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# Performance Evaluation of Weapon Systems Procurement Offices: A Relative Efficiency Measurement Approach

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# PERFORMANCE EVALUATION OF WEAPON SYSTEMS PROCUREMENT OFFICES: A RELATIVE EFFICIENCY MEASUREMENT APPROACH

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## ABSTRACT

Performance evaluation of service organizations requires better efficiency measurement techniques than simple ratios or regression. This paper reports on a new and powerful linear programming based multi-input, multi-output model, Data Envelopment Analysis (DEA) and its application in an Air Force Systems Command product division's twenty-one procurement offices.

## INTRODUCTION

Performance evaluation of service organizations usually attempts to focus on organizational productivity or its often conflicting components, effectiveness and efficiency. In the public sector emphasis has historically been placed on the effectiveness issues: to what degree the public organization has met the goals established for it, or, in the military, whether the mission was accomplished or not. Often this has been done without much awareness of the levels of resources used to accomplish those ends. More recently, budgets have become constrained and taxpayers concerned, and new emphasis has been attached to the efficiency component: the amount of resource inputs needed to produce a unit of output.

This new emphasis calls for better efficiency measurement techniques to relate the multiple inputs and outputs of a public sector organization which lacks the convenient profit measure of the private sector. One such public sector service organization is the Government procurement (or contracting) office, which employs a process inspected by many but assisted by very few. This paper reports on the application of a new and powerful linear programming based technique able to assess the relative efficiency among similar work units. Application of the model to weapon systems procurement offices in the United States Air Force provides an example of its capabilities.

## PREVIOUS RESEARCH

Previous approaches toward the measurement of efficiency may be categorized under ratio analyses, regression analyses, and efficiency frontier analyses. Only the first of these has had much use in the procurement or civilian purchasing arenas.

Ratio analysis attempts to measure efficiency by dividing a numerator, usually an output measure, by a denominator, usually an input measure. Various outputs are analyzed in relation to cost dollars, one at a time, or in relation to the number of units of a given input (usually labor), again one at a time. To consider all pertinent ouput/input combinations would require a lage number of single relation ratios. And even then, the relationship among the different results is not ascertainable. Although certain more useful ratios may be used in an attempt to compare the performance of one organization to others, the result is usually not very meaningful. For one important reason, these simple ratios can not take into account the simultaneous interactions among the entire group of inputs and outputs. When the compared organizations rank high on some ratios but low on others, performance comparison is difficult if not impossible.

Regression analysis is usually applied to single output, multiple input problems. While better in many respects than simple ratio analysis, there are still limitations to this measurement technique. For example, it seeks out, by design, the average relationship among the variables by minimizing the error terms. This average, best-fit line tells us nothing about what any one unit can, or should, be able to produce; that is, its maximum possible output from the various combinations of inputs (i.e., its efficiency frontier). In general, these average estimates are rather uninformative for efficiency assessment purposes, and they could be very misleading.

Efficiency frontier analysis grew out of the economic theory of the production function, which stated that, for any defined level of technology, there would be a maximum obtainable amount of output for given levels of inputs.

Farrell [4] used the theory in 1957 to devise a method for measuring what he called technical efficiency in the simple two input, one output case. Assuming the production function were known and assuming further constant returns to scale, he constructed an isoquant production function (see FF' in Fig. 1), representing all possible combinations of the two inputs which an efficient firm might use to produce one unit of output. Points p and q are on the same ray extending from the origin, therefore they represent using inputs X1 and X2 in the same ratio. But at p, the firm is using more of each input than at q to produce the one unit of output. Thus p represents an inefficient firm compared to q, its reference point on the efficiency frontier.

To determine how inefficient, he divided the distance oq by the distance op. Thus, any point on the isoquant will be technically efficient with the ratio oq/op equal to 1.0. Any point above the isoquant will be inefficient to some degree, with a ratio less than 1.0, because there is a reference point, either real or hypothetical, on the isoquant, which uses inputs in the same proportions but in fewer numbers.

