Proposition of a new ex-ante evaluation method for adapting and selecting ERP solutions

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Résumé

Acquérir une solution ERP est une activité à la fois risquée, fastidieuse et complexe pour toute organisation. Il a été largement rapporté que le choix inapproprié d'une solution ERP est l'une des principales causes derrière l'échec de sa mise en œuvre. Dans cet article, notre objectif est d'élaborer une nouvelle méthode d'évaluation ex-ante d'adaptation et de sélection des solutions de type ERP. Cette méthode, dénommée SEVALERPS (Systematic EVALuation of ERP Systems), est destinée à aider les organisations, plus particulièrement les grands comptes, à mieux adapter et à évaluer des solutions ERP potentielles, afin d'en choisir celles qui réalisent les meilleurs compromis de leurs exigences. Afin de gérer les différents aspects d'évaluation des solutions, la méthode SEVALERPS se base sur plusieurs techniques mathématiques. Il s'agit de la programmation linéaire à variables binaires pour le choix des meilleurs scénarii d'adaptation des solutions ERP, de la technique MACBETH pour exprimer, sous une forme quantitative ou qualitative, les préférences de l'équipe de sélection sur les critères d'évaluation, et de l'intégrale discrète de Choquet pour gérer les interdépendances qui pourraient exister entre les critères d'évaluation.

Abstract

Acquiring an ERP system is one of the most risky, tedious and complex decision making activities for any organization. It has been widely reported that selecting an inappropriate ERP is one of the major reasons for its implementation failure. In this paper, we will develop a new ex-ante evaluation method for ERP system tailoring and selection. The proposed method, called SEVALERPS (Systematic Evaluation of ERP Systems), is basically elaborated to help organizations, especially large ones, to better customize and evaluate the potential ERP solutions in order to choose the ones that meet their best requirements' tradeoff. SEVALERPS relies on many sound mathematical techniques to handle various evaluation aspects: 0-1 linear programming to choose the best ERP tailoring scenarios, MACBETH to express the preferences of the selection team in both a qualitative and quantitative way, and the discrete Choquet integral to address interdependencies that might exist among evaluation criteria.

Mots-clés

Évaluation ERP, Couverture fonctionnelle, Sélection ERP, Adaptation ERP, MACBETH, Intégrale de Choquet, Programmation linéaire à variables binaires

Keywords

ERP Evaluation, ERP Functional coverage, ERP Selection, ERP Tailoring, MACBETH, Choquet Integral, 0-1 linear Programing.

1. Introduction

The industrial concept of Enterprise Resource Planning (ERP) denotes an integrated commercial off-the-shelf software package which streamlines and encompasses a large spectrum of business processes within organizations (Chofreh *et al.*, 2014). Since the appearance of these solutions on the market in the 1990s, they have known a spectacular development. Indeed, organizations have become aware of the strategic competitive advantages that could be bestowed from such technology, if its implementation is successfully done. They aim to sustain their market share in a highly severe competition by adopting the main worldwide best practices generally embedded in these ERP solutions. Basically, these packaged solutions are destined to cut redundant costs, raise quality, receive pertinent information in a timely manner and improve customer satisfaction (Martin *et al.*, 2014).

Historically, ERP systems were destined to large organizations that were willing and able to spend tens or hundreds of millions of dollars on an integrated software system (Katerattanakul *et al.*, 2014). However, over the past few years, the ERP market has shown signs of saturation as large companies almost completed their significant ERP implementa¬tions. The time was ripe for the main vendors to steadily maintain the challenge of Small and Medium Enterprises (SMEs) (Consulting, 2013). On the one hand, the vendors have started turning their marketing sights towards the mid-market and redesigning their strategies to match its requirements. On the other hand, SMEs would unfavorably disrupt their business activities if they failed to upgrade their information systems to communicate with their supply chain partners or with those of their corporate headquarters (Pérez–Salazar *et al.*, 2013).

However, despite the pace with which numerous organizations have embraced and implemented ERP packages, it should be noted that not all ERP implementations have given satisfactory results. Actually, since the dawn of ERP proj¬ects, it has been widely reported that many of them fail to yield the expected payoffs (Katerattanakul *et al.*, 2014). More than half of these projects have been reported in the literature to be a pure loss, as they often fail to reach their objectives (Poba-Nzaou and Raymond, 2011), let alone the large scale investments engaged by their adoption, which tend to be a very heavy burden on the organizations' budgets. Thereby, given their alarmingly low level success rate, ERP projects are now regarded as highly risky activities that might jeopardize the very existence of even large organizations; the case of smaller sized enterprises is more problematic. In fact, SMEs have limited budgets and little experiences in addressing and overcoming these matters (Chofreh *et al.*, 2014).

But, surprisingly, an extensive part of the academic literature has dealt mainly with ERP implementation and post-implementation issues and has skipped the pre-implementation stage of these solutions, especially the way they are selected (Addo-Tenkorang and Helo, 2011); (Zeng and Skibniewski, 2013). Actually, the major purpose of ERP selection activity is to identify the alternative that would best cover the business re¬quirements of a given organizational context. In light of this, the choice of the appropriate ERP solution is obviously one of the most critical success factors on which relies its future implementation. This seems to explain why the research that has previously been done to address the high failure rate of ERP projects hasn't yet brought satisfactory results. Given that organizations are still ill-equipped to select the most promising solutions which could fit their business requirements, we believe that it is highly justifiable to express more interest in developing selection methods and models geared towards ERP solutions.

According to (Pérez–Salazar *et al.*, 2013), ERP evaluation and selection have become increasingly difficult for the decision makers due the hundreds of soft¬ware products available in the marketplace. Other authors argue that methodologies developed for custom commercial off-the-shelf solutions may not all be applicable to ERP ones (Yıldız and Yıldız, 2014). Organizations will have to be armed with the right tools to avoid serious errors and make purchases that will generate good returns (Munkelt and Völker, 2013).

