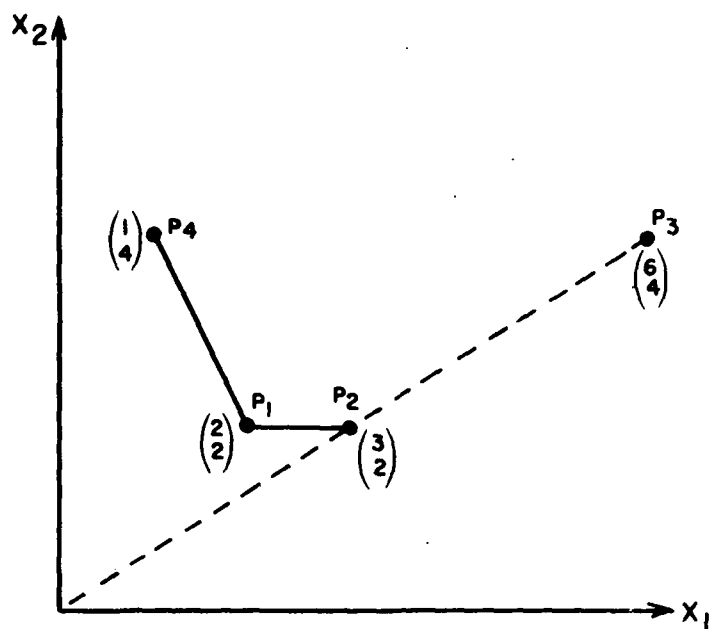


Figure A1. Example problem with a simple geometrical solution.

To evaluate P_2 , its coordinates are inserted into Equation A3 to obtain:

Minimize: $\theta - \epsilon S_1^- - \epsilon S_2^- - \epsilon S_1^+$

Subject to:

$$3\theta = 2\lambda_1 + 3\lambda_2 + 1\lambda_3 + 6\lambda_4 + S_1^-$$

$$2\theta = 2\lambda_1 + 2\lambda_2 + 4\lambda_3 + 4\lambda_4 + S_2^-$$

$$1 + S_1^+ = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4$$

for which the solution is:

$$\theta^* = 1, S_1^{-*} = 1, \lambda_1^* = 1 \text{ and}$$

$$S_2^{-*} = S_1^{+*} = \lambda_2^* = \lambda_3^* = \lambda_4^* = 0$$

Although $\theta^* = 1$, DMU P_2 is not fully efficient since S_1^{+*} equals 1. The fact that $\lambda_1 = 1$ means that P_2 is being evaluated against P_1 . Moreover, the value of $S_1^{+*} = 1$ means that, when comparing P_2 with P_1 , P_2 uses one more unit of input 1 than does P_1 to produce the same amount of output. In other words, P_1 produces the same amount of output as P_2 , but with one unit less of input, I_1 , and the same amount of I_2 .

For P_2 to be as efficient as P_1 , it has to reduce I_1 by one unit, which produces the same result as if the transformation (Eq A5) had been applied.

The solution of Equation A3 for P_1 is:

$$\theta^* = 1, S_1^{-*} = S_2^{-*} = S_1^{+*} = 0, \lambda_1^* = 1$$

$$\lambda_2^* = \lambda_3^* = \lambda_4^* = 0$$

which means that P_1 is fully efficient, and also that it is evaluated against itself, ($\lambda_1^* = 1$). Thus, no other DMU is more efficient than P_1 .

In the same way, the result of evaluating P_4 is:

$$\theta^* = 1, S_1^{-*} = S_2^{-*} = S_1^{+*} = 0, \lambda_4^* = 1$$

$$\lambda_2^* = \lambda_3^* = \lambda_1^* = 0$$

which means that P_4 is fully efficient, and no other DMU is more efficient than P_4 , ($\lambda_4^* = 1$).

Referring to Figure A1, the solid line connecting P_4 , P_1 , and P_2 is called the "efficiency frontier" and is made up of convex combinations of DMU with the efficiency rate equal to 1, ($\theta^* = 1$). Note that, although P_2 is a frontier point, it is not DEA efficient because ($S_1^* = 1$). A point such as P_2 is called, in DEA jargon, a "corner point" of the efficiency frontier.

Similarly, the result of evaluating P_3 is:

$$\theta^* = 1/2, S_1^{-*} = 1, \lambda_1^* = 1 \text{ and}$$

$$S_2^{-*} = S_1^{+*} = \lambda_2^* = \lambda_3^* = \lambda_4^* = 0$$

which is to say that P_3 is being evaluated against $P = 1$ ($\lambda_1^* = 1$). The value of $\theta^* = 1/2$ represents the ratio of the Euclidean distance from the origin to P_3 . For P_3 to be as efficient as P_1 , it has to reduce its inputs in accordance with Equation A5 as follows:

$$I_{13} = 6 \times 1/2 - 1 = 2$$

$$I_{23} = 4 \times 1/2 = 2$$

The reduction in inputs represented by $\theta^* I_{10}$ bring P_3 to P_2 . This reduction is a contraction in which the mix of inputs (technology) does not change. The reduction in input represented by S_1^* , on the contrary, requires a change in input mix, which brings P_3 from P_2 to P_1 , and it does not increase the efficiency rate, θ^* . Consequently, the contraction represented by $\theta^* I_{10}$ projects the inefficient unit into the efficiency frontier, whereas the reduction represented by S_1^* brings the inefficient unit into the so-called DEA efficiency region.

DEA Properties and Interpretations

Properties and interpretations of the DEA model above are summarized below.

Relative Efficiency

One hundred percent relative efficiency is attained by any DMU only when comparison with other relevant DMUs provides no evidence of inefficiency in the use of any input or output.

Weights

DEA does not require *a priori* determination of weight to compute efficiency.

Efficiency Rating (θ^)*

The efficiency rating assigned by DEA is the best possible value attainable by the DMU being evaluated. The efficiency rating does not depend on the units in which the inputs and outputs are measured.

Reference Set

DEA also provides the relatively inefficient units with a set of relatively efficient units that have a "similar" input/output mix.

Efficiency Frontier

The efficiency frontier consists of a piecewise linear combination of the efficient units, which means that it is practically attainable since it is in the production possibility set.

Efficiency Improvement

V_i^* and U_r^* are the dual variables of Equation A2, representing the marginal gain in efficiency if one less unit of the i th resource is used or one more unit of the r th output is produced.

The transformation (Eq A5) that makes an inefficient unit DEA efficient can be seen as a two-stage process:

1. The reduction of I_i to $\theta^* I_{i0}$ increases the efficiency rate to 1 without changing the input mix ("recipe").
2. $S_i^{\theta^*}$ and S_r^{+*} represent the additional marginal improvements possible for the unit to become truly efficient.

