ENTERPRISE RESOURCE PLANNING (ERP) SYSTEM SELECTION: A DATA ENVELOPMENT ANALYSIS (DEA) APPROACH

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ABSTRACT

Over the last five to eight years a large number of businesses worldwide have implemented Enterprise Resource Planning (ERP) Systems. ERP systems are a category of software that offer extensive support to manage business processes. They are application software that can be used in most kind of businesses and organizations. Adoption and implementation of ERP systems involves risks and a large number of organizations have wasted millions of dollars as a result of failed implementations. Some of these failed implementations may be attributed to the selection of an ineffective ERP system. This paper applies Data Envelopment Analysis (DEA) to the process of selecting an ERP system.

KEYWORDS

Enterprise Resource Planning (ERP)
Data Envelopment Analysis (DEA)
INTRODUCTION

Enterprise resource planning (ERP) is a software suite that integrates back-office operations such as manufacturing, finance, accounting, sales, distribution and human resources in an enterprise and links these operations to the front-office and supply chains. In 1997 more than 20,000 firms worldwide paid $10 billion to ERP vendors and the total ERP company revenue for 2002 was expected to top $52 billion [17]. The purchase and use of ERP software is an expensive undertaking and it is important that organizations select an appropriate packaged system from amongst a large number of ERP solutions available.

In this paper, data envelopment analysis (DEA) is proposed as an approach to identifying an ERP system that provides the best combination of performance attributes. Developed by Charnes, Cooper and Rhodes [9], DEA is a mathematical programming technique that uses multiple inputs and outputs to calculate the relative efficiencies of multiple decision making units (DMUs). Through the conversion of multiple critical attributes into a single measurement of relative efficiency for each ERP system, DEA will help managers assess the importance and usefulness of each ERP system with respect to all other systems being considered.

The next section of the paper describes ERP systems evolution, their features and the importance of selecting an appropriate ERP package. Next, we provide an introduction to DEA and its application in management decision-making. Stages in ERP system selection process are discussed in the following section. Finally, DEA models for ERP selection are developed, model results are presented, managerial implications of the DEA approach to ERP system selection are identified and conclusions are drawn.
ENTERPRISE RESOURCE PLANNING (ERP) SOFTWARE

ERP software programs help an organization manage company wide business processes by using a common database operating on a common computing platform and shared management reporting tools. ERP software support the efficient operation of business processes by integrating business activities including sales, marketing, manufacturing, materials management, accounting and human resources. Data is entered into an ERP system once and only once and applications in all the functional areas use the same consistent, complete and common data. For example, when data from a sales order is entered by an order entry person into an ERP system the data has a ripple effect and triggers a number of business processes. This data becomes immediately available for use by all other functional areas of the business. Materials management module of the ERP system does an availability check and if stock is on hand the process of order fulfillment starts. If there is no stock available, the ERP system issues either a purchase order or a production order. Manufacturing can initiate the fulfillment of the order and the human resources functionality of the ERP system can initiate process for scheduling workforce or hiring additional workers if needed. Logistics can initiate shipping activities and accounting can start formulating customer invoice.

ERP software has evolved from Manufacturing Resource Planning (MRP II) software which in turn has evolved from Materials Requirement Planning (MRP) software [6]. In the 1980’s MRP software were developed based on principles of inventory control and management. MRP software allowed a plant manager to plan production and raw materials requirement by examining the forecast of demand and the production schedule required to meet the demand. The raw material needed to meet the production was calculated and the purchase orders were
sent to suppliers. MRP II emerged in the 1980’s as an extension of MRP to support production activities on the shop floor and also activities to facilitate distribution of manufactured products. In the 1990’s MRP II was extended to support other business functions such as accounting, finance, human resources, sales and marketing. During this time, principles of Just in Time (JIT) and Total Quality Management (TQM) were developed with the objectives of waste minimization and quality improvement, respectively. The concept of ERP emerged as an extension of MRP II and combined with principles of JIT and TQM. Currently, ERP system vendors are trying to extend the core capabilities of ERP by incorporating principles and capabilities of Supply Chain Management (SCM) and Customer Relationship Management (CRM) software.

ERP software is developed using several features that distinguish it from MRP and MRP II software. First, they allow all business areas to access a centralized database thereby eliminating redundant data and improving information float, data accuracy and availability. Second, they are a general purpose software that can be implemented in any business. ERP systems group business processes into modules such as accounting and finance, sales and distribution, human resources, production and materials management. This modular approach enables businesses to select and implement appropriate modules. Thus, a wholesale distributor would initially implement sales and distribution module functionalities. Later, if the business achieves a higher degree of vertical integration through the acquisition of a manufacturing plant, for example they will roll in functionalities under production and materials management module. Finally, ERP systems process and distribute information on a real-time or near real-time basis. This helps businesses achieve a higher level of customer service by being more responsive to
customer needs. Additionally, most ERP systems have multi-lingual capabilities and make use of powerful graphical user interface (GUI).

