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*Measuring Aggregate Process
Performance Using AHP*

by
Frances X. Frei
Patrick T. Harker

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Measuring Aggregate Process Performance Using AHP ¹

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Abstract: When one undertakes a benchmarking study, it is quite typical to collect performance data on a set of business processes from a variety of organizations. While one can compare efficiency on a process-by-process level, how can one compare the overall efficiency of one organization versus another using this process-level data? This note presents a methodology that combines tournament ranking and AHP approaches to create a ranking scheme that deals explicitly with missing data and ties in the tournament scheme.

Keywords: AHP, Benchmarking, Process Efficiency

¹Frances X. Frei is at the Simon School of Business, University of Rochester, Rochester, NY 14627, frei@ssb.rochester.edu.

Patrick T. Harker is at the Department of Operations and Information Management, University of Pennsylvania, Philadelphia, PA 19104-6366, harker@opim.wharton.upenn.edu.

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1. Introduction

Social science and applied business research often uses indices to indicate the value of some phenomena. The question that repeatedly arises is how to bring together the various components to form a single index. In the case where the various components are measured along the same dimension and range, the most obvious method is to take an average score of the components. Such index creation often arises in the context of benchmarking studies. Benchmarking studies typically involve the collection of a vast quantity of statistical, anecdotal, and qualitative information concerning the relative performance of various business processes within and between organizations. Thus, such benchmarking is at the heart of the modern reengineering a phenomenon that is sweeping through organizations throughout the world (Hammer and Champy, 1993; Davenport and Short, 1990).

More than just an interesting tool for industry, the ability to compare the relative merits of various business process designs is crucial in understanding the drivers of competitiveness and performance in organizations. The design of a business process is neither an input or output as it is neither created nor consumed as other inputs and outputs; rather, the design provide the structure for the creation and consumption of the existing inputs and outputs. The process, according to Morroni (1992), actually defines how capital and labor interact in order to produce outputs. For example, Morroni provides an illustrative example in which there are ten ditch diggers with ten shovels. If an eleventh shovel is added, the process of ditch digging must be changed. That is, an additional shovel will not benefit the one-person, one-shovel process. The point here is that a process typically defines the relationship between capital and labor and thus, they are not immediately interchangeable. Thus, the process design defines the production technology for the organization.

Given that process designs are not the same as inputs like labor, how can processes be analyzed for their relative efficiency? For analyzing the relative efficiency of a single process, Frei and Harker (1995) present an extension of Data Envelopment Analysis (DEA) to incorporate process design characteristics. However, organizations are composed of multiple business processes. How is one organization compared to another when measuring business process-level

data? This question is the focus of the current note.

This note presents a method for determining an index in the instance when each of the components is a relative ranking. That is, when there are a group of relative performance measures across a variety of measures, and it is necessary to aggregate these measures, what method of aggregation should be used? Taking an average is the most obvious thing to do, but there are several problems with this approach. First, if the relative performance measures are ratio-scale numbers, then their average is meaningless theoretically (Saaty 1986). We present a method that allows for ratio-scale numbers and missing data to come up with an aggregation score or index. We then apply this method to a small to show how it is more suitable than considering average performance.

Using an Analytic Hierarchy Process (AHP)-like method, we present an alternative that is theoretically and practically superior to the most common index-creation scheme, especially when using relative measures. This method overcomes the problem of aggregating ratio-scale metrics and thus, is useful in wide array of social science and operations management contexts.

The remainder of this note is structured as follows. The next section will review the Frei and Harker (1996) method for analyzing the efficiency of a single process and will be followed by the description of the proposed method of aggregating these single process metrics to create organizational efficiency scores in Section 3. The note will then conclude with the description of a small example of this method to demonstrate its superiority to existing methods.

