



# The Evaluation of ERP Systems Using Data Envelopment Analysis

Edward W.N. Bernroider and Volker Stix  
Department of Information Business  
Vienna University of Economics and Business Administrations  
Aug. 2-6, 1090 Vienna, Austria  
FAX: (+43) (1) 31336-739

Tel: (+43) (1) 31336-5231 Tel: (+43) (1) 31336-5209  
Edward.Bernroider@wu-wien.ac.at Volker.Stix@wu-wien.ac.at

## ABSTRACT

*This paper discusses the use of data envelopment analysis (DEA) as a decision tool for enterprise resource planning (ERP) systems. DEA provides a number of opportunities, which seem to justify its use in this field. This includes the requirement of minimal a priori assumptions, objectifying characteristics of subjective measurements and diplomatic group decision. Both the ERP system and its requirements as well as the DEA model are introduced and a model for group decision as often required for ERP solutions is developed.*

## INTRODUCTION

ERP is a fine expression of the inseparability of information technology (IT) and business. They represent large, complex, computerized and integrated systems, which can strongly influence long-term business success. ERP systems promise the development and sustainment of competitive advantage in the global marketplace through enhanced decision support, reduced asset bases and costs, more accurate and timely information, higher flexibility or increased customer satisfaction (Dav-enport, 2000; Poston & Grabski, 2000; Rizzi & Zamboni, 1999). But the far-reaching structural changes following an ERP software implementation can also be disastrous as has been shown (Bingi, Sharma, & Godla, 1999; Scott, 1999). This research was motivated by an empirical study of the ERP decision making process in Austrian enterprises (Bernroider & Koch, 2002). It revealed that only 30% of the organizations (when excluding conventional financial evaluation methods) used some sort of formal evaluation techniques. Almost all of these organizations applied methods based on some kind of ranking and scoring technique (Remenyi, Money, Sherwood-Smith, & Irani, 2000), the remaining minority used a real option (Taudes, 1998; Trigeorgis, 1996) or hedonic wage model technique, which was introduced by Sassone (Sassone, 1984, 1987). The ERP system selection is a semi-structured decision problem without an agreed-upon formal procedure (Laudon & Laudon, 1998) and is a very critical task which involves many different views of many different people of many different critical evaluation elements. All this demands for a tool which supports: multi-factor input to output evaluation and objective and consistent group decision capabilities.

In this article we focus on data envelopment analysis (DEA) to support decision making for ERP systems. DEA is a method of comparative efficiency measurement and has been successfully used over many years to measure the performance of any form of decision making units (Athanasopoulos & Thanassoulis, 1995; Boufounou, 1995; Bowlin, 1986; Thanassoulis, 2001). The field of application is vast, we want just mention a few recent articles in different management areas. The DEA method was extensively applied to purchasing decisions (Narasimhan, Talluri, & Mendez, 2001; Papagapiou, Mingers, & Thanassoulis, 1997). In (Yan, Wei, & G., 2002) the DEA model was used for production input/output estimation when some of the original input/output entities are revised in order to be more competitive. DEA was used in decision models for technology selection problems, e.g. in the area of manufac-

turing technologies (Baker & Talluri, 1997; Khouja, 1995). Other interesting fields of application were to analyse the economic value of IT (Dasgupta, Sarkis, & Talluri, 1999; Shao & Lin, 2002) or the productivity of software engineering projects (Mahmood, Pettingell, & Shaskevich, 1996).

All these applications use the DEA method because of some strong features paired with an appealing simplicity in application, which also apply to the ERP system selection problem. One important advantage is that DEA tries to objectify the benefits of different ERP solutions, even though the measurements of individual aspects of these approaches may originate from subjective and/or diffuse sources. Such a source can be the opinion of practitioners, experts, researchers or even a committee. It can be supposed that especially for the latter one, an objective cumulative decision is complicated to achieve. DEA solves this task by giving each solution approach under evaluation the opportunity to "present" itself at its best.

## Three steps for the DEA approach in ERP selection

We used the DEA model initiated by Charnes, Cooper and Rhodes (1978) (CCR-Model) which is based on the assumption of constant returns to scale and maps a fractional linear measure of efficiency into a linear programming (LP) format. We limit the model's discussion to some basics here and refer of the above mentioned literature for more detail. See also (Thanassoulis, 2001) who collected several approaches based on the CCR and applications of DEA and additionally offers a solver-software for the different models. Next we like to guide through the necessary steps using DEA for an ERP selection.