Production Process

The DEA model assumes that each input has some relationship to one or more outputs, but it is not necessary to specify these functional relationships explicitly.

APPENDIX B:

EXPLANATION OF COMPUTER OUTPUT

Table B1 contains the FY85 computer output for the 21 installations of MACOM #1. For each installation, there are five lines, of which the first three lines contain the values of the weight, slack, and input/output as follows:

Column 1: Name of the installation.

Columns 2-6: Output-related values (note that O_2 is missing because of data unavailability). For the installation, there are three numbers under each of these columns. Consider for example, column 2 (Output-1: Population Served) of row 1 (installation #1):

1. First number (u_1) = 0.001163. This is the weight assigned to output O_1 (population size) installation #1.

2. Second number (O_1) = 50.79. This is the value of output O_1 for installation #1. That is, the population of installation #1 is 50,790.

3. Third number (SO_1) = 0. This is the slack in output 1. To illustrate this value, consider installation #5 which has 5.065528 thousand slack. Thus, using the current resources, installation #5 could serve roughly 5065 additional people. (Appendix A gives details.)

Columns 7-11: Input-related values. For example, column 7 (Input 2: K account) of row 1 has three numbers:

1. $V_2 = 0$: the weight assigned to K account by installation #1.

2. $I_2 = 19.11532$: the amount of funds (in millions of dollars) received by installation #1 under K account.

3. $SI_2 = 0$: Slack (inefficiently used) money by installation K under K account.

Column 12: Efficiency rating (performance) of the installation. This efficiency rating is relative to other installations in the reference set.

In addition, the reference set of each inefficient installation and its corresponding λ_i values (as described in Appendix A) are reported in the two lines named REF. SET. and LAMBDA.

Tables B2 and B3 contain the results for MACOM #1 for FY84 and FY83, respectively. Table B4 contains the results for MACOM #2 for FY85; Table B5 lists results of the joint analysis for MACOMs #1 and #2 in FY85.

Table B1

DEA Results for MACOM #1, FY85

UNIT EVALUATED	U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	EFFICIENCY
	O1	O2	O3	O4	O5	S1	S2	S3	S4	S5	
	SO1	SO2	SO3	SO4	SO5	SI1	SI2	SI3	SI4	SI5	
1	0 016585	0 4 207306	0 000417	0 0001	0 347802	0 0001	6 569159	3 556382	14 00879	100 00	
	50 79	0 23 365	29 51768	1 575665	29 63011	19 11532	5 819449	7 935924	1 459	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	1	1									
LAMBDA											
2	0 143052	0 0 096689	0 000580	71 91345	1 749086	0 0001	0 0001	5 803910	15 08883	100 00	
	41 295	0 17 408	252 0161	1 282491	17 84937	36 65980	4 617007	7 794262	1 54	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	2	2									
LAMBDA											
3	0 799031	0 0 0001	0 000652	38 83414	0 485267	0 0001	0 0001	6 106295	19 90893	100 00	
	80 487	0 11 254	57 58146	0 91384	12 20430	19 50505	2 450487	10 11598	1 5	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	3	3									
LAMBDA											
4	0 862162	0 0 0001	0 000967	122 3930	0 0001	0 0001	15 95779	7 406007	57 44602	100 00	
	15 132	0 9 346	488 8780	0 706575	10 41354	15 18643	0 322458	6 239739	0 848	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	4	4									
LAMBDA											
5	0 0001	0 0 0001	0 000534	144 4227	5 935199	0 0001	0 0001	4 700293	42 75963	95 13	
	11 524	0 8 3 294	8113 0 657605	7 96232	13 61374	2 518795	5 347827	0 642	0	0	
	5 065528	0 1 215179	0	0	0	0 0 238690	0 534784	0	0	0	
REF SET	5	5									
LAMBDA											
6	0 257749	0 3 289438	0 0001	0 0001	1 698490	0 755384	0 0001	3 303908	0 0001	93 74	
	64 404	0 23 449	9 333843	1 617933	22 45047	32 50205	5 274838	11 48981	2 333	0	
	0	0	0 154 8502	0 004533	0	0 0 830328	0 0 157584	0	0	0	
REF SET	6	6									
LAMBDA											
7	0 782865	0 5 584307	0 0001	0 0001	2 475819	0 0001	11 28350	0 0001	45 43333	87 84	
	25 594	0 12 144	85 10421	0 757919	11 68280	25 82272	3 37952	8 959907	0 725	0	
	0	0	0 166 1466	0 060425	0	0 2 860670	0 0 148389	0	0	0	
REF SET	7	7									
LAMBDA											
8	0 242792	0 242792	0 264293	1 148736	0 050048	0 151788	0 0001	45 43333	0 725	0	
	0	0	0	0	0	0	0	0	0	0	
REF SET	8	8									
LAMBDA											

Table B1 (Cont'd)

UNIT EVALUATED	U1 O1 SO1	U2 O2 SO2	U3 O3 SO3	U4 O4 SO4	U5 O5 SO5	V1 I1 S11	V2 I2 S12	V3 I3 S13	V4 I4 S14	V5 I5 S15	EFFICIENCY
8	0	161236	0	3	898770	0	0	0	0	0	0
	0	23	357	23	90834	1	594364	18	18247	39	80743
	0	44	363	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
REF SET	2/										
LAMBDA	1	180930	0	071652	0	193001					
9	0	906749	0	11	27665	0	0	0	0	0	0
	0	5	292	0	8	441	151	4646	0	711375	5
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
REF SET	9										
LAMBDA	1										
10	2	233384	0	24	12789	0	0	0	0	0	0
	4	511	0	3	722	118	0038	0	23854	2	544618
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
REF SET	10										
LAMBDA	1										
11	0	940763	0	3	477403	0	0	0	0	0	0
	45	64	0	10	243	162	3534	0	688226	21	44733
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
REF SET	11										
LAMBDA	1										
12	0	659232	0	4	300580	0	0	0	0	0	0
	51	64	0	14	766	55	56294	1	043105	13	50181
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
REF SET	12										
LAMBDA	1										
13	0	0	0	0	0	0	0	0	0	0	0
	6	826	0	4	366	211	6446	0	320895	5	391996
	1	057828	0	0	324703	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
REF SET	13										
LAMBDA	1										
14	0	694697	0	0	0	0	0	0	0	0	0
	32	294	0	11	26	201	1950	0	756418	9	988661
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
REF SET	14										
LAMBDA	1										

Table B1 (Cont'd)