The selection of an ERP solution is basically a typical MCDA (Multi Criteria Decision Aid) problem (Pérez–Salazar *et al.*, 2013). This is due to its propensity to operate under multiple, often conflicting criteria and the discrete decision space in which the decision is made. By applying MCDA methods, justifiability and accountability will be improved considering that they are regularly seen as the pre-requisites of a complex and risky purchasing decision (Razmi and Sangari, 2013). Taking this into account, we argue that there is a key feature that should be also considered when it comes to ERP selection. Actually, ERP solutions, unlike custom packaged software, are customizable ones, giving them more flexibility to best meet the specific requirements of each organization. In this regard, ERP candidates should be undoubtedly evaluated according to their anticipated fitness with the business requirements instead of with their current one. In other words, the selection team must be able to determine the best tailoring actions that could resolve, in an optimal way, the mismatches relating to each ERP candidate solution. This resolution should be done by seeking, within limited total cost of ownership, a trade-off between maximizing the functional fitness of each candidate solution and minimizing its non-adaptation risk. And it is only after determining how each ERP candidate solution should be customized that organizations should, in order to choose their best solutions, conduct global evaluations by considering both alternatives' functional and non-functional criteria. Indeed, the selection criteria should go beyond functional aspects to encompass strategic, economic and technical ones.

Despite their importance, the selection methods and approaches proposed in the literature still fail to deal with this aforementioned key feature. With this end in view, in this paper, we will develop a new ex-ante evaluation method that aims to help organizations, especially large ones, to customize the ERP candidate solutions at hand, and choose among them those that could best meet their business requirements. This method, denoted by SEVALERPS (Systematic EVALuation for ERP Selection), is designed to tackle the current shortcomings underlined above. Actually, SEVALERPS development addresses the two following research questions:

- Given that ERP packages provide numerous options to customize them, how should the selection team choose the best tailoring actions that could offset the functional coverage improvement against the non-adaptation risk reduction?
- Due to the heterogeneous kinds of evaluation criteria and their interdependencies, which systematic evaluation processes and models should the selection team adopt to evaluate locally and globally the ERP candidate solutions against these criteria?

In the remainder of this paper, we underline in a nutshell some of the most common criticism made against the evaluation methods and approaches proposed in the literature relating to ERP selection. We introduce the evaluation process and model of SEVALERPS method, and discuss how the developed method addresses the two aforementioned research questions. A public administration case study is detailed to illustrate how SEVALERPS could be applied in a real context. Indeed, we elaborate, in more detail, the background of using SEVALERPS in this specific case study by focusing on its application scenarios. Analyses of the obtained results are also given. Finally, we present some perspectives for our future research.

2. Previous ERP selection approaches in a nutshell

Over the past two decades, both researchers and practitioners have progressively started to develop methodologies, approaches and methods to assess the fitness of some software packages with given organizational contexts. This growing body of academic literature witnesses the importance of the pre-implementation stage of software adoption, usually referred to by the headings of package procurement, acquisition or selection (Addo-Tenkorang and Helo, 2011).

Our literature review and classification of the previous ERP selection methods and approaches have revealed that the past research addresses, in general, the following aspects: evaluation and selection processes, evaluation models and techniques, selection criteria and automation tools supporting the proposed methods. However, when it comes to their scope, these previous works still remain general, even if their authors pretend that they are especially developed to handle the special case of ERP systems. Indeed, in these methods, neither the evaluation models nor the selection processes take into account that, unlike ordinary software packages, ERP ones are customizable solutions (Please refer to our literature reviews presented in our previous works: (Khaled and Janati-Idrissi, 2011); (Khaled and Janati-Idrissi, 2012)). In this regard, we argue that mismatch handling activity geared towards enhancing the global coverage of the required functionalities should be at the heart of any ERP evaluation approach.

Furthermore, the analytic hierarchy processes (AHP) (Saaty, 2013) and the weighted scoring method (WSM) are the most widely used multi-criteria evaluation models to determine the global scores of candidate packages. Nonetheless, AHP and WSM rely on an additive aggregation model which assumes that evaluation criteria must be totally independent. Actually, such assumptions are often unrealistic in practice (Sen *et al.*, 2009); (Pérez–Salazar *et al.*, 2013).

Finally, a mandatory feature of package software selection methods is the ability to deal with both quantitative and qualitative data when it comes to evaluating candidate packages on selection criteria. In this regard, a great deal of the existent methods uses numerical models that transform qualitative judgments, voided out by the selection team, into quantitative ones. The final score of each ERP candidate is obtained through compensating mutually its preference scores, basically heterogeneous, on the various criteria. However, so as to obtain valid results, the numerical representations relating to these criteria must be at least commensurate among each other in order to ensure their aggregation significance (Bustinza *et al.*, 2013). In practice, this assumption seems to be ignored by many of the evaluation methods proposed so far. A systematic procedure to elaborate commensurate representations based on the qualitative judgments of the selection team should then be considered when conducting package evaluation activity.

The next section of this paper presents the SEVALERPS method which is mainly developed to address the highlighted limitations of the previous methods.

3. Presentation of SEVALERPS method

SEVALERPS relies on a systematic six stage process that defines the activities that should be carried out to evaluate ERP candidate packages. The flow chart of this process is depicted in Fig. 1. It comprises the following stages: requirements and criteria gathering, candidate searching and screening, functional gap analysis, mismatch handling, elementary and global evaluations. The remainder of this section describes, in more details, each stage of SEVALERPS's process and discusses how the proposed method overcomes the shortcomings highlighted in the literature review section.

