Evaluation and Selection of ERP Software by SMART and Combinatorial Optimization

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Abstract: One of the key factors for success of any organization is to implement the appropriate resource planning systems. Implementation of such system is a crucial issue for today's highly competitive enterprises environment. The choice of the best suited for the need of the enterprise system is a challenge due the multiple key performance indicators that have to be considered. An approach for selection of enterprise resource planning systems by simple multi-attribute rating techniques and combinatorial optimization is proposed. The results of numerical validation show the possibility for practical application of this approach in selection of the appropriate enterprise resource planning system among the given set of alternatives.

Keywords: *Enterprise resource planning systems, simple multi-attribute rating technique, group decision making, combinatorial optimization.*

1. INTRODUCTION

Enterprise resource planning (ERP) systems are type of business management software intended for integrating different applications used to collect, store, manage and interpret data from variety business activities (like product planning, purchase, manufacturing/service delivery, marketing and sales, inventory management, shipping and payment). Implementation of most appropriate ERP software is a key factor for success of any organization. In many cases, vendors claim that their software systems are universal and can be

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adjusted to the needs of any business, but this is disputable. Despite the universality of the general configuration of ERP systems, many vendors adapt ERP packages to meet different organizational factors [Aslan et al., 2015]. This requires carefully analyzing the characteristics of the ERP systems to make the right choice in accordance with the organization objectives. The choice of the best ERP system is a challenge due the multiple key performance indicators that need to be considered. In this respect, multicriteria decision making (MCDM) seem to be a natural systematic approach in the process of selection among a set of possible alternatives. When the number of alternatives is finite, the choice problems are known as multi-attribute decision making (MADM) [Zanakis et al., 1998]. Usually the term MADM is used to indicate discrete MCDM problems. Application of MADM models contributes in creation of a transparent and auditable process that helps a team of managers in choosing of vendor and software in an efficient and consensus building way. Different approaches are proposed to tackle with the problem of ERP system selection as: artificial neural network based on analytic network process [Yazgan et al., 2009]; integrated fuzzy multi criteria group decision making [Efe, 2016]; fuzzy modeling [Bueno & Salmeron, 2008; Peneva & Popchev, 2009]; integrated decision making approach [Karsak & Ozogul, 2009]. In the process of selecting of ERP software proper criteria are to be defined [Uta et al., 2007; Tsai et al., 2009]. In general, the bottleneck for enterprises is decision making to find the best alternative from a predefined set of alternatives. Despite of variety of MADM approaches, there are no better or worse techniques, but some techniques better suit to particular decision making problems than others do. Due to the complexity of such problems, a group of experts with different skills, experience and knowledge relating to different aspects of ERP system are to be involved. Group decisions making can benefit from multi-attribute utility theory (MAUT) by incorporating them into a group decision support system [Mustakerov & Borissova, 2014]. In multi-attribute group decision making (MAGDM) the problem can be described as follows: multiple DMs make judgments or evaluations by virtue of respective knowledge, experience and preference for a decision space (i.e., a finite set of alternatives) under multiple attributes to rank all the alternatives or give evaluation information of each alternative, and then decision results from each DM are aggregated to form an overall ranking result for all the alternatives [Pangc & Liang, 2012]. Simple multi-attribute rating technique (SMART) is the simplest form of the MAUT methods. The ranking value of alternative is obtained simply as the weighted algebraic mean of the utility values associated with it [Fulop, 2005]. This technique is widely used due the simplicity required for responses of the DMs and the manner in which these responses are analyzed [Goodwin & Wright, 2004].

In the paper, simple multi-attribute rating technique is modified and combined with combinatorial optimization to select the most appropriate ERP system. For numerical testing, normalization schemes are used to obtain comparable and dimensionless units to eliminate the problems caused by differing measurement units.

2. PROBLEM DESCRIPTION

The selection of ERP system should provide ability to integrate various business processes across different functions depending on the activity of particular organization. For the goal, an authorized working committee should identify all of the business requirements across focal enterprise, customers and partners [Sun et al., 2015]. This committee also provides the information about system functionality, reference sites, vendors, implementation partners, local support capabilities, etc. The final result of the committee's work is the presence of a list of potential ERP systems. On the next stage, it is advisable to involve a group of decision makers (DMs) to evaluate the advantages and the disadvantages of alternatives included in the list. It is also advisable the group of DMs to be experts with different knowledge and experience from different areas to ensure global viewpoints on ERP implementation. The ultimate goal of the entire process is to select the most appropriate ERP system considering different experts' opinion.