UNIT EVALUATED	u1		u2		u3		u4		u5		v1		v2		v3		v4		v5		EFFICIENCY
	O1	S01	O2	S02	O3	S03	O4	S04	O5	S05	V1	S11	V2	S12	V3	S13	V4	S14	V5	S15	
15	1	271009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.00
	7	943	0	3	73	62500	0	253815	3	0024	6	4038	1	2107	7	7813	0	373	0	373	100.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
REF SET																					
LAMBDA	15																				
16	0	974420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75.15
	14	305	0	7	798	231	4702	0	578615	9	273363	16	27916	3	136487	9	357042	0	555	0	555
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
REF SET																					
LAMBDA	20																				
17	0	0001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55.11
	2	099	0	1	551	2531	645	0	12763	4	324993	4	826782	0	822503	2	942144	0	168	0	168
	1	156669	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
REF SET																					
LAMBDA	15																				
18	0	837165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89.37
	12	813	0	7	272	201	8163	0	58935	6	40662	17	01283	1	891752	11	47715	0	662	0	662
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
REF SET																					
LAMBDA	20																				
19	1	613793	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65.89
	28	837	0	4	261	85	79787	0	540095	12	42371	25	14478	5	071001	16	45796	0	787	0	787
	0	0	0	1	423332	68	81548	0	0	0	0	0	0	0	0	0	0	0	0	0	
REF SET																					
LAMBDA	15																				
20	0	132701	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.00
	1	046520	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.00
	32	279	0	17	83	245	6338	1	23008	16	85609	18	95926	3	88255	9	038273	0	864	0	864
REF SET																					
LAMBDA	20																				
21	0	582329	0	4	708750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.00
	27	306	0	15	244	71	55891	1	074365	9	811973	21	51981	2	137524	7	474892	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
REF SET																					
LAMBDA	21																				

Table B2

DEA Results for MACOM #1, FY84

UNIT	U1	U3	U4	U5	V1	V2	V3	V4	V5	EFFICIENCY	REFERENCE SET
EVALUATED	O1	O3	O4	O5	S11	S12	S13	S14	S15		
1	0 004784	0 025321	0 000003	0 0 011133	0 013798	0 0 028433	0 0 028433	0 0 028433	0 0 028433	100.00%	1,3,8,9,15,
	48 758	30 276	20 71997	2 116645	34 95897	22 17873	3 833888	9 158269	1 612		
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		
2	0 004286	0 0 000002	0 533201	0 015920	0 0 025998	0 336838	0 0 025998	0 336838	0 0 025998	85.53%	1,8,9,15,20,
	40 625	17 309	413 7018	1 275213	17 72705	30 09883	5 072391	8 044555	1 51		
	0 0 559437	0 0	0 0	0 0	0 7 519214	2 194052	0 0	0 0	0 0		
3	0 007886	0 036647	0 000001	0 0 012430	0 008921	0 048426	0 0 008913	0 0 008913	0 0 008913	100.00%	1,3,8,11,15,20,
	76 572	11 225	57 58146	0 913455	11 07796	14 41234	2 008648	10 34400	1 531		
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		
4	0 007102	0 0 000004	0 883440	0 026378	0 0 043076	0 558093	0 0 043076	0 558093	0 0 043076	74.93%	1,8,9,15,20,
	17 677	9 349	140 4297	0 70525	10 87770	13 68061	2 287025	6 05922	0 81		
	0 0 361455	0 0	0 0	0 0	0 1 80233	0 160291	0 0	0 0	0 0		
5	0 015892	0 0 1 458445	0 076888	0 0 014425	0 0 018165	0 193343	0 0 018165	0 193343	0 0 018165	76.86%	8,9,20,
	6 02	5 681	73 47538	0 461375	4 534417	4 906534	0 809588	3 774354	0 541		
	0 0 083980	13 88874	0 0	0 0	0 1 109971	0 033531	0 156441	0 0	0 0		
6	0 001091	0 030688	0 0 142185	1 627175	22 14366	35 78067	4 73625	12 45534	2 331	79.37%	1,8,9,20,
	60 928	23 697	8 120 3795	0 065660	0 0 014425	0 0 018165	0 193343	0 0 018165	0 193343		
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		
7	0 011723	0 061213	0 000004	0 0 014425	0 0 0354083	0 0 657028	0 0 0354083	0 657028	0 0 0354083	98.89%	1,8,11,15,
	21 397	12 048	83 21821	0 751005	18 37996	19 01707	1 603445	7 511523	0 653		
	0 0	0 0	0 0	0 0	0 089754	3 818083	9 395996	0 0	0 0		
8	0 004555	0 031013	0 000001	0 0 009725	0 0 054490	0 0 379704	0 0 054490	0 379704	0 0 054490	100.00%	1,8,11,15,20,
	74 426	21 311	34 67586	1 456833	14 65792	30 45720	2 649242	8 845209	1 878		
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		
9	0 014967	0 0 000003	1 307869	0 030377	0 0 153576	0 1 151218	0 0 153576	0 1 151218	0 0 153576	100.00%	8,9,11,15,20,
	4 518	8 432	151 4646	0 71251	4 043864	4 920256	0 539724	3 971684	0 689		
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		
10	0 003389	0 089959	0 0 043792	0 0 043792	0 0 030044	0 377647	0 0 030044	0 377647	0 0 030044	100.00%	8,9,10,20,
	24 42	10 196	114 6907	0 51843	7 873325	12 64898	2 940263	6 570573	0 565		
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		

Table B2 (Cont'd)

UNIT	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	EFFICIENCY
EVALUATED	SO1	SO2	SO3	SO4	SO5	SO6	SO7	SO8	SO9	SO10	SO11	SO12	SO13	SO14	SO15	
11	0 010635	0 0 00005	0 691663	0 00000	0 416928	0 0 00012	0 416928	0 0 00000	0 00000	0 00000	0 00000	0 00000	0 00000	0 00000	0 00000	100 00%
	44 812	11 104	122 2488	0 755825	20 84858	15 63885	2 319847	9 774013	0 578	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	1,3,8,9,11,15,
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	0 011150	0 0 00012	0 416928	0 0 00012	0 416928	0 0 00012	0 416928	0 0 00012	0 416928	0 0 00012	0 416928	0 0 00012	0 416928	0 0 00012	0 416928	100 00%
	50 726	14 84	51 79790	1 040302	14 55506	26 12024	2 910996	5 986634	1 415	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	1,8,12,15,
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13	0 082606	0 157639	0 000037	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	98 10%
	6 75	4 358	168 3161	0 320335	5 752341	8 477987	0 370898	4 29258	0 396	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	3,8,9,15,
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	0 005954	0 037413	0 000002	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	75 17%
	39 674	13 773	114 5777	0 92262	15 64938	21 57968	3 619463	8 405238	1 344	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	1,3,8,9,15,20,
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	0 049616	0 000012	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	100 00%
	5 757	3 056	62500	0 21119	4 3617	4 9469	1 4779	7 2888	0 182	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	1,8,15,
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	0 012040	0 0 000002	1 052134	0 024437	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	8,9,11,15,20,
	20 718	8 284	266 4464	0 60411	9 351525	17 06436	1 709477	8 610378	0 602	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	0 013098	0 0 000001	1 200805	0 063303	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	57 97%
	2 219	1 534	1002 004	0 127855	4 44082	5 012698	0 433913	2 681033	0 168	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	1,15,19,
	0 747611	0 278760	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	
18	0 013098	0 0 000001	1 200805	0 063303	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	8,9,15,20,
	13 774	7 292	314 2381	0 59085	5 793662	15 15580	2 743312	9 32922	0 662	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0 004540	0 053752	0 000000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	11,15,19,20,
	26 721	16 345	116 8474	1 086198	23 13094	23 91687	2 516734	13 11878	0 75	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0 006664	0 002189	0 000001	0 568808	0 013546	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	100 00%
	37 566	18 102	171 2240	1 25216	17 23586	18 47946	3 778614	9 082145	0 946	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	1,8,9,11,15,20,
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0 006539	0 041865	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	0 0 00000	79 60%
	25 807	14 983	86 83495	1 063731	11 84973	16 96845	1 971135	8 853482	1 499	0 000239	0 277220	0 003919	0 548703	0 00000	0 00000	1,3,8,9,20,
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table B3