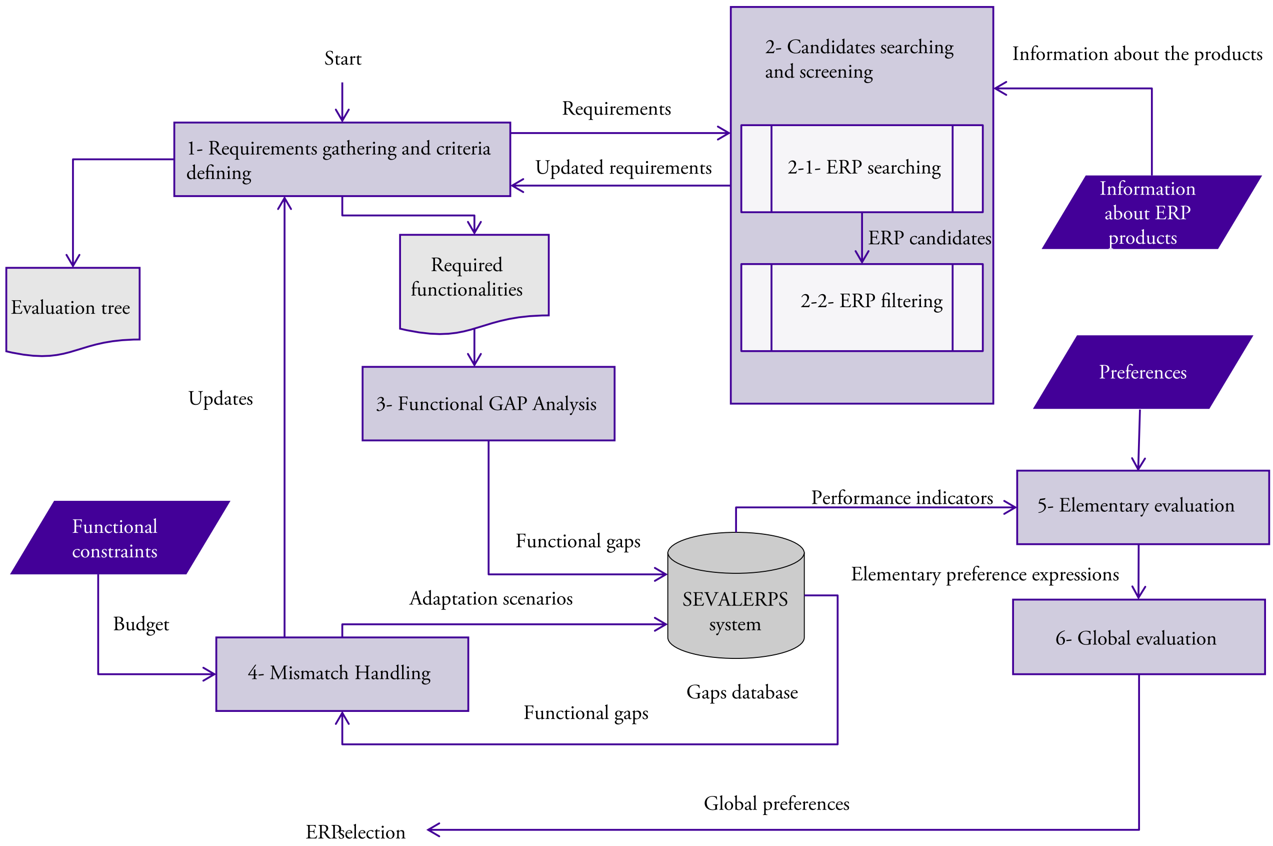

Figure 1. SEVALERPS evaluation flow chart

3.1. Requirements and criteria gathering

First of all, SEVALERPS is a requirement-driven selection method that enables organizations to rely on both functional and non-functional requirements to define their evaluation criteria, which will be used to evaluate and then to choose the appropriate candidate package. In this regard, numerous methods have been proposed in the literature to support requirements gathering (Zoukar *et al.*, 2013). However, these methods could be classified into two groups of strategies that could be adopted to manage requirement specification.

By adopting the first strategy, the selection team defines all its requirements from scratch based only on the organization business needs without considering what the available ERP solutions on the market could really offer. Even if this strategy would be ideal for the organization, it requires both time and effort and would lower the chances to find a solution that could satisfy all the specified requirements.

The second strategy suggests a solution-driven paradigm to define these requirements. Even though it requires less time and effort, it is considered less flexible when it obliges the organization to adopt the predefined business logic of a given ERP system.

Each strategy has its strengths and weaknesses. Nonetheless, when it comes to ERP packages, choosing one of them must take into account that these systems, unlike in-house ones, are not developed from scratch. This means that requirements specification should be kept at a moderate abstraction level in order not to discard all available ERP options.

For this reason, SEVALERPS uses mainly the first strategy to capture the organization's high-level requirements and to point out some candidate solutions that would satisfy them. The second strategy is also used during the candidate package examination so as to enrich and to update the initial requirements obtained by the first strategy.

To support the selection team in its functional requirement specification, SEVALERPS suggests using UML's use case formalism to describe, in a higher abstraction level, what functionalities are expected from the future solution. Furthermore, characteristics that define how the future system must operate could also be taken from some standard quality models such as ISO-9162 (ISO9126, 2001).

3.2. Candidate searching and screening

In this stage, a wide market searching activity geared towards looking for ERP potential solutions and inquiring about them should be immediately carried out so as to detect the most promising ones and to narrow their spectrum. Basically, this searching and filtering activity relies on the criteria defined in the previous stage. Besides, many information sources relating to ERP solutions could be used in this stage. They include internet, benchmarking studies conducted by consulting firms, white papers published by ERP editors, functional and technical brochures of some solutions, specialized conferences and also requests for proposals (RFP) that could be launched by the organization.

3.3. Functional gap analysis

The third stage concerns detecting and assessing mismatches relating to the ERP candidate solutions with reference to the organizational requirements. That's why the selection team should appraise to what extent a given ERP candidate package would satisfy a required functionality $f_j \in F^* = \{f_1, f_2, \ldots, f_J\}$. As a result, we define a satisfaction function, denoted by SAT, which shows initial satisfaction levels given by ERP solutions. This function is illustrated in (1).

$$\begin{aligned} SAT &: ERP^* x F^* \rightarrow [0,1] \\ (ERP, f_j) &\rightarrow a_{ij} \end{aligned} \quad (1)$$