2. Analyzing Single Process Efficiency

Frei and Harker (1996) describe an extension of Data Envelopment Analysis (DEA) to analyze the relative efficiency of a given business process across multiple organizations. Creating a process map is the standard first step in the evaluation of processes (Shostack, 1987; Kingman-Brundage, 1992). However, even after a careful study of process maps has occurred, it is still difficult to determine how efficient a single process is or, from a group of processes, which is *better*. There is no existing methodology that helps us to formally compare processes. The technique developed by Frei and Harker builds on existing frontier estimation methods to provide a way to evaluate processes with multiple inputs and outputs, at least some of which have non-market values. The first step is to determine the relative efficiency of a given process, the other firms that might be used for benchmarking this process, and the managerial implications of the choices involved.

The work of Brockett and Golany (1996) introduces the concept, in the context of Data Envelopment Analysis (DEA), of organizing decision making units (DMUs) into subgroups in order to determine if one subgroup outperforms another. This logic is easily transferred to processes, where it is recognized that while all processes require the same categories of inputs to produce similar categories of outputs, there are vastly different ways of organizing the way in which the work occurs. Brockett and Golany determine the efficient frontier for each subgroup in order to determine which input and output scenarios are dominant within each subgroup. Although it is easy to visually understand which process-design group is dominant in two dimensions, Brockett and Golany provide no means of determining this in higher dimensions. Thus, although Brockett and Golany's idea of comparing frontiers is useful in two dimensions, it is quite difficult in higher dimensions. Frei and Harker (1996) present a methodology for comparing process groups in higher dimensions.

3. Analyzing Organizational Process Efficiency

The previous section outlined an approach for analyzing the efficiency of business processes on a process-by-process basis. However, organizations are a collection of such processes. How can these be aggregated to form an index of efficiency for the organization as a whole? This question is addressed herein.

A standard approach for aggregating data at an institutional or ‘team’ level is to conduct institutional comparisons is a tournament-ranking scheme. The first step in using a tournament ranking scheme is to develop a matrix of ‘wins’; i.e. a matrix $W = (w_{ij})$ where each entry, w_{ij} , represents the number of times that Participant i beat Participant j . That is, if there are 10 participants there will be a 10x10 matrix such that each entry in the matrix $W = (w_{ij})$ represents the number of times Participant i performed better than Participant j . In the case where two participants have never competed against each other, the entries are left blank and treated as “missing data.” This “missing data” can be handled by using the correction developed by Harker (1987).

In the case where Participant i outperforms Participant j for all of their common processes, a zero would be entered in cell w_{ij} , and the number of common processes entered in cell w_{ji} . Traditionally, the second step in tournament ranking analysis is to develop a matrix of wins-to-losses where each entry is replaced with $\frac{w_{ij}}{w_{ji}}$. However, when considering the case where one participant wins all of the matches against another participant (i.e., $w_{ji} = 0$), the result is an undefined value as one entry in the wins-to-losses matrix. Thus, this entry would state that Participant i is infinitely better than Participant j . In most cases, such infinite values make no practical sense.

In order to limit the value of the matrix elements, one can invoke the bounded scale property axiom in Saaty’s (1986) Analytic Hierarchy Process. Thus, creating a bounded scale leads us to use Saaty’s bounded reciprocal matrix approach to forming the matrix that represents the relative power of one organization or participant over the other (see Harker and Vargas 1987 for details). Thus, rather than having each matrix entry as the number of wins divided by the number of losses or $\frac{w_{ij}}{w_{ji}}$ (where there would be potentially undefined entries), each entry is

represented by $e^{\frac{\ln(\alpha)^{w_{ij}-w_{ji}}}{w_{ij}-w_{ji}}}$, where α represents the bound of how much better one organization is than another. The bound used in this note is the number proposed by Saaty (1986) (i.e., $\alpha = 9$). This allows for an entry of 1 when two organizations have the same numbers of wins and losses and ranges from $1/\alpha$ to α for the range of possible performance scores when there are uneven wins and losses. Thus, if one participant wins all of the matches, that participant will have an entry of 9 in the wins-to-losses matrix, and the losing participant will have an entry of $1/9$.