ERP software are available from a large number of vendors [15]. Some large ERP software vendors include SAP, J.D. Edwards, BaaN, Oracle, and Peoplesoft. SAP R/3 Software is the top seller. Brooks and Zeltmann [7] provide an introduction to SAP, present successful implementations at selected companies including Colgate-Palmolive, Nestle, Micro Software Group. Japan’s Yamaha Motor Co., Ltd. and IBM and discuss some features of SAP. The contributions of ERP system to organizational success has been recognized by business organizations as well as academic institutions. ERP modules have been integrated into the academic curriculum (such as ERP financial application class) in order to provide students with hands-on experience in ERP financial system [16].

In December 2004, Oracle bought Peoplesoft for around $10.3 billion. Depending on the vendor, ERP packages cost several thousand, hundreds of thousands, and even millions of dollars [20]. They consume a large portion of an organizations capital budget and the selection and subsequent purchase of an inappropriate system can have an adverse effect on the organization. Several papers have raised the issues for a successful ERP implementation. For example, Zviran et al [21] conducted an empirical examination of two success indicators of ERP implementation, namely user satisfaction and perceived usefulness. Ahituv, Neumann and Zviran [1] suggested the system development approach, which combines three traditional system development models; the information system life cycle model (SDLC), the prototyping model, and the application software package model.

There is a growing consensus amongst ERP system implementers that selecting an inappropriate system is a major reason for ERP implementation failure. They also emphasize the
importance of selecting an appropriate ERP system for a successful ERP implementation. This paper demonstrates how Data Envelopment Analysis (DEA) can be applied to the process of selecting an appropriate ERP system.

**DATA ENVELOPMENT ANALYSIS (DEA)**

DEA was initially developed by Charnes et al [9] as an application of linear programming to measure and compare the relative efficiencies of decision-making units (DMUs), which involve multiple, incommensurate inputs and outputs. DEA has been widely used in several areas such as measuring performance of physician practices [2], component suppliers [14], schools [10], district councils [19] banks, hospitals, courts etc.

Thanassoulis et al [19], Boussofiane et al [5] and several other papers addressed the fact that information obtained from DEA assessment can be used to discover which DMUs can be classified as efficient or inefficient, identify possible good operational practices and explore the possibility of setting targets for inefficient units. Banker et al [4] presented the DEA formulation to evaluate the efficiency of DMU when some of the inputs and outputs are exogenously fixed and beyond the control of the DMU. Recently, DEA has been integrated with the multiple-objective linear programming (MOLP) as an interactive approach to a resource-allocation problem in organizations with a centralized decision-making environment [17]. Golany, B. [12] proposed the use of preference information when setting the performance targets in the context of DEA. Sutton et al [18] used DEA notion to evaluate decision choices. They suggested the modified DEA to find weights which show the performance of options and to provide a framework to elicit and use information exogenous to the decision alternatives.
The efficiency score of each DMU is determined by the weighted sum of outputs divided by weighted sum of inputs. Charnes et al [9] recognized difficulty in seeking common weights because each DMU may value inputs and output differently; they proposed to use a set of weights that give the highest possible relative efficiency scores.

The fractional form of DEA, which maximize the efficiency $h_0$ of the $j_0$ DMU is defined as follows:

$$\text{Max} \quad h_0 = \frac{\sum_{r=1}^{t} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}}$$

s.t. \quad \frac{\sum_{r=1}^{t} u_r y_{rf}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad j = 1…, j_0 …, n

\begin{align*}
  u_r &\geq \varepsilon \quad r = 1… t, \\
v_i &\geq \varepsilon \quad i = 1…m,
\end{align*} \quad \text{(Model M1)}

where

- $y_{rf}$ is the amount of the $r$th output from unit $j$,  
- $u_r$ is the weight given to the $r$th output,  
- $x_{ij}$ is the amount of the $i$th input to the unit $j$,  
- $v_i$ is the weight given to the $i$th input, and  
- $\varepsilon$ is a very small positive number.