Farrell next relaxed the assumption of a known production function and instead constructed a piecewise linear approximation of the isoquant (see SS' in Fig. 2) by connecting points representing empirically observed input and output levels that were most efficient. Fig. 2 plots various organizations' observed values of X1 and X2 required to produce one unit of output. Since organizations closer to the origin produce the one unit of output with fewer of one or both inputs than those organizations inside the frontier, we can say that a, b, and c are relatively efficient while p, r and others inside the frontier (constructed by joining the relatively efficient units) are relatively inefficient. Measurement is done as indicated above except the reference points on the frontier for inefficient points such as p are constructed as a linear combination of the closest endpoints of the segment; thus, q is a calculated linear combination of a and b and acts as the frontier reference point for p.

Farrell's construct was extended to the more complex multiple input, multiple output case also, but without the benefit of a geometric interpretation.

## DATA ENVELOPMENT ANALYSIS

In 1978 Charnes, Cooper and Rhodes [2] were able to operationalize and extend Farrell's ideas. Starting with a non-linear, non-convex ratio of outputs to inputs, they transformed the formulation into an ordinary linear programming problem through use of their previously developed theory of linear fractional programming. Their model, called Data Envelopment Analysis (DEA), is shown in the Appendix.

DEA allows measurement of the relationships between multiple inputs and multiple outputs, considered simultaneously, and uses an extremal algorithm to effect the frontier concept which was not possible in linear regression. Variables may be non-commensurate (measured in different units) and can be selected to reflect the real world inputs and outputs of any organization. A single aggregate measure is produced, with a maximum achievable value of 1.0. The construction of the model is such that each organization receives the highest possible rating and is compared only to those efficient organizations closest to them in terms of the mix of inputs and outputs. Not only will the model indicate the degree of efficiency compared to a similarly structured efficient reference set, but it will indicate input overages or output shortages which led to the inefficient measurement. DEA has been used in several public sector applications and its theory is continuously being extended.

## APPLICATION IN THE U.S. AIR FORCE

DEA and one of its extensions, Constrained Facet Analysis (CFA) [3], have been applied through numerous thesis and dissertation projects to several possible uses in various U.S. Air Force functional environments, including tactical fighter wings, civil engineering work order branches, fire departments, individual A-10 aircraft, and transportation squadrons.

The present application was an attempt to provide an efficiency measurement technique for use in performance measurement of systems procurement offices in the Air Force Systems Command. Preliminary research revealed very little work done in the procurement or civilian purchasing department arenas beyond use of various output per buyer ratios or combinations of ratios weighted a priori on very subjective bases. The particular challenge was to ascertain if the model could reflect the many complexities involved in the contracting process which essentially used labor inputs to transform requirements into contracts.

Twenty-one procurement offices in one of the Air Force Systems Command's major weapon systems buying divisions were selected for analysis over a recent two year period. A list of potential input and output variables was developed and, with procurement managers and staff from the Command, reviewed for relevance and feasibility of use. Several were eliminated either because they were not ultimate outputs or data for their measurement were not available (i.e., missing for some offices, collected inconsistently, or just did not exist).

Criteria for selection of variables for use in the model were taken from Bessent, Bessent, and Clark [1]: (1) outputs should represent important organizational goals; (2) inputs should represent the physical quantities used by the organization in producing outputs; (3) the magnitudes of physical input and output quantities should be represented; (4) the quality of inputs and outputs should be represented; (5) all input and output measures should be common to all the organizations and exist in non-zero amounts in all organizations; and (6) there should be a logical basis for believing that changes in the outputs are caused by changes in the inputs.

Table 1 defines the variables selected. The four resource variables, X1 through X4, depict the four categories of labor input, by far the predominant resource used in the contracting process. The vast majority of their efforts are captured in the two output variables: Y1, number of contractual documents, which gives a relative picture among offices of the quantity of output, and Y2, dollar value obligated on the documents, which gives a relative indication of the complexity involved in that output. The work surrogates represent the level of incoming raw materials or demand for service for the office (X5) and an indication of its relative complexity (X6).

Twenty-two runs of the DEA and/or CFA model were used to evaluate various groupings or combinations of the variables: for example, combining all four labor categories into one generalized labor variable; using dollars alone as the output measure; using quantities of contractual documents alone as the output measure; or using one or the other of the work surrogates, or both. Some of the runs used adjusted variables to reflect various elements of complexity which procurement managers felt were not always reflected in raw count data or dollar figures.