3. SIMPLE MULTI-ATTRIBUTE RATING TECHNIQUE AND COMBINATORIAL OPTIMIZATION FOR ERP SELECTION

The Simple Multi-Attribute Rating Technique (SMART) is utility based approach with the ability to handle both quantitative and qualitative data. The originally SMART describes the whole process as rating the alternatives and weighting of attributes [Edwards, 1977]. Performance criteria of each alternative are associated with corresponding scores within scale 0 to 10. The weighting coefficients are within the range of 0 to 1, where 0 represents the worst expected performance on a given criterion and 1 represents the best expected performance.

The main stages of SMART method follows the steps: 1) identify the group of DMs; 2) identifying the goal of decision; 3) identifying the set of alternatives; 4) identifying evaluation criteria; 5) assigning values for each criterion; 6) determination the weight of each of the criteria; 7) calculation a weighted average of the values to each alternative, and 8) making the decision [Barfod & Leleur, 2014].

The proposed approach modifies the steps 7 and 8 by using combinatorial optimization to select the best alternative. The corresponding weighted decision matrix (WDM) is represented as $m \times n$ table with m number of alternatives, n number of criteria and the same number of criteria weights as shown in Table 1.

Table 1. Weighted decision matrix

Alternatives	*Decision variables*	C_1	C_2	C_3	...	C_n
		w_1	w_2	w_3	...	w_n
A_1	x_1	r_{11}	r_{12}	r_{13}	...	r_{1n}
A_2	x_2	r_{21}	r_{22}	r_{23}	...	r_{2n}
...	...	...	...	...	r_{ij}	...
A_m	x_m	r_{m1}	r_{m2}	r_{m3}	...	r_{mn}

where $A_1, A_2, ..., A_m$ are the set of alternatives and for all of them corresponding decision variable $x_i \in \{x_1, ..., x_m\}$ is assigned; $C_1, C_2, ..., C_n$ are evaluation criteria, r_{ij} is the evaluation rating of alternative A_i toward criterion C_j, and w_j is the weight of criterion C_j.

The combinatorial optimization model to select the best alternative is:

$$\text{maximize} \sum_{j=1}^{n} \sum_{q=1}^{k} w_j^q R_j^q \qquad (1)$$

subject to

$$\forall j = 1, 2, \ldots, \mathrm{n} : (\forall q = 1, 2, \ldots, \mathrm{k} : R_j^q = \sum_{i=1}^{m} r_{i,j}^q \, x_i \,) \qquad (2)$$

$$\sum_{j=1}^{\mathrm{n}} w_j = 1, \;\; w_j \in [\,0, 1\,] \qquad (3)$$

$$\sum_{i=1}^{\mathrm{m}} x_i = 1, \;\; x_i \in \{\,0, 1\} \qquad (4)$$

where the set of alternatives is denoted by A = $\{A_i\}$ for $i = 1, 2, \ldots, m$; evaluation criteria are denoted by set of $C = \{C_j\}$ for $j = 1, 2, \ldots, n$; group of DMs are denoted by DM = $\{DM^q\}$ for $q = 1, 2, \ldots, k$; $r_{i,j}^q$ are the evaluation rating for each alternative A_i accordingly the corresponding criterion C_j; w_i are the weighted coefficients representing the importance of each criterion from the viewpoint of each DM, and x_j are binary integer variables assigned to each alternative.

To obtain comparable scales and to eliminate computational problems caused by differing measurement units some normalization should be applied. The normalized ratings have dimensionless units and the larger values correspond to more preferable evaluations. For criteria that should be maximized, the alternatives evaluations rating r_{ij} are normalized as:

$$r_{ij}^{*} = \frac{r_{ij}}{\max_i r_{ij}} \quad (5)$$

and for criteria that should be minimized

$$r_{ij}^{*} = \frac{\min_i r_{ij}}{r_{ij}} \quad (6)$$

The described optimization model (1) – (4) can be modified to select more than one alternative by modifying the equation (4) to select a number z of alternatives:

$$\sum_{i=1}^{m} x_i = z,\ \ x_i \in \{0,1\} \ \text{ and } \ 1 < z < m \quad (4^*)$$

In this way, the single choice problem is transformed to multiple-choice problem [Mustakerov et al., 2012].