3.4. Mismatch handling

Unlike ordinary packages, ERP solutions are customizable ones. This feature must be taken into account when it comes to their evaluation. For this reason, ERP evaluation shouldn't be undertaken based on the current functional coverage of these solutions, but rather on their anticipated fitness resulting from tailoring them, in order to handle the mismatches detected in the previous stage.
According to (Brehm *et al.*, 2001), there are nine tailoring patterns that identify adaptation strategies that the selection team could apply to handle identified mismatches. These tailoring patterns are: configuration, bolt-on, screen mask, extended reporting, user exit and programming. For each ERP candidate package, the choice of the optimal mismatch handling scenario depends on three main factors: maximizing anticipated functional coverage, reducing non-adaptation risk and respecting the financial resources' limit.
This end in view, we introduce the concept of adaptation strategies, denoted by $S_{ijk}, k \in IN$, relating to a given ERP_i candidate product and a required functionality, denoted by f_j. Each adaptation strategy S_{ijk} aims to improve the ERP_i functional coverage of f_j from a_{ij} to b_{ijk}. Furthermore, the potential implementation of S_{ijk} incurs to the organization a non-adaptation risk, denoted by r_{ijk} and induces an additional adaptation cost, denoted by c_{ijk}.
However, at most, only one adaptation strategy S_{ijk} must be chosen to handle a given mismatch relating to ERP_i and f_j. For this reason, we consider a binary unknown factor x_{ijk} to mention whether an adaptation strategy is chosen or not. Table 1 sums up the parameter set used in SEVALERPS mismatch handling model.
To determine which adaptation strategies are included in the optimal tailoring scenario of a given ERP candidate package, binary values relating to x_{ijk} must be assigned. For this purpose, SEVALERPS relies on the linear optimization model of (2) to determine these values.
In this optimization system, the objective function O_i makes a tradeoff between functional coverage improvement and its underlying non-tailoring risk, through the use of the multiplication operator. In this regard, the more the adaptation risk is important, the less is the value of O_i; and, conversely, the more the functional coverage's improvement is important, the more is the value of O_i.

In addition, the first constraint of this optimization system ($\sum_k x_{ijk} \leq 1$) indicates that, at most, only one adaptation strategy must be chosen. The second constraint ($\sum_{j,k} x_{ijk} c_{ijk} \leq \cos t_i$) indicates that the elementary adaptation costs' sum mustn't exceed the budget limit, $cost_i$, relating to ERP_i.

$$(\forall i) \left\{ \begin{array}{c} \max(O_i) \\ O_i = \sum_{j \mid a_{ij} \neq 1} w_j (b_{ijk} - a_{ij})\,(1 - r_{ijk}) x_{ijk} \\ (\forall j \mid a_{ij} \neq 1)\ \sum_k x_{ijk} \leq 1 \\ (\forall j,k \mid a_{ij} \neq 1)\ \sum_{j,k} x_{ijk} c_{ijk} \leq \text{cost}_i \end{array} \right. \quad (2)$$

Parameter	Description
ERP_i, i=1…I	ERP products from which the organization has to choose its solution
f_j,j=1…J	Required functionalities from ERP products
w_j with $\sum_j w_j = 1$	f_j's importance weight describing its importance in achieving organizationnal goals
S_{ijk},k=1…K	Tailoring strategies related to f_j and ERP_i. These strategies are destined to handle the identified mismatches between the required functionality and the one proposed by the ERP. These mismatches are identified in the Functional Gap Analysis stage of SEVALERPS's process.
$a_{ij} \in [0,1]$	Initial functional coverage relating to f_j and ERP_i
$b_{ijk} \in [0,1]$	Anticipated functional coverage relating to f_j and ERP_i after applying S_{ijk}
$r_{ijk} \in [0,1]$	Tailoring risk relating to S_{ijk}
$c_{ijk} \in \mathbb{R}$	Tailoring cost relating to S_{ijk}
$cost_i \in \mathbb{R}$	Budget limit allowed for ERP_i tailoring
$x_{ijk} \in \{0,1\}$	Decision binary unknown factor to mention whether the adaptation strategy S_{ijk} is chosen (x_{ijk}=1) or not (x_{ijk}=0).

Table 1. Parameters of SEVALERPS model

By solving this linear 0-1 programming system, we define, for each ERP_i, the optimal tailoring scenario expected under a specific budget constraint. By adopting this mismatch handling model, we provide an answer to our first research question. Finally, based on the values of the aforementioned adaptation model, we define in Table 2, in order to evaluate ERP candidate packages in the next stages of SEVALERPS, a set of performance indicators relating to the anticipated functional coverage, the non-adaptation risk, the adaptation cost and the non-guaranteed functional coverage of the ERP candidate packages.

Performance indicators	Description
Anticipated Functional coverage $(ERP_i) = \sum_j w_j \max\left(\sum_k b_{ijk} x_{ijk}, a_{ij}\right)$	It represents the new functional coverage relating to ERP_i after its adaptation.
Non-adaptation risk $(ERP_i) = 1 - \frac{\sum_{j,k \mid a_{ij} \neq 1} \Gamma_{ijk} x_{ijk}}{\sum_{j,k \mid a_{ij} \neq 1} w_j \Delta_{ijk} x_{ijk}}$ With $\Delta_{ijk} = (b_{ijk} - a_{ij})$… and … $\Gamma_{ijk} = w_j \Delta_{ijk} (1 - r_{ijk})$	It represents the global risk associated to the all adaptation strategies.
Adaptation cost $(ERP_i) == \sum_{j,k \mid aij \neq 1} c_{ijk} x_{ijk}$	It represents the global cost induced by the chosen adaptation strategies
Non-guaranteed functional coverage $(ERP_i) == \sum_{j,k \mid aij \neq 1} w_j \Delta_{ijk} x_{ijk} \Omega_{ijk}$ With $\Omega_{ijk} = \begin{cases} 0 \text{ if } S_{ijk} \equiv \text{ customization} \\ 1 \quad \text{Otherwise} \end{cases}$	It represents the functional coverage's part that the organization would lose immediately after the ERP_i version update.

Table 2. Performance indicators of SEVALERPS

3.5. Elementary evaluation

In this stage, the selection team has to express quantitatively their preferences relating to the ERP candidate packages on the lower criteria of the hierarchical evaluation tree, defined in stage 1. The preference expression relating to the upper criteria is defined, in the next stage of SEVALERPS, as the aggregation of the preferences defined on their sub-criteria.