Charnes and Cooper [8] provides approaches to convert Model M1 into a linear programming by setting the denominator in the objective function to some arbitrary constant and
moving the denominator in the first constraints to the right-hand side of the constraint. For computational convenience, the DEA linear programming model is converted into a dual model as follows:

\[
\text{Max} \quad Z_0 - \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{t} s_r^+ \right)
\]

s.t. \quad Z_0 x_{j_0} - \sum_{j=1}^{n} x_{j} \lambda_{j} - s_i^- = 0 \quad i = 1 \ldots m

\sum_{j=1}^{n} y_{j} \lambda_{j} - s_r^+ = y_{j_0} \quad r = 1 \ldots t

\lambda_{j}, s_i^-, s_r^+ \geq 0 \quad \text{(Model M2)}

where \( \lambda_{j}, s_i^-, s_r^+ \) are the dual variables.

There are alternatives to measure the efficiency of a DMU. One may use either the input-reducing efficiency or an output-increasing efficiency measure. Both model M1 and M2 measure output-increasing efficiency. In measuring the input-reducing efficiency, the relative efficiency of DMU (for example DMU \( j_0 \)) is evaluated by finding the best practice DMU’s minimum effort required to produce the same amount of outputs as DMU \( j_0 \) does. In other words, how much effort it takes for the best practice DMU (reference DMU) to produce as much outputs as of DMU \( j_0 \).

We consider the application of DEA to ERP selection; the choices of DMU become ERP alternatives. For simplicity, we apply model M1 to select the best ERP candidate.

**EPR SOFTWARE SELECTION PROCESS**
The efficacy of large-scale ERP selection and implementation is based on a qualitative as well as a quantitative approach. Often qualitative issues are as important as the quantitative factors in the process of evaluating ERP systems. DEA is a quantitative technique and is used for a quantitative evaluation of ERP systems. This section discusses the use of DEA for ERP software selection.

Fisher and Kiang et al. [11] used DEA to analyze and compare the performance of ERP packages. However, their study is restricted to the mid-level ERP software, which were designed for mid-sized organizations. In addition, their evaluations are based on information provided by ERP vendors. This may not relate to some organizations and may not reflect the organizations’ needs. Our study provides a case study on how DEA can be applied for ERP performance evaluation based on the real corporate data. Since the information was provided by an organization that selected and implemented an ERP system, our analysis and evaluation are consistent with the organization’s needs and requirements.

Data for developing the model was obtained from a trading company in the Upper Great Plains. To maintain confidentiality, the organization would be referred to as the firm. The firm is a leader in the sales and distribution of electrical parts and has operations in seventeen United States locations and a branch overseas. It serves the Industrial, Utility, Construction and Data Communications market segments and also operates retail lighting showrooms in three branch locations. In 1989, the firm went live with a legacy system developed specifically for the electrical distribution industry. By early 2000, the business needs of the firm and those of its customers and suppliers had changed and the firm decided to replace the legacy system with ERP software.
The ERP selection process adopted by the firm included the following three stages: Initial selection stage, candidate evaluation stage and final evaluation stage. The initial selection stage was a filtering phase where filtering criteria such as operating system, data base requirements, network architecture and implementation cost were used to develop a candidate list. The candidate list was evaluated using product/vendor ranking models and benchmarking to reduce it to a smaller set. In the final evaluation stage, a smaller set of vendors were required to demonstrate how their ERP systems met the functionalities identified by the firm. DEA is used at the final evaluation stage to select the most efficient system out of the candidates that qualified to and were a part of the smaller set.

**DEA MODEL FOR SOFTWARE SELECTION AND DISCUSSION OF RESULTS**

For each candidate ERP system, DEA converts multiple critical attributes into a single relative efficiency measurement. This will help a decision maker measure the degree of usefulness of each ERP system relative to others being considered.

ERP selection process at the final evaluation stage is based on the evaluation of two broad sets of criteria: ERP system attributes that can help an organization meet its business needs and attributes related to the vendor of the ERP system. Of the several factors that are included in the two sets the following were used to develop the DEA model: Complexity of implementation, estimated cost of implementation, functional match and vendor profile. Complexity of implementation is a measure of the internal effort with respect to the time and effort involved in the configuration, documentation, training and support functions of the ERP implementation. The estimated cost of implementation includes cash flow for acquisition of hardware, software and networking devices, end user training and documentation. Functional match is a measure of
the strength and capability of the ERP system to meet the business requirements of the firm. Vendor profile is an attribute based on factors such as the financial strength of the ERP system vendor, regional presence of the vendor and prompt availability of software upgrades and technical support.

Values for these input and output attributes for the six ERP systems at the final evaluation stage were obtained through the process of an in person interview with a manager from the firm and are shown in Table 1.0. This individual was the project manager for the ERP selection and implementation project. At the request of the project manager the names of the six actual ERP systems have been changed to A, B, C, D, E and F.