Program complexity results from the unique characteristics of the specific programs each contracting office supports. These programs differ in the number and types of contractor interfaces required, the difficulties faced in negotiations with particular contractors, the number of systems/subsystems supported, the need for special terms and conditions in the contracts, the nature and recurrence of funding impacts, and other ways. These characteristics make processing of similar requests more demanding in some offices than in others; therefore, the work request input should be adjusted to reflect the relative complexity. To construct a program complexity factor, we adapted a rating scheme already in use by the product division staff for other purposes. This scheme consisted of eight program characteristics, like those noted above, which were weighted as to relative importance by the staff. Each procurement office was rated on a scale of 1 to 10 as to the relative influence of that characteristic in its work effort. Total scores for each office were normalized to the low total, thus providing scaled factors to be used as complexity multipliers for the work request inputs. This resulted in a new definition for X5 REQNBR and elimination of X6 REQ$$$ in runs incorporating complexity.

Administrative complexity results, not from different programs with different characteristics, but from the varying amounts of administrative effort required to process contracts of different dollar magnitudes. Depending on estimated dollar value, there are different data, documentation, and review requirements as well as differences in allotted time and higher level interest. This requires adjusting the contractual document outputs to reflect the varying effort involved. To develop the administrative complexity factor, we used a set of time standards set for various dollar categories of procurement efforts by manpower planners, and converted them into weights normalized on the lowest category. The number of contracts in each category of an office's contractual document output was multiplied by the weight and summed. This resulted in a new definition for Y1 CONTNBR and the elimination of Y2 CONT$$$.

## RESULTS

Table 2 displays the actual values for all variables for the twenty-one offices in the study. The last column shows the DEA rating for each office when all of the original variables and values were used. Eight of the offices were rated efficient (1.000) while others ranged down to .359.

Because DEA is actually a linear programming model, additional useful information is available from the results. For example, additional analysis of model output indicates which offices make up a given office's reference set, so a plan for improvement would begin by looking at those efficient offices as "role models." Slack variable or surplus variable values at optimality can be used to indicate underutilization of specific inputs (resources) or underachievement of output for the given level of inputs. In fact, we can calculate "values if efficient" indicating what output level should have been attained given the level of inputs (compared to the efficient offices in the reference set); or given the output level of the office, what reduced level of inputs should have been enough to produce that output level (compared to the efficient offices in the reference set).

We can also determine whether a given office is well-enveloped (closely surrounded by a sufficiently large number of efficient offices similar in input and output mix) or is an outlier (not well-enveloped). We place high confidence in the DEA rating given to well-enveloped units, but are less certain about the rating of the outliers. CFA, an extension of the DEA theory, helps in this regard as it calculates a lower bound efficiency measure in addition to an upper bound (essentially the DEA result) for each office; the wider the range between the two, the more of an outlier or less well-enveloped the unit is.

Table 3 displays the values of the variables used and DEA results for the data adjusted for complexity. Note the adjusted values for Y1 and X5, as explained above. The results indicate that only three of the twenty-one offices were rated efficient using the new complexity-weighted data. These three had also been efficient in the original data run, but five offices originally rated efficient were here rated inefficient, some quite so. The managers and staff personnel who were interviewed felt that the data weighted for complexity provided the more realistic picture. In general, they agreed with the ratings of the offices (at least in relative terms).

## CONCLUSION

Data Envelopment Analysis is quickly gaining popularity among management science theorists and also among practicing managers of a wide variety of organizations. It can provide Air Force managers with an additional tool to use in performance evaluation of similar organizations. As such, it deserves their consideration for potential use and for studies of its application to new settings.