Formally, the algorithm for the tournament-ranking scheme for aggregating process-level efficiency analyses is as follows:

- Step 1.** Determine the rank of each institution for each process using the process described in Frei and Harker (1995).
- Step 2.** Determine a matrix of “wins” and losses for each process where w_{ij} equals the number of processes for which institution i outranks institution j . Enter one for each diagonal entry.
- Step 3.** For each instance in which there are no competitions in common between two participants (i.e., $w_{ij} + w_{ji} = 0$), add 1 to the diagonal of the win-loss matrix for each participant and replace the two cells which correspond to the lack of competition with zeros.
- Step 4.** Scale the win-loss matrix with $e^{\frac{\ln(\alpha)^{w_{ij}-w_{ji}}}{w_{ij}-w_{ji}}}$ to ensure that one organization is not considered infinitely better than another is. Do not perform the scaling for “missing data” cells but rather keep their value as zero.
- Step 5.** Determine the eigenvector of the scaled win-loss matrix. This eigenvector contains the relative performance over each institution for the set of processes.

In order to illustrate the algorithm, consider the following small example. Three competitors have competed against each other in up to four competitions. The matrix shown in Table 1 represents the rank of each team in each competition. For example, in the second competition, Team C won and Team B came in second; Team A did not compete in the second competition. The mean rank is included in the last row to indicate the traditional measure for evaluating the best performer. According to the mean rank, the order of performance for the teams is A, C, and B. We will show how the rank from our methodology differs from this and

more closely resembles relative performance.

Table 1. Sample Matrix of Ranks

	Team A	Team B	Team C
Competition 1	1	2	
Competition 2		2	1
Competition 3		1	2
Competition 4	1	2	
<i>Mean Rank</i>	<i>1</i>	<i>1.75</i>	<i>1.5</i>

Table 2 represents the matrix of wins and losses for each team (Step 2). That is, each row represents the number of times that a team beat the competitor in the corresponding column. For example, Team A beat Team B twice. In addition, each column represents the number of times that a competitor lost to the competitor in the corresponding row. For example, Team C lost to Team B once. Notice that a one is entered for each diagonal entry.

Table 2. Sample Matrix of Wins and Losses

	Team A	Team B	Team C
Team A	1	2	0
Team B	0	1	1
Team C	0	1	1

The next step is to determine which participants did not compete against each other (Step 3). In this example, Team A did not compete against Team C, and thus one must be added to the diagonal for Team A and Team C. In addition, a zero is recorded for each of the missing data locations. Next each entry is scaled according to the formula $e^{\frac{\ln(\alpha)(w_{ij}-w_{ji})}{w_{ij}-w_{ji}}}$ in order to determine the scaled matrix of wins-to-losses (Step 4). The scaled results are recorded in Table 3.

Table 3. Scaled Matrix of Wins and Losses

	Team A	Team B	Team C
Team A	2	9	0
Team B	1/9	1	1
Team C	0	1	2

Finally, the eigenvector of the matrix is determined using the scaled data as shown in Table 4. As can be seen in this table, the order of performance for the teams has changed in this

method as compared to using the mean rank. This is because the mean performance does not adequately account for the situation when some competitions include only a subset of the teams. In this example, Team C has a better mean score than Team B even though they split their head-to-head competitions. While Team B lost to Team A twice, this loss should not inform Team B's ranking relative to Team C as Team C did not compete against Team A. It could very well be that Team A is simply better than Team B and that Team B and Team C are equal to one another. The method described in this note produces this very result which we feel more accurately reflects the relative performance of this data.

Table 4. Eigenvector and Rankings

	Eigenvector	Eigenvector Order	Mean Rank	Mean Rank Order
Team A	0.82	1	1	1
Team B	0.09	2	1.75	3
Team C	0.09	2	1.5	2

The methodology just described generates a composite performance score for each team when competing across a number of competitions. As can be seen from the above example, simply using the average performance can be misleading, especially when there is missing data. The proposed method takes into account the missing data and more accurately produces a ranking which reflects relative performance.