DEA Results for MACOM #1 FY83

UNIT	U1	U3	U4	U5	V1	V2	V3	V4	V5	EFFICIENCY	REFERENCE SET
EVALUATED	SO1	SO3	SO4	SO5	S11	S12	S13	S14	S15		
1	0 0 03880	0	0	0	0 00326	0 079433	0 028235			91.39%	2,12,20,
	42 024	23 445	18 27986	1 338125	30 72541	32 73009	5 063551	10 21331	2 131		
	14 14612	0 154	2942 0	142480	5 67353	0 1 480134	0				
2	0 002462	0 010941	0 0	0 565096	0	0 0 162625	0 089753			100.00%	2,9,12,20,
	40 675	17 07	112 1453	1 261886	18 20349	27 14743	2 563309	6 497167	1 509		
	0	0	0	0	0	0	0	0	0		
3	0 011048	0 01498	0 00084	0 272758	0 044793	0	0 0 313195			100.00%	3,9,15,17,20,
	49 956	11 971	56 62193	0 945575	11 55234	19 53848	1 024778	10 02651	1 544		
	0	0	0	0	0	0	0	0	0		
4	0	0	0 1 040185	0	0	0	0 0 106919	0 475948		86.27%	9,20,
	17 347	11 129	58 42351	0 02935	12 37327	12 89422	1 523955	5 791663	0 8		
	2 780122	0 422055	109 6291	0	1 281485	1 118140	0 107285	0	0		
5	0 009161	0 176086	0	0 070145	0	0 1 000404	0 075178			100.00%	3,5,9,20,
	4 883	5 364	41 19501	0 433455	3 956194	3 905781	0 500212	2 932925	0 545		
	0	0	0	0	0	0	0	0	0		
6	0 007740	0 014771	0	0 020925	0	0	0 0 210978			86.03%	11,12,20,
	65 435	23 759	7 013999	1 439613	24 23639	39 61589	4 03902	12 89452	2 336		
	0	0	146 3504	0 034445	0	3 755649	0 427151	1 167150	0		
7	0 021891	0 051898	0	0 039691	0	0 0 770235				100.00%	7,11,20,
	20 778	10 504	186 0811	0 484739	11 81048	13 70310	1 547052	5 840519	0 383		
	0	0	0	0	0	0	0	0	0		
8	0 001789	0 044124	0	0 017545	0	0 0 042880	0 096729			100.00%	8,9,12,20,
	40 032	21 039	35 71683	1 432334	16 55021	27 50491	3 486705	6 445323	1 846		
	0	0	0	0	0	0	0	0	0		
9	0 013864	0 104888	0 000279	0 0 064882	0	0 0 464522	0 073648			100.00%	3,9,12,17,20,
	5 546	8 409	147 2754	0 71024	4 038596	5 443833	0 972358	3 887154	0 679		
	0	0	0	0	0	0	0	0	0		
10	0 022730	0 042541	0 000126	0 0 064237	0	0 0 389234				100.00%	3,10,12,20,
	24 22	10 322	81 85315	0 54198	6 990409	19 28489	2 129446	6 492006	0 935		
	0	0	0	0	0	0	0	0	0		

Table B3 (Cont'd)

UNIT	U1	U3	U4	U5	V1	V2	V3	V4	V5	EFFICIENCY
EVALUATED	SO1	SO3	SO4	SO5	SI1	SI2	SI3	SI4	SI5	
11	0 015325	0 027616	0 000050	0 0 041143	0 0 041143	0 0 041143	0 0 041143	0 0 041143	0 0 041143	3, 11, 12, 20, 100 00%
	44 812	11 104	131 7991	0 755825	18 63043	18 98907	2 504183	8 200745	0 578	
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	
12	0 012166	0 0 000074	0 434672	0 034179	0 009812	0 0 009812	0 0 009812	0 0 009812	0 0 009812	3, 9, 12, 15, 20, 100 00%
	44 413	14 87 55	13895 1	0 047985	12 59094	16 15444	2 007774	5 991353	1 426	
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	
13	0 0 159801	0 000207	0 0 098809	0 0 098809	0 0 098809	0 0 098809	0 0 098809	0 0 098809	0 0 098809	7, 9, 17, 81 69%
	6 505	4 922	146 4357	0 36016 5	033003 8	497814 1	094711 4	573994 0	0 35	
	0 112240	0 0 006387	0 0 006387	0 2 136045	0 233134	1 167406	0 0 006387	0 0 006387	0 0 006387	
14	0 013472	0 025178	0 000077	0 0 038093	0 0 038093	0 0 038093	0 0 038093	0 0 038093	0 0 038093	3, 10, 12, 17, 20, 79 54%
	33 813	13 106	126 4062	0 88486 14	17885 23	29181 2	273241 8	125425 1	1 318	
	0 0	0 0	0 0 015119	0 0 015119	0 0 015119	0 0 015119	0 0 015119	0 0 015119	0 0 015119	
15	0 036464	0 0 000385	1 988448	0 150485	0 053426	0 024629	0 1 266140	0 1 266140	0 1 266140	3, 9, 12, 15, 17, 20, 100 00%
	5 757	2 978	409 5004	0 259965	3 3098	4 2315	0 6731	5 3938	0 181	
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	
16	0 000760	0 0 000098	1 306918	0 020909	0 0 193813	0 0 193813	0 0 193813	0 0 193813	0 0 193813	7, 9, 15, 17, 20, 82 53%
	15 103	8 432	261 9858	0 603015	9 214614	15 61440 1	211421 8	050986 0	0 576	
	0 0 044747	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	
17	0 033059	0 129881	0 000330	0 0 158811	0 0 158811	0 0 158811	0 0 158811	0 0 158811	0 0 158811	3, 9, 10, 12, 17, 20, 100 00%
	1 538	1 233	2386 634	0 10544 4	932028 5	223706 0	662022 2	547701 0	0 142	
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	
18	0 026646	0 054463	0 000219	0 408883	0 117762	0 0 117762	0 0 117762	0 0 117762	0 0 117762	3, 9, 10, 12, 17, 93 70%
	9 037	7 272	267 0940	0 58935 4	741871 15	788881 1	59101 8	907848 0	0 662	
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	
19	0 0 050771	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	3, 5, 20, 89 45%
	26 607	17 618	90 03255	1 174317	25 98239	17 18228	1 913548	13 40839	1 35	
	9 146894	0 118 7233	0 127488	8 103911	0 0 103911	0 0 103911	0 0 103911	0 0 103911	0 0 103911	
20	0 010007	0 022060	0 000081	0 152044	0 043370	0 0 043370	0 0 043370	0 0 043370	0 0 043370	9, 10, 12, 17, 20, 100 00%
	37 087	18 671	239 6728	1 287765	16 56978	17 08814	1 903621	7 93215	1 028	
	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	
21	0 001780	0 061882	0 0 024907	0 0 024907	0 0 024907	0 0 024907	0 0 024907	0 0 024907	0 0 024907	3, 5, 9, 20, 98 16%
	25 802	15 12	64 26239	1 070744	11 98782	20 11339	1 47036	9 22367	1 48	
	0 0	0 0	0 186 3435	0 127843	0 5 720102	0 0 5 720102	0 0 5 720102	0 0 5 720102	0 0 5 720102	