## REFERENCES

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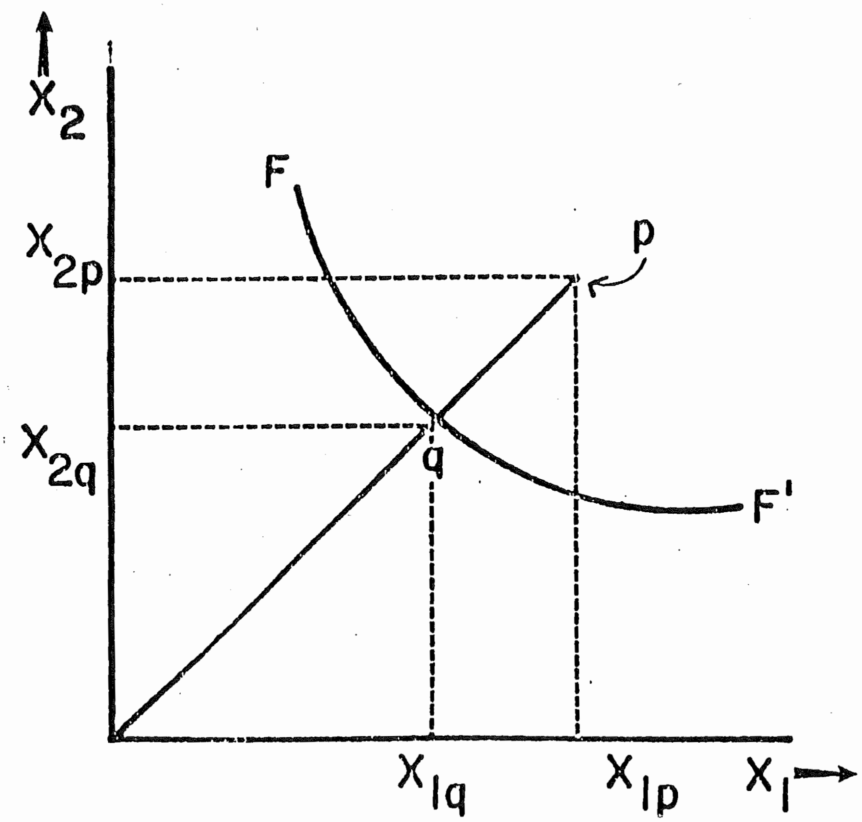


Figure 1

Isoquant Production Function

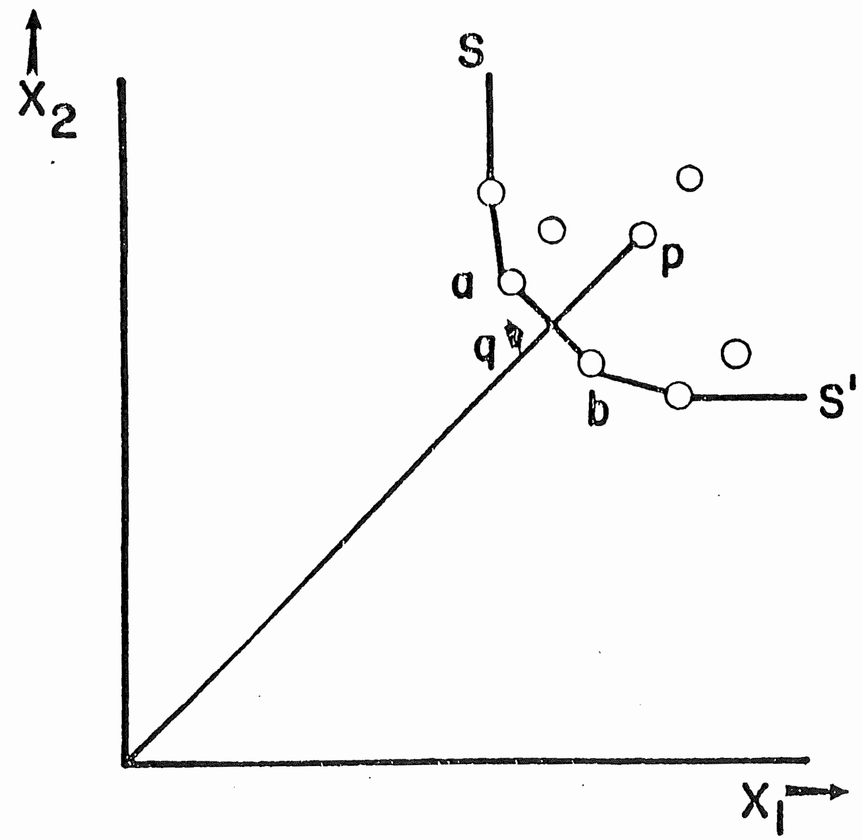


Figure 2

Linear Approximation Based on Empirical Data

# APPENDIX

## Data Envelopment Analysis Model

The original Charnes, Cooper, and Rhodes nonlinear, ratio formulation of the DEA model follows:

$$\text{\underline{Maximize}} \quad h_o = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{1}$$