4. An Empirical Example with the Banking Industry

In order to demonstrate the usefulness of the technique developed herein, we apply it to a data set from the banking industry. This data is a result of the retail banking study undertaken at the Wharton Financial Institutions Center. The retail banking study was aimed at understanding the drivers of firm performance and the relationship between industry trends and the experiences of the retail banking labor force.

Participation in the study required substantial time and effort on the part of organizations. Therefore, commitment to participation was sought by approaching the 70 largest U.S. BHCs directly, and, in the second half of 1994, the participation of one retail banking entity from each BHC was requested. Fifty-seven BHCs agreed to participate. Of these, seven BHCs engaged the participation of two or more retail banks in the BHC, giving 64 retail banks in total.

Multiple questionnaires were delivered to each organization in this sample. Questionnaires ranged from 10 to 30 pages, and were designed to target the “most informed respondent” (Huber and Power, 1985) in the bank in a number of areas, including business strategy, technology, human resource management and operations, and the design of business processes.

Altogether, the entire survey of retail banking covers 121 BHCs, and 135 banks, which together comprise over 75% of the total industry, as measured by asset size. The scope and scale of this survey make it the most comprehensive survey to date on the retail banking industry. For this paper, we analyze the set of retail banks for which we have data on process performance and financial measures. This reduces our sample to forty-five retail banks.

The process performance measures used in this paper rely on the ability to grade a firm for each individual process relative to the other banks in the study. That is, for each firm there are grades for up to eleven processes. The methodology used to grade the processes is described in Frei and Harker (1996), which demonstrates an extension of DEA to analyze the relative efficiency of a given business process across multiple organizations. After determining the process-level efficiency score for each institution, the grade is determined by normalizing the efficiency scores to a scale of 0% to 100%, with the efficient banks scoring 100%.

Before we present our analysis, we need a formal description of a production process. A production process is the way in which work is organized and inputs are consumed in order to produce outputs. For example, a process might be the way in which a checking account is opened. The inputs consumed are the labor (platform representative) and capital (information technology), and the outputs produced are the opening of the account in a way that is convenient for the customer (in terms of customer time involved and when they have access to their money). In order to understand the process of opening a checking account, we need to know the steps involved, the order of these steps, the way in which people are involved, and the role of technology. For our analysis, we look at a process as a mapping from inputs to outputs and identify the critical design issues that lead to greater value.

For each of the eleven processes in this study, the efficiency analysis described in Frei and Harker (1996) has been performed. This analysis determines the efficiency with which each bank produces a set of outputs from a set of inputs. The categories of inputs and outputs for each process are shown in Table 5. For each process, the banks have been ranked according to

their efficiency score and thus there are up to eleven rankings for each of the banks. The results of this individual process analysis are then aggregated using the methodology described herein to create an institutional aggregate process efficiency score. The aggregated score is used to analyze the role of process efficiency in describing performance of a bank.

Table 5. Summary of Process Inputs and Outputs

	<i>Inputs</i>	<i>Outputs</i>
<i>Open Checking Account</i>	Activity Time Checking IT Functionality	Customer Time Check Cycle Time ATM Cycle Time
<i>Open Small Business Loan Account</i>	Activity Time SBL IT Functionality	Customer Time Approval Cycle Time Money Cycle Time
<i>Open Certificate of Deposit</i>	Activity Time CD IT Functionality	Customer Time
<i>Open Mutual Fund</i>	Activity Time MF IT Functionality	Customer Time
<i>Open Home Equity Loan Account</i>	Activity Time HE IT Functionality	Customer Time Approval Cycle Time Money Cycle Time
<i>Correct A Checking Double Post</i>	Activity Time Checking IT Functionality	Customer Time Correct Cycle Time
<i>Correct A Home Equity Loan Double Post</i>	Activity Time HE IT Functionality	Customer Time Post Cycle Time Notify Cycle Time
<i>Correct A Small Business Loan Double Post</i>	Activity Time SBL IT Functionality	Customer Time Post Cycle Time Notify Cycle Time
<i>Redeem A Premature Certificate of Deposit</i>	Activity Time CD IT Functionality	Customer Time Redeem Cycle Time
<i>Stop Payment on A Check</i>	Activity Time Checking IT Functionality	Customer Time
<i>Replace A Lost ATM Card</i>	Activity Time Checking Tech Functionality	Customer Time Replace Cycle Time

Does Process Efficiency Matter?