4. NUMERICAL APPLICATION

An adapted numerical example from [Efe, 2016] is used to illustrate the proposed MAGDM approach for mathematically reasoned ERP software selection. To evaluate the set of given ERP software alternatives, four criteria (performance indicators) are used: 1) cost; 2) vendor specifications; 3) technical specifications; and 4) ease of use. Cost criterion includes the price for acquisition of software and following updating fees to get the latest version. Vendor specifications criterion emphasizes on training and consultant services, vendor's reputation and references of software among companies in the sector. Technical specifications criterion accentuates on software interface, functionality, compatibility with other existing platforms, reliability and supporting data files. The ease of use criterion is focused on software ergonomics, suitability for the user - expressed as satisfaction of software utilization, learnability – software can be learned quickly and easily, reporting – convenient compilation of the requested reports.

In this numerical example a predefined set of 5 ERP alternative systems need to be evaluated toward the described above 4 criteria. A group of 3 authorized experts are involved in the process of group decision making: database administrator (DM-1), financial consultant (DM-2) and business analyst (DM-3). All of these experts are considered as equal members of group and their competencies of knowledge and experience is considered as equally important. The corresponding DMs evaluation rating scores for performance indicators (*Cost, Vendor specifications, Technical specifications and Ease of use*) for 5 alternatives are shown in Table 2. The importance of each indicator/criterion is represented via weighted coefficients in accordance to the relation (3). All input data of normalized WDM are shown in Table 2.

Table 2. Normalized WDM with 5 alternatives, 4 criteria and 3 DMs

DMs/ Alternatives	*Cost* (C_1)	*Vendor specifications* (C_2)	*Technical specifications* (C_3)	*Ease of use* (C_4)
DM-1	$w_1^1 = 0.10$	$w_2^1 = 0.25$	$w_3^1 = 0.40$	$w_4^1 = 0.25$
A_1	0.92757	0.89738	0.14286	0.92757
A_2	0.55556	0.33333	0.42857	0.42857
A_3	0.55556	0.81087	0.33333	0.42857
A_4	0.77778	0.14286	0.89738	0.89738
A_5	0.68785	0.46577	0.63224	0.58876
DM-2	$w_1^2 = 0.50$	$w_2^2 = 0.25$	$w_3^2 = 0.10$	$w_4^2 = 0.15$
A_1	0.55556	0.68712	0.33333	0.55556
A_2	0.92757	0.33333	0.42857	0.92757
A_3	0.77778	0.89738	0.42857	0.77778
A_4	0.55556	0.92757	0.33333	0.42857
A_5	0.46577	0.68785	0.63224	0.63224
DM-3	$w_1^3 = 0.15$	$w_2^3 = 0.15$	$w_3^3 = 0.30$	$w_4^3 = 0.40$
A_1	0.33333	0.89738	0.14286	0.33333
A_2	0.81087	0.92757	0.24560	0.92757
A_3	0.24560	0.24560	0.42857	0.33333
A_4	0.33333	0.33333	0.33333	0.14286
A_5	0.63224	0.63224	0.68785	0.46577

The solution of the optimization task (1) – (4) with normalized data from Table 2, defines the Alternative A2 as the best alternative.

5. DISCUSSION

The results of numerical testing of the proposed modified SMART approach show its applicability. Using the optimization model (1) – (4) and normalized input data from Table 2 determine the *Alternative 2* as the best group decision alternative. In case when 2 good alternatives have to be determined instead of the relation (4) the modified relation (4*) is used for $z = 2$. The corresponding solution defines *Alternative 2* and *Alternative 5* as two good alternatives.

The proposed approach can be implemented in spreadsheet environment provided that some optimization solver is available. This would facilitate the managers to use group decision making based on numerical reasoned consensus while all calculations are performed in the background. In spreadsheet environment adding or modifying of alternatives, performance criteria and number of experts without need of specific mathematical knowledge. This flexibility of the described approach turns it into a useful tool, for practitioners on ERP selection.

6. CONCLUSION

The paper describes an approach for evaluation and selection of ERP Software by group decision making based on simple multi-attribute rating technique combined with combinatorial optimization modelling. As the implementation of most appropriate ERP software is a key factor for success of any organization, the choice should be done considering various experts' evaluations for multiple key performance indicators. The proposed approach determines numerically proved best consensual alternative. With minor modification, this approach can be used to determine a given number of good alternatives to be used for final choice. The applicability of the proposed approach is numerically illustrated for the example of ERP software system selection. In the future it is interesting to consider the implementation criteria of ITIL (Information Technology Infrastructure Library) for better evaluation of ERP software.

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