In SEVALERPS, we use the multi-criteria Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) (Bana e Costa *et al.*, 2011) to handle the elementary evaluation of candidate packages. MACBETH is mainly developed in the context of multi-criteria decision aid, and it is based on sound mathematical foundations. MACBETH introduces the concept of cardinal scales to define the curve of the selection team preferences with reference to the alternatives. The main reason behind choosing this technique is that it requires only verbal judgments that qualify the attractiveness differences between every two single actions to quantify their underlying attractiveness.

MACBETH comprises seven predefined judgments which describe the difference of attractiveness between every two candidate products: No difference of attractiveness, Very weak difference of attractiveness, Weak difference of attractiveness, Moderate difference of attractiveness, Strong difference of attractiveness, Very strong difference of attractiveness, Extreme difference of attractiveness. MACBETH introduces two reference actions: SUP and INF. Those actions denote respectively the best and the worst potential actions relating to the evaluation criterion.

In the context of elementary evaluation of ERP candidates, an illustrative example of a judgment matrix relating to the comparison of three ERP systems (ERP A, ERP B and ERP C) with respect to the security criterion is illustrated in Fig. 2. The MACBETH interval scale is obtained thanks to the M-MACBETH software that supports MACBETH method.

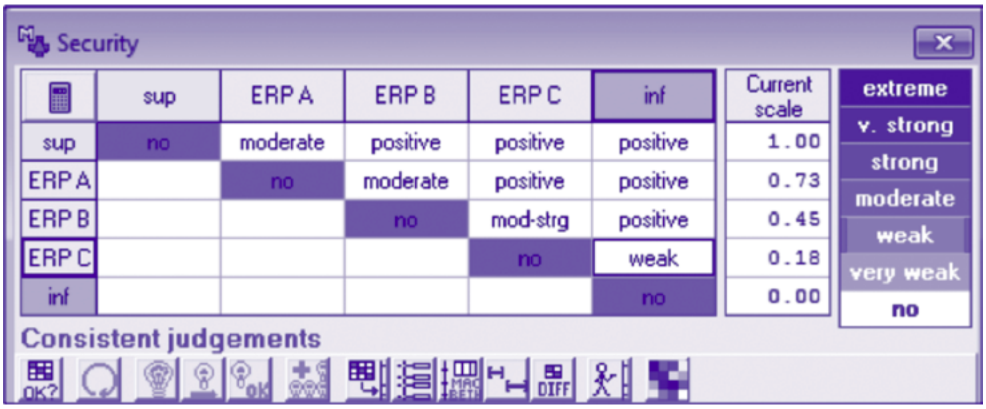

Figure 2. Judgment matrix of MACBETH

For more details about using MACBETH in ERP selection, the reader is asked to refer to our previous work (Khaled and Janati-Idrissi, 2011b).

3.6. Global evaluation

The global preference score relating to an ERP candidate product is defined through aggregating preferences values along the evaluation criteria tree. Based on these scores, recommendations about optimal solutions are given with respect to their decreasing ranking order. Accordingly, the best candidate is the one that has the highest score. The originality of SEVALERPS is its introduction of a new aggregation function which is based on the discrete Choquet Integral (Choquet, 1953). In fact in order to represent the interdependencies among criteria, SEVALERPS relies on the criteria coalitions' importance concept.

Indeed, for a set of criteria, denoted by $N,(1_X,0_{N-X})$ represents a binary vector which has the value of 1 on the criteria belonging to X and the value of 0 on the criteria belonging to N-X. The set of $\{\forall X \subseteq N | (1_X,0_{N-X})\}$ represents the all possible coalitions of the criteria belonging to N. In order to assign an importance value to each coalition, SEVALERPS uses MACBETH to determine these values on interval scales. To illustrate this concept, we suppose that the selection team has to define the importance weights relating to the coalitions of the three following criteria: security, portability and extensibility. These importance weights are needed, for instance, to judge the quality of an ERP candidate package that has respectively the following three scores on those criteria: 5%, 35% and 45%.

If we suppose that the qualitative judgments of the evaluation team relating to the importance of differences between each two couples of the 3-uplets criteria coalitions are given in Fig. 3; then the strategic importance of each coalition is defined in the scale column illustrated in the same figure.

	upper	(1,1,0)	(0,1,1)	(1,0,1)	(0,1,0)	(1,0,0)	(0,0,1)	lower	Current scale
upper	no	very weak	weak	mod-strg	moderate	strg-vstr	v. strong	extreme	1.00
(1,1,0)		no	very weak	very weak	moderate	strong	strg-vstr	v. strong	0.86
(0,1,1)			no	very weak	weak	moderate	mod-strg	strong	0.73
(1,0,1)				no	weak	moderate	moderate	strong	0.70
(0,1,0)					no	very weak	weak	strong	0.51
(1,0,0)						no	very weak	moderate	0.35
(0,0,1)							no	weak	0.24
lower								no	0.00

Consistent judgements

Figure 3. Attractiveness' differences among criteria's coalitions

Accordingly, we denote by $\mu(X)|X\subset N$ the importance function that assigns weights to each coalition of the X criteria belonging to N as it is illustrated in (3).

$$\forall X\subseteq N \;\; \mu(X) = \mathrm{SCALE}_{\mathrm{MACBETH}}\,(1_X, 0_{N\setminus X}) \qquad (3)$$

In order to extend the definition of μ from $\{0,1\}^n$ to $[0,1]^n$ (n is the number of elements within N), we interpolate the μ function within the $[0,1]^n$ domain. According to (Grabisch, 2006), the discrete Choquet integral is the only valid linear interpolator of such functions, called capacities. The Choquet integral relating to a μ capacity is defined in (4).

$$\begin{cases} (C_\mu(X)=\sum_1^n x_{\sigma(i)}\,[\mu(A^{\sigma(i)} - \mu(A^{\sigma(i+1)})] \\ X=(x_1,x_2,\ldots,x_n) \in [0,1]^n \end{cases} \qquad (4)$$