While there is a significant body of theoretical (Morrone, 1992) and anecdotal

(Davenport and Short, 1990) evidence on the importance of process management, there is little statistical evidence that process management matters with respect to the ‘bottom line’ of the institution. We show that, while no individual process is correlated with firm performance, the aggregate measure of process performance is correlated with firm performance.

We consider the relationship between the process efficiency of a bank, as measured by its aggregate process performance, and the financial performance of the institution. Deciding on a single measure of financial performance of a firm is difficult. We have consulted with industry and academic experts and have come up with five financial performance measures that fall into roughly three categories. The first category is the most traditional, return on investment. In this category, we have return on assets (ROA) and return on equity (ROE). The second category contains the market measures of market-to-book ratio and Tobin’s Q. The final category contains a profit efficiency measure derived by Berger and Mester (1997).

There is a significant positive relationship between the banks’ process performance and financial performance for each of the financial measures as shown in Table 6. That is, as aggregate process performance improves, so does financial performance. Of course, there are two explanations for this relationship. First, it may be the case that better process performance does indeed drive financial performance. The other explanation is that firms that are financially secure have the resources to be better process performers. In addition, there could well be other drivers of financial performance for which we need to control. To this end, we have run multivariate regressions with aggregate process performance and firm size (as measured by log assets) as the independent variables. We use firm size since it is commonly believed to be the largest determinant of financial performance. Our results demonstrate that, for our sample of banks, while there is not a clear relation between firm size and our financial performance measures and there is a clear relation between aggregate process performance and our financial performance measures.

While these simple regressions cannot conclusively determine that aggregate process performance affects firm financial performance, this evidence does, in concert with theoretical and anecdotal evidence, suggest that aggregate process performance as we have measured it, is related to financial performance. Thus, we take this as support of the usefulness of our aggregation technique described herein, and recommend its use for those situations where

there are repeat competitions amongst many competitors, but that not every competitor plays every other competitor.

Table 6. Firm Size, Process Performance, and Financial Performance

Independent Variable	ROA	ROE	Market to book	Tobin's Q	Profit efficiency
Constant	0.74	-32.09**	110.55	1.79***	-0.83
Log Asset	0.02	1.96***	0.47	-0.03	0.05
Process Perform.	0.97*	14.96**	106.29**	0.52*	1.13*
Adjusted R ²	0.036	0.196	0.047	0.089	0.074

* - Indicates significance at the 10% level

** - Indicates significance at the 5% level

*** - Indicates significance at the 1% level

5. Conclusions and Future Research

This note has presented a new methodology for determining a composite measure for performance given that a team or institution competes across several competitions, and for situations where not all teams compete with one another. The tournament ranking literature has been extended to allow for the situation in which one competitor wins all of the matches between two competitors. The approach was then used to illustrate how it more accurately reflects aggregate performance than such traditional measures as average performance.

The proposed methodology treats all processes as equivalent when undertaking the aggregation procedure. Obviously, some processes are more important to an organization or an industry than others. Thus, a clear extension of the current methodology is to weight the various process performance metrics by their importance, and to then conduct the synthesis to generate the institutional rankings; this is left for future research. In order to accomplish this weighting, we would need to solicit expert judgments or data on worth of the relative importance of each process using a methodology like the Analytic Hierarchy Process (Saaty 1986). We have presented the basic mechanics in our model, which is easily extended to allow for this circumstance.

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