<table>
<thead>
<tr>
<th>ERP Alternative</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complexity of Implementation</td>
<td>Estimated Cost of Implementation ($ millions)</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>5.6</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>1.6</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>1.65</td>
</tr>
</tbody>
</table>

The input and output attributes were used to develop DEA models for each of the six ERP systems. The objective function and the constraints of the DEA model for ERP system A are shown in Table 2.0.
Table 2.0: DEA Model for ERP System A

<table>
<thead>
<tr>
<th>ERP System</th>
<th>Objective Function</th>
<th>Constraints</th>
</tr>
</thead>
</table>
| A          | Maximize 3.9 y_{1,A} + 5.0 y_{2,A} | \[5.0 x_{1,A} + 5.6 x_{2,A} = 1.0\]  
|            |                    | \[3.9 y_{1,A} + 5.0 y_{2,A} - 5.0 x_{1,A} - 5.6 x_{2,A} \leq 0.0\]  
|            |                    | \[3.9 y_{1,A} + 5.0 y_{2,A} - 5.0 x_{1,A} - 5.0 x_{2,A} \leq 0.0\]  
|            |                    | \[2.4 y_{1,A} + 4.0 y_{2,A} - 4.0 x_{1,A} - 1.6 x_{2,A} \leq 0.0\]  
|            |                    | \[1.9 y_{1,A} + 2.0 y_{2,A} - 4.0 x_{1,A} - 1.2 x_{2,A} \leq 0.0\]  
|            |                    | \[2.4 y_{1,A} + 3.0 y_{2,A} - 2.0 x_{1,A} - 0.6 x_{2,A} \leq 0.0\]  
|            |                    | \[0.4 y_{1,A} + 1.0 y_{2,A} - 1.0 x_{1,A} - 1.65 x_{2,A} \leq 0.0\]  
|            |                    | \[y_{1,A}, y_{2,A}, x_{1,A}, x_{2,A} \geq 0.001\]  

The six models were solved using the linear programming module of Management Scientist [3]. The relative efficiency scores and other results from the model solution for the five ERP systems are shown in Table 3.0.

Table 3.0: DEA Solutions using Management Scientist

<table>
<thead>
<tr>
<th>ERP Alternatives</th>
<th>Relative Efficiency (%)</th>
<th>(y_{1j})</th>
<th>(y_{2j})</th>
<th>(x_{1j})</th>
<th>(x_{2j})</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>66.4</td>
<td>0.001</td>
<td>0.132</td>
<td>0.199</td>
<td>0.001</td>
</tr>
<tr>
<td>B</td>
<td>66.4</td>
<td>0.001</td>
<td>0.132</td>
<td>0.199</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
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<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>66.6</td>
<td>0.001</td>
<td>0.166</td>
<td>0.250</td>
<td>0.001</td>
</tr>
<tr>
<td>D</td>
<td>39.5</td>
<td>0.207</td>
<td>0.001</td>
<td>0.250</td>
<td>0.001</td>
</tr>
<tr>
<td>E</td>
<td>100</td>
<td>0.001</td>
<td>0.333</td>
<td>0.500</td>
<td>0.001</td>
</tr>
<tr>
<td>F</td>
<td>66.5</td>
<td>0.001</td>
<td>0.665</td>
<td>0.998</td>
<td>0.001</td>
</tr>
</tbody>
</table>

An ERP alternative with 100% efficiency is classified as efficient; others are inefficient. For our scenario, ERP system E is classified as efficient and the remainder five systems as inefficient. This means that for the given complexity of implementation and the estimated cost of implementation no other ERP system offers a better functional match and vendor profile. An examination of the attributes data presented in Table 1.0 does not make the identification of the most efficient ERP system obvious. Thus DEA simplifies the process of identifying the most efficient ERP system offering the best combination of input and output attributes.

An analysis of results presented in Table 3.0 helps us establish with relative ease the reasons why a given ERP system is not as efficient as the most efficient system. For example, ERP alternative A is 34% less efficient than E. An examination of its attributes reveals that the complexity of implementation and the cost of implementation of system A are more than that of system E.

CONCLUSION

The primary objective of this paper was to demonstrate how a systematic analysis of Enterprise Resource Planning system selection can be done using Data Envelopment Analysis. The methodology assesses the relative efficiency of each ERP system given a set of input and output
variables. The approach discussed in the paper can be used for the selection of other enterprise wide application software. These could include but are not limited to application software for Supply Chain Management (SCM) and Customer Relationship Management (CRM). For any selection process the key would be to meaningfully determine the various attributes used in the selection process and to carefully classify them as input and output variables. Businesses that have implemented SCM and CRM systems could be used as a source data on input and output attributes.

REFERENCES