σ is a n-permutation that ranges the elements of X as follows:

$$x_{\sigma(1)} \le x_{\sigma(2)} \le \ldots \le x_{\sigma(n)}$$

$$\begin{cases} A^{\sigma(i)} := \{\sigma(i),\ldots,\sigma(n)\} \\ A^{\sigma(n+1)} = \varnothing \end{cases}$$

For instance, in our previous example, by considering the importance values obtained through MACBETH as a capacity in the Choquet integral, we compute the following aggregated score of Fig. 3. This score is assigned to the preference vector of (5%, 35%, 45%) given above.

```
> Quality <-c(0.05,0.35,0.45)
>
>
> mu <- capacity(c(0,0.35,0.52,0.24,0.86,0.70,0.73,1))
>
> mu
                capacity
{}              0.000000
{1}             0.350000
{2}             0.520000
{3}             0.240000
{1,2}           0.860000
{1,3}           0.700000
{2,3}           0.730000
{1,2,3}         1.000000
>
>
>
> Choquet.integral(mu,Quality)
[1] 0.293
```

Figure 4. Global scores computed by Choquet integral

Hence, by using this systematic evaluation process and model, SEVALERPS provides a quantitative approach to comparatively evaluate ERP candidate packages, which represents our answer to the second research question. For further information about using Choquet integral in evaluating ERP packages, the reader is asked to refer to our previous work: (Khaled and Janati-Idrissi, 2011a); (Khaled and Janati-Idrissi, 2011b).

4. Case study

In this section, in order to validate SEVALERPS, we present its experimentation through a case study relating to an organization belonging to the public administration in Morocco. Due to confidentiality concerns, we won't disclose the name of the organization and we denote it by "X".

4.1. Background

In this case study, our goal is to experiment to what extent SEVALERPS could predict and assess the risks relating to choosing one alternative among the others. Indeed, organization "X" aimed to acquire an ERP system to manage its public accounting process. This project was started in 2009 and resulted in choosing a solution that hasn't given satisfactory outcomes. For this reason, by applying SEVALERPS on this case study, we underline the SEVALERPS added value and see whether our method, applied in 2015, would have recommended the same risky solution chosen by organization "X".
The ERP system which should be chosen has to manage mainly the following aspects:

- Public Expenditure management;
- Public Income management;
- Public Accounting management;
- Public Debt management.

More precisely, the selected ERP system should cover the modules depicted in Fig.5.

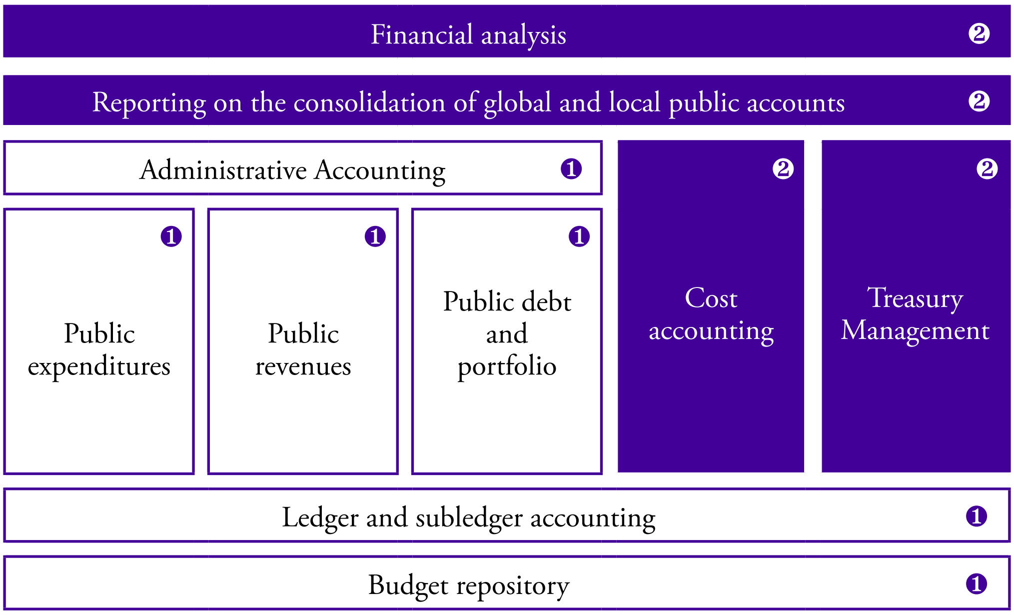

Figure 5. Functional project's scope

These modules represent the functional scope of the acquisition project. Furthermore, the modules tagged with number "1" represent the mission critical functions that must be covered immediately by the adopted system, whilst the ones tagged with number "2" are not urgently needed and could be implemented in the medium term. Hence the implementation strategy adopted by organization "X" is based on progressive acquisition of the modules described in the project's scope. In addition, it is worth mentioning that upon the completion of the implementation project, organization "X" aims to interoperate its ERP system by exchanging financial data with other information systems belonging to other public departments, such as the tax and the custom ones.
Organization "X" has to choose among three market leader ERP systems, which we denotes here by "Solution 1", "Solution 2" and "Solution 3". These solutions have respectively the following three initial acquisition costs: $5.8 million, $4 million, and $2 million. It should be noted that based on the organization financial resource constraint, the selection team of organization "X" has basically a tendency to choose solution 2.
In this overall context, it should be noted that the selection team has already defined the required functionalities relating to each module as well as the evaluation criteria tree which will be used to judge the potential ERP solutions. Accordingly, in this case study, SEVALERPS is applied starting from the third step of the evaluation process described in Fig.1. Besides, four main criteria categories are taken into account by the selection team in order to evaluate the candidate products: Functional, Technical, Strategic and Financial.

4.2. Application of SEVALERPS

SEVALERPS was applied, in this case study, with regard to three different scenarios:

- First evaluation scenario (short term), in which SEVLAEPRS is applied to recommend an ERP solution based only on the functionalities relating to the first module of Fig. 5;
- Second evaluation scenario (medium term), in which SEVALERPS is applied to choose an ERP solution based on the functionalities comprised in both the first and the second sets of modules of Fig. 5;
- Third evaluation scenario (long term), in which SEVALEPRS is applied to evaluate the three ERP solutions by taking into account the fact that the whole information systems of public departments should interoperate with each other.