Subject To

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \; ; \quad j=1,2,\ldots,o,\ldots,m \tag{2}$$

$$x_i,\; y_r,\; u_r,\; v_i \; > 0 \; ; \quad r=1,\ldots,s \; ; \quad i=1,\ldots,m \tag{3}$$

The $y_{rj}$, $x_{ij}$ are the observed outputs and inputs of the jth unit, and the $u_r$, $v_i > 0$ are the "weights" to be determined by the model. The subscript of "o" identifies the unit being rated; and "the indicated maximization, then accords the most favorable weighting that the constraints allow" [4:430]. The equivalent linear program can be stated as follows:

$$\text{\underline{Maximize}} \quad h_o = \sum_{r=1}^{s} u_r y_{ro} \tag{4}$$

$$\text{\underline{Subject To}} \quad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \tag{5}$$

for $j = 1,2,\ldots,o,\ldots,n$ (all organizations including organization "o", the unit currently being evaluated, in the reference set)

$$\sum_{i=1}^{m} v_i x_{io} = 1 \tag{6}$$

$$u_r, v_i > 0 \; ; \quad r = 1,2,\ldots,s \; ; \quad i = 1,2,\ldots,m \tag{7}$$

The constraint (6) in which the sum of the weighted inputs for the organization being rated equals one is the constraint that enables the transformation from an intractable nonlinear mathematical program to a comparatively easy to solve linear program [6].

Table 1

Variable Labels and Definitions

| Label | | Definition |
|---|---|---|
| **Output Measures** | | |
| Y1 | CONTNBR | Total number of contractual documents issued during fiscal year |
| Y2 | CONT$$$ | Total dollars obligated on documents issued during fiscal year |
| **Input Measures: Resources** | | |
| X1 | SUPNBR | Total number of personnel in supervisory positions |
| X2 | PCONBR | Total number of personnel in contracting officer positions |
| X3 | BUYNBR | Total number of personnel in buyer positions |
| X4 | CLKNBR | Total number of personnel in clerk positions |
| **Input Measures: Work Surrogates** | | |
| X5 | REQNBR | Total number of work requests received during fiscal year |
| X6 | REQ$$$ | Total dollar value of work requests received during fiscal year |

Table 2

Results for DEA Run Using All Original Variables and Data

(Dollars in millions)

| Office | Y1 CONTNBR | Y2 CONT$$$ | X1 SUPNBR | X2 PCONBR | X3 BUYNBR | X4 CLKNBR | X5 REQNBR | X6 REQ$$$ | DEA RESULT |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | .736 | 1.5 | 3.5 | 2.0 | 1.0 | 13 | 4.947 | .359 |
| 2 | 103 | 284.589 | 1.5 | 3.5 | 6.0 | 2.0 | 52 | 680.127 | .855 |
| 3 | 104 | 112.905 | 1.5 | 6.5 | 9.0 | 5.0 | 214 | 88.305 | .624 |
| 4 | 71 | 74.287 | .5 | 2.5 | 7.0 | 3.0 | 91 | 48.498 | 1.000 |
| 5 | 4 | 3.975 | .5 | 1.0 | .5 | 1.0 | 7 | 5.401 | .454 |
| 6 | 44 | 1905.752 | 4.0 | 6.0 | 10.0 | 3.0 | 75 | 201.044 | 1.000 |
| 7 | 265 | 1027.824 | 3.5 | 5.5 | 15.0 | 6.0 | 52 | 458.277 | 1.000 |
| 8 | 86 | 693.737 | 6.5 | 10.5 | 16.0 | 7.0 | 100 | 404.069 | .403 |
| 9 | 51 | 76.408 | 1.5 | 3.5 | 5.0 | 2.0 | 26 | 183.882 | .552 |
| 10 | 212 | 720.893 | 2.5 | 6.5 | 15.0 | 4.0 | 108 | 1728.015 | .843 |
| 11 | 121 | 75.255 | 1.5 | 3.0 | 11.0 | 5.0 | 250 | 58.836 | .737 |
| 12 | 159 | 63.400 | 1.5 | 7.5 | 9.0 | 3.0 | 155 | 44.219 | 1.000 |
| 13 | 78 | 160.427 | 1.5 | 1.5 | 8.0 | 3.0 | 106 | 2352.348 | .623 |
| 14 | 135 | 1415.310 | 2.5 | 3.5 | 8.0 | 4.0 | 182 | 12653.684 | 1.000 |
| 15 | 184 | 31.352 | 1.5 | 2.5 | 8.0 | 4.0 | 322 | 42.600 | 1.000 |
| 16 | 83 | 293.628 | 2.0 | 4.0 | 11.0 | 4.0 | 81 | 204.784 | .528 |
| 17 | 119 | 162.334 | 1.5 | 2.5 | 8.0 | 4.0 | 117 | 113.447 | .953 |
| 18 | 127 | 451.934 | 1.0 | 2.0 | 8.0 | 2.0 | 64 | 1084.507 | 1.000 |
| 19 | 583 | 2757.056 | 7.0 | 7.0 | 27.0 | 3.0 | 323 | 857.549 | 1.000 |
| 20 | 138 | 150.617 | 5.0 | 6.0 | 12.0 | 7.0 | 383 | 553.608 | .509 |
| 21 | 66 | 532.622 | 1.5 | 1.5 | 9.0 | 3.0 | 89 | 7829.830 | .879 |

