[Postprint] Please cite as: López C, Ishizaka A, GAHPSort: a new group multi-criteria decision method for sorting a large number of the cloud-based ERP solutions, Computers in Industry, 92, 12-24, 2017

GAHPSort: a new group multi-criteria decision method for sorting a large number of the cloud-based ERP solutions

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Abstract

Companies are increasingly introducing cloud-based ERP systems as a solution for integrating all-in-one business functions into the Internet. To support this decision, this paper proposes the Group Analytic Hierarchy Process Sorting (GAHPSort) method, which extends the classical AHP for sorting problems with a large number of alternatives. Our study is specifically based on two steps: Firstly, the cloud-based ERP vendors are sorted with GAHPSort into two classes: accepted or rejected. Secondly, a single solution is selected with Analytic Network Process (ANP) among accepted vendors. To validate our model, we present the results obtained from a real case study.

Keywords: Cloud ERP, Selection, Sorting problems, Multi-criteria group decision making, GAHPSort, ANP.

1. Introduction

Multi-criteria decision analysis (MCDA) methods have been developed to solve choice, sorting, ranking, description, elimination and design problems [1]. Among them, the Analytic Hierarchy Process (AHP) is a useful and widespread method for solving choice and ranking problems [2, 3]. It has been recently adapted to solve sorting problems with AHPSort [4]. This means that alternatives are sorted into predefined ordered classes, for example good, average and bad classes. This type of classification is not possible with a ranking method. AHPSort allows simultaneous qualitative and quantitative criteria treatment. This means that a table of performance is not needed a priori. Moreover, GAHPSort inherits the advantages of AHP: it has associated consistency measures. Thus, inconsistent answers from participants can be discussed or discarded. Finally, AHPSort requires far less pairwise comparisons than AHP, which facilitates decision making within large scale problems. As most problems are solved by several people (committees, task force, etc.), we further extend AHPSort to group sorting problems with Group Analytic Hierarchy Process Sorting (GAHPSort) in this paper. This new method has been used to select the cloud-based ERP system that best suits the adopter firm's needs.

The cloud computing paradigm has in the last years been propagated in the enterprise systems industry. Nowadays, more and more ERP vendors offer cloud-based systems [5]. Unlike on-premises packages, cloud-based ERP applications do not locate end-users' data and computing resources in the IT infrastructure of the adopter company [6]. These are based on a distribution computing architecture that allows its users to easily access software and associate data in the cloud at any time and regardless of their location [7]. The complexity of the in-house IT infrastructure thus decreases, thereby leading to a reduction in capital expenditure [8]. [9] have found that cloud computing investment significantly increases the firm's market value.

Cloud-based ERP packages are not licensed or owned by the adopter firms. They only pay a monthly fee for the services that they use in the cloud, enabling operative cost savings and a more efficient use of IT resources [10, 11]. The cloud computing model also provides other benefits to business performance derived from the improved productivity, security, flexibility, and scalability of enterprise IT infrastructure [8, 12-14]. Likewise, it makes the deployment and upgrade of IT-related resources easier, allowing a continuous and agile alignment between the rapidly changing business need of the adopter firm and its operative ERP.

Given the above-mentioned benefits, more and more firms are currently deciding to adopt cloud-based ERP applications. A study of [15] estimates that cloud-based systems accounted for 2% of the total ERP market by 2011, although this figure was expected to grow by about 21% annually through 2015. In order to attain the expected benefits derived from cloud-based ERP adoption, the selection of the most suitable package from among a large number of options on the market is a critical decision. In fact, a wrong choice can adversely affect the adopter's performance [16, 17].

Selecting a cloud ERP system can be considered more challenging than choosing an on-premise ERP. Cloud ERP services are still new and unfamiliar to firms in comparison with products offered in the mature market of traditional ERP systems. [18] carried out an extensive market analysis of 651 cloud providers for enterprise systems. They point out the lack of transparency in the cloud providers market, which make cloud enterprise system selection more difficult. Some cloud ERP packages do not even provide the advanced functionality of classical ERP systems [19]. In the same line, a recent report reveals companies carry on largely implementing on-premise ERP rather than cloud ERP [20]. This also denotes a lack of understanding of cloud products and the perceived risks of security breaches.