Table B4

DEA Results for MACOM #2 FY85

UNIT	UNIT																	EFFICIENCY
EVALUATED	U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	S1	S2	S3	S4	S5	S6		
1	0.0001	0.224300	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	100.00	
REF SET	8.904	0	10.236	65.80494	0.693742	16.098	31.354	2.224	4.459	0.596	0	0	0	0	0	0		
LAMBDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
2	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	99.89	
REF SET	46.049	0	20.67	66.85792	1.525868	21.821	36.582	5.947	10.529	1.426	0	0	0	0	0	0		
LAMBDA	29.85406	0	1.562497	663.9434	0	0	0	0	0	0	0	0	0	0	0	0		
3	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	91.02	
REF SET	42.212	0	17.289	36.88699	1.310005	18.032	23.834	4.469	10.336	1.575	0	0	0	0	0	0		
LAMBDA	15.06786	0	1.868189	505.9534	0	0	0	0	0	0	0	0	0	0	0	0		
4	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	100.00	
REF SET	2.245	0	1.483	876.4241	0.099975	2.252	2.153	0.414	1.551	0.025	0	0	0	0	0	0		
LAMBDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
5	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	100.00	
REF SET	1.698	0	4.873	85.91286	0.316338	0.718	2.811	0.461	1.209	0.912	0	0	0	0	0	0		
LAMBDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
6	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	100.00	
REF SET	43.2566	0	7.586483	0.000254	0.0001	1.293164	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		
LAMBDA	46.233	0	10.417	188.3644	0.716229	15.35	32.448	4.511	9.331	0.302	0	0	0	0	0	0		
7	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	99.17	
REF SET	15.765	0	7.763	83.39588	0.495335	10.139	13.055	1.637	7.633	0.449	0	0	0	0	0	0		
LAMBDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
8	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	100.00	
REF SET	47.0879	0	4.7377	0	0	0	0	0	0	0	0	0	0	0	0	0		
LAMBDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
9	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	99.17	
REF SET	15.765	0	7.763	83.39588	0.495335	10.139	13.055	1.637	7.633	0.449	0	0	0	0	0	0		
LAMBDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
10	0.0001	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	100.00	
REF SET	47.0879	0	4.7377	0	0	0	0	0	0	0	0	0	0	0	0	0		
LAMBDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

Table B4 (Cont'd)

UNIT EVALUATED	UNIT															EFFICIENCY
	U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	S1	S2	S3	S4	S5	
8	01	02	03	04	05	11	12	13	14	15						
	SO1	SO2	SO3	SO4	SO5	SI1	SI2	SI3	SI4	SI5						
	0 199488	0 10 26290	0 0001	0 0001	0 0001	0 992002	0 0001	10 36751	6 455184	81 72324						
	23 874	0 9 278 181	2579 9	615065	12 356	0 0	16 03	2 694	4 632	0 366						100 00
REF SET	0	0	0	0	0	0	0	0	0	0						
LAMBDA	21	0	12	0	0	8	1									
9	0 0001	0 10 43363	0 0001	238 3436	11 02324	2 530375	9 362139	9 429581	104 7205							
	2 784	0 3 758 1123	595 0	254581	3 074	6 989	0 368	3 027	0 157							100 00
	0	0	0	0	0	0	0	0	0	0						
	0	0	0	0	0	0	0	0	0	0						
REF SET	21	0	18	0	0	14	12									9
LAMBDA	0	0	0	0	0	0	0									1
10	0 0001	0 0 0001	0 0001	208 6132	10 81407	0 972921	0 0001	0 0001	83 94344							
	12 656	0 5 089 262	5340 0	378755	5 233	13 383	3 616	7 427	0 362							79 04
	35 38782	0 0 693880	1268 524	0	0	0	1 465494	0 796727	0							
	0	0	0	0	0	0	0	0	0							
REF SET	12	0	11	0	0	9										
LAMBDA	0 241748	1 631352	0 127041													
11	0 0001	0 0 0001	0 0001	1113 494	57 93260	4 953670	0 0001	0 0001	431 4758							
	25 503	0 1 5 832 5701	0 08973	0 516	3 648	0 477	1 43	0 115	0 000							100 00
	0	0	0	0	0	0	0	0	0							
	0	0	0	0	0	0	0	0	0							
REF SET	12	0	11	0	0	9										
LAMBDA	0	0	1	0	0	0										
12	0 046754	0 0 0001	0 004088	118 7551	3 392649	2 076382	0 0001	1 739689	30 29091							
	25 174	0 11 824 124	5174 0	827437	12 027	15 539	2 368	9 787	0 327							100 00
	0	0	0	0	0	0	0	0	0							
	0	0	0	0	0	0	0	0	0							
REF SET	21	0	12	0	0	9										
LAMBDA	0	0	1	0	0	0										
13	0 0001	0 1 390743	0 0001	54 19097	0 0001	0 984157	8 038635	2 183242	17 13109							
	40 012	0 19 437 35	03286 1	346354	19 21	23 74	3 12 231	1 392	0 000							100 00
	0	0	0	0	0	0	0	0	0							
	0	0	0	0	0	0	0	0	0							
REF SET	21	0	18	0	0	9										
LAMBDA	0	0	0	0	0	0										
14	0 0001	0 5 802166	0 0001	131 0919	6 110793	1 407833	5 055298	5 192294	57 89374							
	15 499	0 6 737 105	1533 0	46455	6 297	11 13	1 589	4 418	0 357							100 00
	0	0	0	0	0	0	0	0	0							
	0	0	0	0	0	0	0	0	0							
REF SET	21	0	18	0	0	9										
LAMBDA	0	0	0	0	0	0										