Table 3

Results for DEA Run Using Variables and Data Weighted for Complexity

(Dollars in millions)

| Office | Y1 ACONTNBR | X1 SUPNBR | X2 PCONBR | X3 BUYNBR | X4 CLKNBR | X5 AREQNBR | DEA RESULT |
|---|---|---|---|---|---|---|---|
| 1 | 10.46 | 1.5 | 3.5 | 2.0 | 1.0 | 13.00 | .073 |
| 2 | 286.60 | 1.5 | 3.5 | 6.0 | 2.0 | 65.00 | .674 |
| 3 | 285.17 | 1.5 | 6.5 | 9.0 | 5.0 | 220.42 | .549 |
| 4 | 183.00 | .5 | 2.5 | 7.0 | 3.0 | 91.00 | .934 |
| 5 | 14.04 | .5 | 1.0 | .5 | 1.0 | 7.00 | .393 |
| 6 | 257.41 | 4.0 | 6.0 | 10.0 | 3.0 | 104.25 | .365 |
| 7 | 1070.94 | 3.5 | 5.5 | 15.0 | 6.0 | 72.28 | 1.000 |
| 8 | 322.73 | 6.5 | 10.5 | 16.0 | 7.0 | 129.00 | .282 |
| 9 | 140.57 | 1.5 | 3.5 | 5.0 | 2.0 | 32.50 | .394 |
| 10 | 761.22 | 2.5 | 6.5 | 15.0 | 4.0 | 135.00 | .907 |
| 11 | 299.67 | 1.5 | 3.0 | 11.0 | 5.0 | 257.50 | .519 |
| 12 | 373.07 | 1.5 | 7.5 | 9.0 | 3.0 | 181.35 | .719 |
| 13 | 316.09 | 1.5 | 1.5 | 8.0 | 3.0 | 125.08 | .790 |
| 14 | 491.85 | 2.5 | 3.5 | 8.0 | 4.0 | 214.76 | .859 |
| 15 | 370.10 | 1.5 | 2.5 | 8.0 | 4.0 | 322.00 | .748 |
| 16 | 278.04 | 2.0 | 4.0 | 11.0 | 4.0 | 94.77 | .416 |
| 17 | 362.73 | 1.5 | 2.5 | 8.0 | 4.0 | 136.89 | .735 |
| 18 | 391.60 | 1.0 | 2.0 | 8.0 | 2.0 | 80.00 | 1.000 |
| 19 | 1865.38 | 7.0 | 7.0 | 27.0 | 3.0 | 432.82 | 1.000 |
| 20 | 354.78 | 5.0 | 6.0 | 12.0 | 7.0 | 451.94 | .412 |
| 21 | 311.19 | 1.5 | 1.5 | 9.0 | 3.0 | 105.02 | .778 |