**The first step** is to define different criterions  $C_i$  which describe the qualities of the ERP alternatives under evaluation (we chose five alternatives, labeled A-E, in this example). In an empirical study of the decision making process concerning investments in ERP software in Austrian organizations (Bernroider & Koch, 2000), 29 different ERP selection criteria were identified through application of the Delphi Method with students, practitioners and researchers. Here we limit the number of considered criteria for the analyzed example to four software specific characteristics, which showed up as most important in the empirical study cited above. These criteria are:  $C_1$ =processing times,  $C_2$ =software maturity,  $C_3$ =interconnectivity and  $C_4$ =support quality.

**The second step** is to measure the selected criterions from step one. These measurements  $M_i$  of these criterions for each ERP solution can be objective achievable, like e.g. processing times, or interconnectivity, but they can also originate, as already mentioned, from subjective judgments, normally obtained from experts in the field of subjects (like e.g. the maturity of a software system). It can be recommended to re-scale (if necessary) all measurement for each criterion between e.g. 0 (worst) and 10 (best). These measures for all ERP alternatives can be found in Table 1.

Table 1. Measurements of four criterions for 5 ERP system alternatives

ERP Solution	Processing Times	Maturity	Interconnectivit y	Support Quality
A	5	7	3	6
B	7	9	6	10
C	8	7	8	8
D	4	8	3	9
E	9	4	4	9

The overall benefit  $B$  of each ERP alternative is then measured by a weighted sum of all  $M_i$  for each alternative.

$$B = \sum_{i=1}^4 W_i M_i, \text{ where } W_i \text{ are the weights for each criterion.}$$

One way would be to weight the various characteristics by pre-selected fixed weights as e.g. it is necessary in some kind of ranking and scoring techniques. As already mentioned, this utilization ranking method is employed by nearly every organization that use an evaluation technique other than financial methods in the ERP software selection process. DEA avoids the numerous a priori assumptions involved in fixed weights by deriving the weights directly from the data. The required weights  $W_i$  are calculated through the DEA model by optimizing an LP and they are not subjectively assigned by persons. DEA calculates a set of weights for each alternative such that the overall benefit of that alternative is maximized with respect to all others. This means that the alternative itself is free to choose the weights in order to make itself look best. Alternatives, which are not able to achieve the highest benefit under these relaxed conditions, can be seen inferior compared to its competitors and they are therefore rejected. Of course there must be a possibility for the management, for researchers or experts to interact with the system as well, otherwise some ERP alternatives would simply set those weights to zero, where they have large deficits. This would completely eliminate the effect of some criterions.

**The third step** is responsible for setting bounds for the weights (not setting the weights itself) in order to prevent the situation sketched above. Thus a committee is responsible to agree upon feasible regions where the weights can be chosen from. It should be mentioned that it is much easier for a committee to agree upon a possible range of a weight than to agree upon a single number of that weight. How such a group decision can be carried out is very important and discussed in the next section.

Without this third step (bounding the weights) the ERP solutions B, C and E are 100% efficient and should be treated as equally good. Each of them chooses a different set of weights in order to maximize its benefit among the other alternatives. The ERP solutions A and D have a benefit of 78% and 90% respectively. These alternatives can be seen as inefficient. Because they were free to choose their own weights, it can be implied that they do not even have any key competence among those four criterions. After agreeing, however, on the bounds for the weights, which is discussed in the next section, the ranking of the ERP alternatives is expressed in Table 2.

Table 2 not only shows the total efficiency of the ERP solution. The DEA analysis provides as well scores for each criterion, to show what would be needed for that solution in order to be competitive. ERP solution C, for example, spend too much effort in interconnectivity and performance figures. They should instead spend more resources in the required maturity of the software and should offer a better support.

As you might expect, there is not always a clear-cut ranking as in this example. There might be more than one efficient solution. This is especially true when using more criterions which add more amount of freedom to the system. The (ranking) RCCR model proposed by (Anderson & Peterson, 1993) is a simply variation of the CCR model and very helpful for ranking the various alternatives. The new formulation (re-

Table 2. DEA Efficiencies together with required scores to be competitive.

ERP Solution	Efficiency y	Processing Times	Maturity	Interconnectivit y	Support Quality
A	66.88%	+2	+2	+3	+4
B	100%	-	-	-	-
C	93.98%	-1	+2	-2	+2
D	80.39%	+3	+1	+3	+1
E	85.71%	-2	+5	+2	+1

spectively modification of the LP constraints) allows technically efficient scores to be greater than 1 resulting in a more discriminating set of scores suitable for ranking purposes. (Adler & Sinuany-Stern, 2002) give a review of possible ranking methods in the context of DEA.