Table B4 (Cont'd)

UNIT EVALUATED		U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	EFFICIENCY
		O1	O2	O3	O4	O5	S11	S12	S13	S14	S15	
		S01	S02	S03	S04	S05						
15	0.0001	0	13.18668	0.0001	0.0001	7.752356	0.0001	0.0001	0.0001	3.906483	89.24733	
	15.822	0	7.583.37	17748	0.473115	7.239	23.888	2.504	6.503	0.207	100.00	
	0	0	0	0	0	0	0	0	0	0	0	
REF SET		11										
LAMBDA		15										
		1										
16	0.377237	0	13.79036	0.003011	0.0001	3.025150	0.0001	0.0001	0.0001	8.337181	168.0317	
	19.015	0	5.876	757.0022	0.36737	7.358	15.276	2.752	4.447	0.242	90.48	
	0	0	0	0	0.02777	0	3.999036	0.937770	0	0	0	
REF SET		14										
LAMBDA		284542										
17	0.416575	0	0.0001	0.014188	531.9166	23.96750	0.0001	0.0001	0.0001	0.0001	501.8879	
	3.807	0	1.918	436.6812	0.132355	2.162	6.529	1.194	2.373	0.096	78.17	
	0	0.026408	0	0	0	0	1.781352	0.654606	0.254391	0	0	
REF SET		12										
LAMBDA		0.051841										
18	0.0001	0	16.55486	0.0001	247.4912	20.26442	3.089941	0.134533	6.415408	140.3406	100.00	
	3.024	0	3.316	222.4252	0.18198	1.472	3.564	0.224	1.407	0.357	100.00	
	0	0	0	0	0	0	0	0	0	0	0	
REF SET		18										
LAMBDA		1										
19	0.0001	0	4.949452	0.0001	43.58322	5.231904	1.334923	0.0001	0.0001	33.33301	62.60	
	19.702	0	8.062	616.5228	0.519221	9.294	16.735	3.588	11.92	0.87	62.60	
	5.529080	0	0.35.38014	0	0	0	0.900731	1.963690	0	0	0	
REF SET		18										
LAMBDA		0.668367										
20	0.0001	0	3.280001	0.0001	43.49523	2.941309	0.0001	0.0001	3.925083	25.10284	87.74	
	35.387	0	14.119	189.1074	0.95207	13.266	25	5.512	8.366	1.121	87.74	
	0.531010	0	0.199.3957	0	0	0.3.339713	1.941923	0	0	0	0	
REF SET		18										
LAMBDA		0.456179										
21	0.0001	0	4.283680	0.0001	56.53683	3.830255	0.0001	0.0001	5.117438	32.70882	100.00	
	47.023	0	12.21	438.4042	0.842773	12.453	15.248	2.9	6.059	0.651	100.00	
	0	0	0	0	0	0	0	0	0	0	0	
REF SET		21										
LAMBDA		1										

Table B5

DEA Results for MACOMs #1 and #2

UNIT EVALUATED	UNIT																EFFICIENCY
	U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	S1	S2	S3	S4	S5	S6	
1	0 105589	0 4 015326	0 000374	0 0001	1 326803	0 486351	0 0001	3 414274	14 64367								
	50 79	0 23 565	29 51748	1 575665	29 63011	19 11532	5 819449	7 935924	1 659	100 00							
	0	0	0	0	0	0	0	0	0	0							
REF SET	/																
LAMBDA	1																
2	0 064398	0 0 0001	0 0001	74 61937	1 554605	0 0001	0 0001	5 858003	17 02091								
	41 295	0 17 408	252 0161	1 282491	17 84937	36 45980	4 617007	7 794262	1 56	98 38							
	0	0 1 563039	50 18612	0	0	0 18 17077	0 544632	0	0	0							
REF SET	/2																
LAMBDA	26																
3	0 416627	0 0 0001	0 0001	71 19850	0 0001	2 882146	11 15920	0 0001	10 95724								
	80 687	0 11 254	57 58146	0 91384	12 20430	19 50505	2 450487	10 11598	1 5	98 69							
	0	0 1 978023	2592 422	0 5 491503	0	0	0 0 295886	0	0	0							
REF SET	32																
LAMBDA	26																
4	0 737840	0 0 0001	0 0001	125 6557	0 0001	5 086932	19 69591	0 0001	19 33358								
	15 132	0 9 346	488 8780	0 706575	10 41356	15 18643	0 322458	6 229739	0 848	100 00							
	0	0 0	0	0	0	0	0	0	0	0							
REF SET	4																
LAMBDA	1																
5	0 0001	0 0 0001	0 000534	144 4327	5 835200	0 0001	0 0001	4 700293	42 75963								
	11 526	0 8 3 294	8113 0	657805	7 96222	13 61274	2 518795	5 367827	0 662	95 13							
	5 065328	0 1 215179	0	0	0	0 238690	0 534784	0	0	0							
REF SET	21																
LAMBDA	20																
6	0 110312	0 0 0001	0 0001	50 21191	0 457431	0 0001	4 071794	3 875980	10 07505								
	64 404	0 23 449	9 333843	1 617933	22 45047	32 50205	5 276858	11 48981	2 353	88 35							
	0	0 0 267372	533 3502	0	0	2 847196	0	0	0	0							
REF SET	42																
LAMBDA	26																
7	0 064283	0 6 725351	0 0001	0 0001	2 914053	0 0001	3 197002	3 209358	36 40442								
	25 594	0 12 144	85 10421	0 757919	11 68280	25 82272	3 37952	8 959907	0 725	83 33							
	0	0 0 478	3129 0	042897	0 3 514270	0	0	0	0	0							
REF SET	39																
LAMBDA	30																
8	0 348829	0 297447	0 030634	0 396644	0 901076												

Table B5 (Cont'd)