4.2.1. First scenario

For each of the three potential ERP solutions, Table 3 shows the number of natively covered functionalities (before tailoring), the number of detected mismatches, and the one relating to the critical functionalities not covered by the standard releases of the ERP solutions.

	Solution 1	Solution 2	Solution 3
Natively covered functionalities	150	110	94
Detected mismatches	25	65	81
Critical functionalities	11	30	41

Table 3. Functional coverage of the three ERP candidate packages

In the SEVLAERPS mismatch handling stage, the selection team has identified several tailoring strategies for each of the ERP potential solutions. By solving the 0-1 linear programming systems of (1) relating to these solutions, the impacts of the best tailoring scenarios on their performances are shown in Table 4.

	Solution 1	Solution 2	Solution 3
Anticipated functional coverage	10%	16%	5%
Number of tailoring strategies	18	53	46
Non-adaptation risk	30%	35%	32%
Total cost of ownership (% tailoring cost)	\$5,8 million (24%)	\$4,2 million (56%)	\$3,7 million (49%)

Table 4. Impact of the best tailoring strategies

In order to assign global evaluation scores to the three ERP solutions, the selection team has to consider interdependencies that might exist among the three criteria of functional coverage, tailoring risk and total cost of ownership. These three criteria share the strategic importance of 75%, whilst the criterion of technical performance was considered as independent and has the strategic importance of 25%. In order to define the importance weight of each coalition relating to the three interdependent criteria, SEVALERPS suggests using MACBETH to represent them on an numerical [0,1] scale. As a result, the aggregation of the three ERP solutions' preference values through the discrete Choquet integral provides the global scores presented in Table 5.

Evaluation criteria	Strategic Importance	Solution 1	Solution 2	Solution 3
Anticipated functional coverage	Coalitions	90% (+10%)	88% (+16%)	48% (5%)
Tailoring Risk		70%	65%	68%
Total cost of ownership		30%	50%	60%
Aggregated score by Choquet integral	75%	0,616	0,6309	0.5664
Technical performance	25%	0,91	0,89	0,35
Global preference score		0,69	0,70	0,51

Table 5. Global preference scores

In this scenario, SEVALERPS has recommended solution 2 as the best one, followed by solution 1 and solution 3. However, we notice that solution 1 and solution 2 have almost the same scores. Even if solution 1 provides more anticipated functional coverage than solution 2, its higher total cost of ownership has downgraded its ranking order.

4.2.2. Second scenario

Similarly to the first scenario, Table 6 describes the standard functional coverage of the three ERP solutions before tailoring them.

	Solution 1	Solution 2	Solution 3
Natively covered functionalities	250	209	175
Detected mismatches	45	86	120
Critical functionalities	25	55	97

Table 6. Functional coverage of the three ERP candidate packages

In this second scenario, solution 3 was discarded because some mismatches relating to a set of critical functionalities couldn't be resolved by the proposed tailoring strategies. Indeed, the number of tailoring strategies (60) is lower than the number of critical functionalities that must be covered through tailoring (97).
Contrary to the recommendation of the first scenario, the aggregated scores obtained for this scenario (see Table 7) show that, in the medium run, solution 1 is more suitable than solution 2. In fact, even if solution 1 remains a bit more costly than solution 2. The tailoring risk of solution 2 is too high to promote its selection. For this reason, the global score of solution 1 is significantly more important compared to the one relating to solution 2.

Evaluation criteria	Strategic Importance	Solution 1	Solution 2
Anticipated functional coverage	Coalitions	85% (+15%)	84% (+35)
Tailoring Risk		72%	35%
Total cost of ownership		50%	52%
Aggregated score by Choquet integral	75%	0,6754	0,4742
Technical performance	25%	0,91	0,89
Global preference score		0,69	0,73

Table 7. Global preference scores

4.2.3. Third scenario

In this last scenario, the selection team of organization "X" has decided to use the RatIop approach (Elmir and Bounabat, 2012) which is geared towards the assessment of the interoperability maturity level among many information systems. In this case study, the interoperability feature is considered as a sub criterion of the technical performance.
According to (Elmir and Bounabat, 2012), it evaluates the compatibility of these systems based on the external interfaces involved within business processes. RatIop takes into account the following three operational aspects:

- Interoperation potentiality (PI);
- Interoperation compatibility (DC);
- Operational performance (PO).

The key performance indicator defined by RatIop to evaluate interoperability is defined in (5).

$$RatIop=(PI+DC+PO)/3 \quad (5)$$

Actually, the chosen ERP system must interoperate with ten other information systems, as it is shown in Fig. 6.

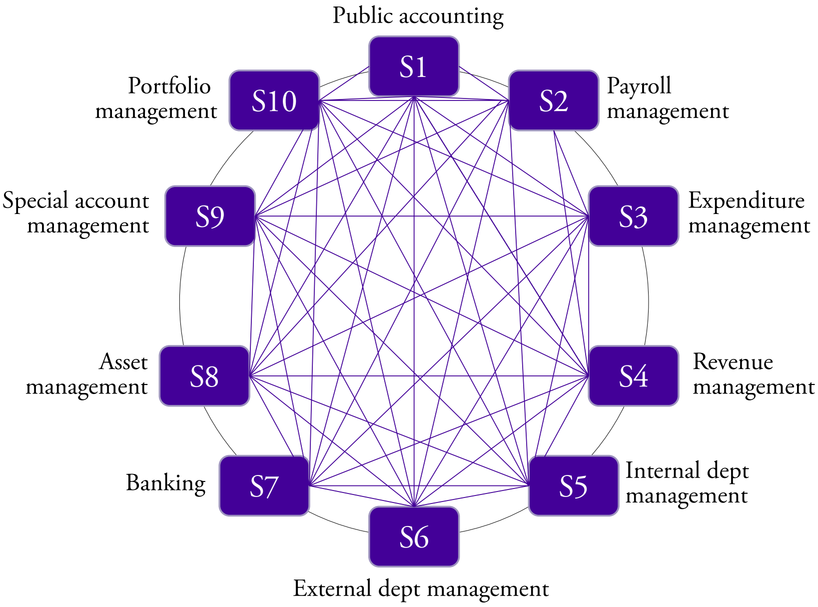

Figure 6. Interoperability among the ten information systems (Elmir and Bounabat, 2012)

According to a previous study conducted by (Elmir and Bounabat, 2012), the levels of interoperation relating to solution 1 and solution 2 are respectively 0.75 and 0.62. Based on these values, the global preference scores of solution 1 and solution 2 are presented in Table 8.