## GROUP DECISIONS

As emphasized above, the third step of the DEA process is a very important one and normally implies any kind of group decision. In Austria the majority of the organizations employ participative decision making for ERP systems (Bernroider & Koch, 2000), i.e. group decisions including diverse stakeholders within the organization. As has been argued (Appleton, 1997; Davenport, 1993; Hammer & Champy, 1993; Willcocks & Sykes, 2000), the participation of the people affected by the system and knowing the business processes leads to better decisions and a higher rate of acceptance later on (Guha, Grover, Kettinger, & Teng, 1997). In (Tayler, 1998) possible benefits arising from a participative type of team structure include the motivational improvement of local participation and attention to individual quality of working life, as well as the necessary attention to strategic purpose and to reciprocal and coordinative social roles.

In our example five different evaluators representing diverse stakeholders within the organization and a consulting organization have estimated their importance on each criterion using their subjective judgments (see table 3). There are a total of 100 points for weighting the importance of the four criterions. So e.g. the IT consultant assumes "Software Maturity" and "Support Quality" equally important where "Processing Times" and "Interconnectivity" should observe only half the attention. Up to this point all estimations originate from the subjective opinion of the group members.

After that step the feasible region of the weights which plays the key role in DEA must be constrained into a region acceptable for the voting committee. (Cooper, Seiford, & Tone, 2000) propose that for each criterion out of table 3 a lower and upper bound for the weights can be extracted and can be coded as additional constraints into the DEA model. This means that the group implicitly decides about the upper and lower bounds, especially if they do not know the choice of the others. The idea can be improved because it is known from psychology that it is easier to compare two items than three and more at the same time. Thus

Table 3. Weight estimations of the 5 evaluators (100 points)

ERP Solution	Processing Times	Maturity	Interconnectivit y	Support Quality
IT consultant	16.7	33.3	16.7	33.3
Top Management	25.0	18.8	18.8	37.5
IT department	20.0	20.0	20.0	40.0
Operating department 1	21.1	31.6	15.8	31.6
Operating department 2	24.0	19.0	19.0	38.0

the ratio between pair-wise weights  $W_i/W_j$  should be considered instead of the absolute weight value  $W_i$  itself. E.g. the IT Consultant finds "Software Maturity" twice as important as "Processing Times" or "Interconnectivity". This leads to a ratio  $R_i = W_i/W_j = 2/1 = 2$ . The upper and lower bound of this value  $R_i$  among all evaluators is then to be considered as feasible region. This fact makes it also possible for the measurements  $M_i$  to be scale invariant. Analogue to that constraints for all other pair-wise weights are added to the DEA model. There you can find e.g. the lower bound for  $W_i/W_j$  to be 0.75 (as suggested by the top management) and the upper bound for  $W_i/W_j$  to be 2 (as suggested by the IT consultant).

Within this model the optimization process of the weights take place. Its advantages are obvious. Non of the evaluators are set better, because they only assign the boundaries for the model. Again the data (the ERP alternative) itself optimizes the weights to "present" itself at its best. The committee only agrees upon the flexibility of "presentation".

## MANAGERIAL IMPLICATIONS FOR DECISION SUPPORT

For the management needful information is revealed after the analysis. This is firstly the ranking of the ERP solutions. Additional a product shape of the non-optimal solutions is presented to the management. This means the management can observe where the shape differs from e.g. the second best to the first one. As seen in table 2, ERP solution C is a wonderful solution, but it seems, that the shape of this product does not fit the companies requirements. On the other hand the company can think again about their constraints in weights and maybe shift their requirements towards an offered product in a second group evaluation/discussion. It can be the case that the management or the company prefers a specific ERP solution. With the DEA the management is able to tell provider of that ERP solution where are their weaknesses and they can negotiate a different and better contract. It becomes clear that the DEA analysis is even a very powerful tool in self-evaluation of ERP solutions.

## CONCLUSIONS

In this paper we have detailed the use of DEA as a decision tool for ERP systems. DEA provides a number of opportunities, which seem to justify its use. This includes the usage of minimal a priori assumptions, objectifying characteristics, group decision capabilities and additional enormous amount of freedom through the simple LP structure. A drawback of this structure is the linear assumption of the weighting-process. This drawback is compensated by the ability of building a large (many variables and constraints) system without losing the possibility of global optimization. This important aspect is often neglected in more complex systems and local solutions or heuristics are treated as the global optimizers. Another aspect to mention is that DEA does neither require to specify the relation between inputs and outputs nor does these hidden functional dependencies has to be equal among all alternatives. This black box approach reminds of the powerful complex system of neuronal networks. Supposable one of the most important benefit of DEA usage is the diplomatic support of the group decisions, which are widely applied in the ERP decision making process.

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