UNIT EVALUATED	UNIT														EFFICIENCY
	U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	S1	S2	S3	S4	S5
8	0 077421	0 0 0001	0 0001	0 0001	54 53379	1 752210	0 0001	0 0001	3 375857	13 90844					
	44 363	0 23 357	23 90834	1 594364	18 18247	39 80743	4 909878	10 82273	2 272	93 57					
	0	0 0 105489	436 0679	0	0	0 13 98452	0 274830	0	0	0					
	REF SET	42	26	21	20										
9	0 457333	0 457333	1 331971	0 085889	0 365114										
	0 089352	0 0 0001	0 0001	139 8841	5 754180	0 628078	0 0001	3 749796	37 26012						
	5 292	0 8 441	151 4646	0 711375	5 710307	8 190885	1 942642	9 657363	0 692	100 00					
	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0					
10	0 134464	0 16 11114	0 0001	165 2382	15 53168	0 0001	0 0001	15 14275	111 3574						
	4 511	0 3 722	118 0038	0 23854	2 544618	8 825912	1 138742	3 192209	0 109	100 00					
	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0					
	REF SET	10	1												
11	0 372333	0 7 460589	0 0001	0 0001	0 0001	1 196710	16 16938	2 796812	40 79907						
	45 64	0 10 245	162 3534	0 688226	21 44733	17 02951	2 255635	7 782973	0 524	93 44					
	0	0 0	0 1403	351 0 007398	10 95808	0	0	0	0	0					
	REF SET	42	33	32	30										
12	0 248098	0 0 0001	0 000490	83 55767	1 182456	0 615391	8 114614	3 844109	17 46619						
	51 64	0 14 766	55 56296	1 043105	13 50181	20 31280	2 326554	7 268419	1 415	100 00					
	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0					
	REF SET	12	1												
13	0 0001	0 0 0001	0 000801	216 5823	8 750568	0 0001	0 0001	7 048909	64 13359						
	4 826	0 4 366	211 6446	0 320895	5 391996	9 773071	1 503468	3 890375	0 396	69 67					
	1 057828	0 0 324703	0	0	0	0 0 032147	0 041304	0	0	0					
	REF SET	21	20	15	10										
14	0 091569	0 091569	0 129564	0 002277	0 262272										
	0 172396	0 3 962945	0 0001	65 82730	1 400793	0 0001	9 007530	8 325933	27 44439						
	32 294	0 11 26	201 1950	0 756418	9 988661	15 56383	2 164391	5 136244	0 859	100 00					
	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0					
15	0 091569	0 091569	0 129564	0 002277	0 262272										
	0 172396	0 3 962945	0 0001	65 82730	1 400793	0 0001	9 007530	8 325933	27 44439						
	32 294	0 11 26	201 1950	0 756418	9 988661	15 56383	2 164391	5 136244	0 859	100 00					
	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0					
16	0 091569	0 091569	0 129564	0 002277	0 262272										
	0 172396	0 3 962945	0 0001	65 82730	1 400793	0 0001	9 007530	8 325933	27 44439						
	32 294	0 11 26	201 1950	0 756418	9 988661	15 56383	2 164391	5 136244	0 859	100 00					
	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0					

Table B5 (Cont'd)

UNIT EVALUATED	u1	u2	u3	u4	u5	v1	v2	v3	v4	v5	EFFICIENCY
	01	02	03	04	05	11	12	13	14	15	
	S01	S02	S03	S04	S05	S11	S12	S13	S14	S15	
15	0 215284	0 3 813660	0 001027	78 12231	1 26813	0 0001	11 13992	9 234094	29 10232	0 373	100 00
	943	0 3 73	62500	0 253815	3 9024	6 6038	1 2107	7 7813	0 373	0	
REF SET											
LAMBDA											
16	0 093017	0 0 0001	0 0001	120 4840	4 637540	0 575693	0 0001	2 168508	49 24501	0 535	71 07
	14 305	0 7 798	231 4707	0 378615	9 273363	16 27916	3 154887	9 357042	0 535	0	
	0	0 0 278585	15 13163	0 0	0 0	0 0	0 0	0 287569	0 0	0	
REF SET											
LAMBDA											
17	0 0001	0 0 0001	0 002247	333 0947	0 0001	0 0001	25 23373	15 37281	200 2889	0 168	48 20
	2 099	0 1 551	2531 645	0 12763	4 329493	4 826782	0 822503	2 962144	0 168	0	
	1 451706	0 0 291497	0 0	0 0 320784	0 023947	0 0	0 0	0 0	0 0	0	
REF SET											
LAMBDA											
18	0 060534	0 0 0001	0 0001	135 8065	7 475854	0 0001	5 992716	0 0001	61 57924	0 662	80 83
	12 813	0 7 272	201 8163	0 58935	6 40662	17 01283	1 891752	11 47715	0 662	0	
	0	0 0 237391	711 5432	0 0	0 0 408107	0 0	0 0	0 1 429089	0 0	0	
REF SET											
LAMBDA											
19	0 081840	0 0 0001	0 0001	83 15681	3 826298	0 601644	0 0001	0 0001	47 43679	0 787	47 28
	28 837	0 6 261	85 79787	0 540095	12 42371	25 14078	5 071001	16 43796	0 787	0	
	0	0 1 330419	648 5244	0 0	0 0	0 0	0 0	0 549609	0 715482	0	
REF SET											
LAMBDA											
20	0 060515	0 0 0001	0 0001	79 68608	3 064230	0 381340	0 0001	1 434215	32 58783	0 864	100 00
	32 279	0 17 83	245 6338	1 23008	16 855609	18 95926	3 808255	9 038273	0 864	0	
	0	0 0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0	
REF SET											
LAMBDA											
21	0 042820	0 0 0001	0 0001	91 98183	3 682673	0 100068	1 423034	2 157354	28 67051	1 449	100 00
	27 304	0 15 244	71 55891	1 074365	9 811973	21 51981	2 137524	7 474892	1 449	0	
	0	0 0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0	
REF SET											
LAMBDA											

Table B5 (Cont'd)