Evaluation criteria	Importance	Solution 1	Solution 2
Anticipated functional coverage	Coalitions	85% (+15%)	84% (+35)
Tailoring Risk		72%	35%
Total cost of ownership		50%	52%
Aggregated score by Choquet integral	75%	0,6754	0,4742
Technical performance	25%	0,83	0,75
Global preference score		0,71	0,54

Table 8. Global preference scores

As result, we conclude that in order to ensure better communication among the information systems and the future solution, it is advised to choose solution 1.

4.3. Analysis and discussion

By analyzing the results obtained in the three aforementioned scenarios, we can see as it is shown in TABLE 9 that the two last scenarios recommend clearly to choose solution 1, whilst the first scenario is barely making a distinction between solution 1 and solution 2. With regard to solution 3, it is either ranked in the last position or eliminated from further consideration.

	Solution 1	Solution 2	Solution 3
Scenario 1	0,69	0,70	0,51
Scenario 2	0,73	0,58	-
Scenario 3	0,71	0,54	-

Table 9. Summary of SEVALERPS evaluation

In the first scenario, we can see that the total cost of ownership has pledged for the selection of solution 2 with a difference of $1.6 million compared to the first solution. We can also notice that both solution 1 and solution 2 have a quite similar tailoring risk given that the most required functionalities relating to the first set of modules are well implemented by these two ERP systems.

Conversely, in the second scenario, SEVALERPS suggests choosing solution 1. In fact, in order to cover the functionalities of the overall modules described in the acquisition project's scope, the tailoring risk of solution 2 reaches 65% compared to 28% relating to solution 1. In this situation, solution 1 seems to be more interesting, because it provides the same functional coverage as solution 2 with lower tailoring risk. The difference of the total cost of ownership between these two solutions is insignificant and doesn't justify a difference of tailoring risk estimated at around 37%. We recall that solution 3 was eliminated from further consideration due to its inability to cover some critical business functionalities, even after its tailoring.
The third scenario reconfirms the outcomes of the second one. Actually, the interoperability levels of the first two solutions with the key information systems belonging to other public departments show that solution 1 provides more favorable conditions to deal with integrating the business processes and data of the relevant departments.

4.4. Validation

As mentioned above, despite the tendency of organization "X" to choose solution 2 (For mainly financial considerations), SEVALERPS considers that choosing solution 1 is highly recommended. The results of the in-depth analysis obtained by applying SEVALERPS method were presented to the senior officials and the decision makers of organization "X". They recognized the interest of SEVELARPS method and systematic approach with which this method deals with the most tedious and complex evaluation questions. In spite of its initial higher acquisition cost, they were finally convinced that solution 1 is the most appropriate solution for the case of organization "X" for the long run. The feedback relating to the real implementation of solution 1 has shown that the adoption of this solution was done smoothly and the tailoring risk was controlled. However, there were some gaps between the estimated outputs and the real ones, as show in Table 10.

	Adjustment
Anticipated fitness	-5%
Tailoring Risk	3%
Total cost of ownership	12%

Table 10. Outputs' adjustments

These results lead us to the issue of the estimation accuracy of the inputs and its impact on the outcomes. In fact, these inputs are often uncertain and are based on the experience of the evaluators. For this reason, it is deemed wise to supplement SEVALERPS by a sensitivity analysis to see how outcomes change if the inputs vary within a limited range.

5. Conclusion

The purpose of this paper is to present SEVALERPS, a new *ex-ante* evaluation method proposed to perform ERP system adaptation and selection. This method is mainly developed to handle some of the research questions resulting from investigating shortcomings relating to the previous ERP evaluation methods. The proposed method serves mainly twofold objectives; firstly it introduces a new systematic evaluation process that considers ERP tailoring and mismatch handling as the cornerstone of the evaluation activity. Secondly, it presents a semi-structured evaluation model that helps the selection team to voice out its preferences. The evaluation model relies on many mathematical techniques to handle the various aspects of the evaluation: 0-1 linear programming to determine the anticipated functional coverage of ERP candidates, MACBETH cardinal scales to represent, in an interactive way, the selection team preferences, and the Choquet integral to address interdependencies among evaluation criteria.
The experimentation of SEVALERPS through a large scale project conducted in a public administration shows that our method is practical and improves the ERP selection process. It should be noted that SEVALERPS is also supported by an automation system called AS-SEVALERPS (Automation System of SEVALRPS). The design and main components of this system will be discussed in our further publications.
The first limitation of SEVALERPS lies, like all the previous evaluation methods, in that the accuracy of its results is completely dependent on the one of its inputs. Now, given that these inputs are mainly obtained through human judgments, the reliability question of SEVALERPS results is raised in case these inputs are somehow uncertain. Thus, a research perspective to improve SEVALERPS is to provide organizations with ready to use knowledge databases from which they could validate their evaluation data. This data is mainly relating to the non-adaptation risks, the initial functional coverage levels of the required functionalities, and the anticipated functional coverage levels of these functionalities after tailoring the ERP solutions. The validation of the data contained in these

knowledge databases should be done through the comparison and the review of data obtained through a predictive way with the one obtained from real evaluation cases.

Finally, applying SEVALERPS method requires the determination of the evaluation criteria against which ERP candidate solutions will be judged. These criteria depend on the business requirements of each organization. In this regard, another way to improve SEVALERPS is to define more relevant criteria for each organizational context and validate them through more specific case studies. These mentioned perspectives are the aim of our future research.

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