UNIT EVALUATED	U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	EFFICIENCY
	O1	O2	O3	O4	O5	S11	S12	S13	S14	S15	
22	0 0001	0 7 801246	0 0001 29 02947	0 109765	0 0001 14 38292	7 652260	46 43088				
	8 904	0 10 236 65	80494	0 633742	16 098	31 354	2 224	4 439	0 594	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	22										
LAMBDA	1										
23	0 033501	0 0 0001	0 0001 62 22533	1 297504	0 0001 0 0001 4 885694	14 19454					
	46 049	0 20 67 46	85792	1 525868	21 821	36 582	5 947	10 529	1 424	97 42	
	0	0 1 648685	272 3600	0	0 12 98224	0 948068	0	0	0	0	
REF SET	24										
LAMBDA	1										
24	0 093701	0 0 0001	0 0001 63 75114	2 036203	0 032959	0 0001 3 640013	15 76713				
	42 212	0 17 289 56	88699	1 310005	18 052	23 834	4 669	10 336	1 575	87 48	
	0	0 1 813603	370 0933	0	0	0 0 270724	0	0	0	0	
REF SET	25										
LAMBDA	1										
25	0 0001	0 45 41021	0 003080	0 0001 0 0001 37 99139	17 16352	0 0001 443 9379					
	2 265	0 1 483 876	4241	0 099975	2 252	2 153	0 414	1 551	0 025	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	26										
LAMBDA	1										
26	0 026803	0 12 65009	0 006450	120 9298	13 00623	2 315340	0 0001 9 114275	86 81894			
	1 698	0 4 873 85	91286	0 316338	0 718	2 811	0 461	1 209	0 912	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	27										
LAMBDA	1										
27	0 459103	0 0 0001	0 0001 109 9569	0 861941	0 0001 0 0001 5 571020	115 1731					
	46 233	0 10 417 188	3664	0 716229	15 35	32 448	4 311	9 331	0 302	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	28										
LAMBDA	1										
28	0 363417	0 8 983587	0 0001 0 0001 0 0001 3 358488	23 28893	0 0001 40 13404						
	15 765	0 7 743 83	39588	0 495335	10 139	13 035	1 637	7 633	0 449	78 64	
	0	0 126 0505	0 035886	0 649335	0	0 0 127921	0	0	0	0	
REF SET	29										
LAMBDA	1										
29	0 318326	0 318326	0 493541	0 493541	0 041884						

Table B5 (Cont'd)

UNIT EVALUATED	U1	U2	U3	U4	U5	V1	V2	V3	V4	V5	EFFICIENC
	O1	O2	O3	O4	O5	S11	S12	S13	S14	S15	
29	0 271770	0 10 05899	0 001016	0 0001	0 0001	0 0001	13 49347	7 299403	80 02876		
	23 874	0 9 278	181 2579	0 615065	12 354	16 03	2 494	4 432	0 364	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	29										
LAMBDA	1										
30	0 0001	0 0 0001	0 001211	387 4529	15 45645	0 441581	5 042884	9 614732	117 4391		
	2 784	0 3 758	1123 595	0 254581	3 074	6 989	0 368	3 037	0 157	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	30										
LAMBDA	1										
31	0 184432	0 0 0001	0 0001	183 7721	8 464537	1 327527	0 0001	0 0001	104 7712		
	12 656	0 5 089	262 5360	0 378735	5 233	13 383	3 616	7 427	0 362	71 97	
	0	0 0 245041	81 31028	0	0	0	1 150099	0 271519	0	0	
REF SET	31										
LAMBDA	1										
32	0 878123	0 0 0001	0 0001	863 9453	39 83517	4 234589	0 0001	0 0001	492 3400		
	25 503	0 1 5 832	5701 0 08973	0 518	3 648	0 477	1 43	0 115	100 00		
	0	0	0	0	0	0	0	0	0	0	
REF SET	32										
LAMBDA	1										
33	0 240702	0 2 002823	0 0001	84 89673	2 492368	1 456779	11 24581	1 202125	27 35389		
	25 174	0 11 824	124 5174	0 827437	12 027	15 539	2 348	9 787	0 327	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	33										
LAMBDA	1										
34	0 276924	0 2 594800	0 0001	25 54104	0 115509	2 091330	8 769936	0 0001	12 67183		
	40 012	0 19 437	35 03286	1 366354	19 21	25 74	3 12 231	1 392	95 91		
	0	0	0 818 0939	0	0	0	0 0 772992	0	0		
REF SET	34										
LAMBDA	1										
PICKETT	33										
LAMBDA	32										
35	0 390246	0 13 94404	0 0001	0 0001	2 904193	0 0001	12 80220	7 533370	109 2842		
	15 499	0 6 737	105 1533	0 46455	6 297	11 13	1 589	4 418	0 237	100 00	
	0	0	0	0	0	0	0	0	0	0	
REF SET	35										
LAMBDA	1										

Table B5 (Cont'd)

UNIT EVALUATED	UNIT															EFFICIENCY
	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	
	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	
	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14	S15	
36	0 477807	0 12 18994	0 0001	0 0001	0 0001	2 749838	0 0001	0 0001	7 039784	165 7563						
	15 822	0 7 583 37	17748	0 473115	7 239	23 888	2 504	6 503	0 207	100 00						
	0	0	0	0	0	0	0	0	0	0						
REF SET																
LAMBDA																
37	0 470970	0 13 56045	0 001345	0 0001	2 811335	0 0001	0 0001	8 305589	175 1133							
	19 015	0 5 876 757	0022	0 36737	7 358	15 276	2 752	4 447	0 242	89 65						
	0	0	0	0	0 028374	0 4 177316	0 942954	0	0	0						
REF SET																
LAMBDA																
38	0 853316	0 0 0001	0 007516	496 8386	14 01969	0 0001	0 0001	15 78937	335 6247							
	3 807	0 1 918 436	6812	0 132355	2 162	6 529	1 194	2 373	0 096	70 11						
	0	0 0 105494	0	0	0 211998	0 250910	0	0	0	0						
REF SET																
LAMBDA																
39	0 074069	0 13 01293	0 0001	306 2370	17 84048	3 271799	19 78012	7 328416	132 5946							
	3 024	0 3 316 222	4252	0 18198	1 472	3 564	0 224	1 407	0 357	100 00						
	0	0	0	0	0	0	0	0	0	0						
REF SET																
LAMBDA																
40	0 013789	0 7 628958	0 000143	0 0001	4 670484	1 405611	0 0001	0 023839	37 68402							
	19 702	0 8 062 614	5228	0 519221	9 294	16 735	3 588	11 92	0 87	41 87						
	0	0	0	0 064478	0	0 0 532973	0	0	0	0						
REF SET																
LAMBDA																
41	0 026975	0 3 499891	0 0001	36 46004	3 392324	0 0001	0 0001	3 311299	24 34614							
	35 387	0 14 119 189	1074	0 95207	13 266	23	5 512	8 366	1 121	85 10						
	0	0	0 492 8385	0	0 5 726128	1 791685	0	0	0	0						
REF SET																
LAMBDA																
42	0 144901	0 4 100336	0 0001	22 13805	3 127174	0 0001	0 0001	4 978104	28 84047							
	47 023	0 12 21 438	4042	0 842773	12 453	15 248	2 9	6 059	0 451	100 00						
	0	0	0	0	0	0	0	0	0	0						
REF SET																
LAMBDA																

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