As a result, when a firm decides to adopt a cloud ERP system it is advisable for it to carry out a screening of cloud technology providers. Accordingly, we propose a two-step based selection framework based. In the first step, the most relevant criteria in the evaluation of cloud-based ERP vendors are identified and cloud ERP vendors are screened with GAHPSort. This method provides a comprehensive way to sort cloud ERP providers into different classes, considering multiple conflicting criteria. Moreover, decision makers can establish additional criteria and constraints using the limit profile mechanism. The results enable them to substantially reduce the initial number of alternatives following the company requirements, at the same time as decision makers attain a better understanding of solutions offered by cloud ERP providers.

GAHPSort sorts alternatives, while traditional MCDA methods, such as AHP, TOPSIS or ANP, prioritize them. According to Vetschera [21], “sorting is significantly different from ranking or choice and therefore requires the use of specific methods”. Hence, GAHPSort cannot be used alone to select the most appropriate cloud ERP.

In the second step, the cloud-based ERP systems of the qualified vendors are evaluated with ANP (Analytic Network Process (ANP). Saaty provided this as a generalization of AHP [22]. ANP has proven to be an effective instrument for supporting ERP selection process [23-25]. This is specifically very suitable to solve problems when the decision criteria cannot be organized in a unidirectional hierarchical way, by applying a network structure. Furthermore, ANP allows considering feedback between criteria. It has proven to alter the final ranking of ERP alternatives [26]. TOPSIS has also been applied in the ERP selection process [27]. However, this method has the weakness of assigning reliable subjective preferences to the criteria. By contrast, ANP is considered a very valuable mechanism when subjectivity exists. To use this, decision makers evaluate criteria using pairwise comparison. Subsequently, ANP enables estimating the relative importance of the weightings of each criterion considered in the cloud-based ERP system selection process. In addition, it generates a cloud-based ERP systems ranking according to the company’s requirements and expectations.

In the following sections, we introduce related works and the theoretical focus upon which this research is grounded. Section 2 introduces the cloud-based ERP systems. Section 3 describes the studies developed for supporting the selection of the accurate ERP system. The technique proposed for sorting cloud ERP vendors is detailed in Section 4. Section 5 presents the case study carried out in order to validate our proposal. Finally, Section 6 provides conclusions as well as possible directions for the development of related works in the future.

2. Cloud-based ERP systems

The adoption of advanced technology solutions by companies is taking place at an accelerated pace. Continuous advancement in information technology (IT) has been modifying the ways we do business. This has motivated a transition from an industrial economy to a network economy [28], where companies take part in a hyper-connected world over the Internet [29].

In the last few years, there has been a growing demand for cloud-based technological resources. A report [30] suggests that the share of the cloud-based market will reach $244 billion by 2017, growing by a compound annual rate of 17%. Cloud-based tools are developed, deployed, delivered, used, and maintained as virtualized computing services on the Web [31]. Adopter companies can thus easily access a shared pool of configurable computer resources [32], purchasing only what they need and paying for only what they really use.

Enterprise Resource Planning (ERP) packages are among the most widespread enterprise applications. This is due to these solutions integrating the whole business functions, improving their productivity and operational efficiency [33], providing more accurate information to business decision making, and, finally, improving financial performances [34, 35]. ERP helps companies to gain or maintain competitive advantages over competitors [36]. Nonetheless, the ERP adoption process is never exempt from challenges and significant hazards [37-40]. In spite of this, numerous companies assume the associated risk and they get the ERP adoption process underway.

The emergence of the cloud computing phenomena is specifically transforming the way ERP solutions are designed, developed, supplied, implemented, updated, maintained, and even paid for. The majority of today's on-premise ERP vendors have expanded their products portfolio with cloud-based ERP solutions, and at the same time new providers have entered into the market [5].

Firms are increasingly adopting cloud-based ERP solutions to re-invent their enterprise systems, decreasing their complexity and costs derived from hardware, software, upgrades, and IT support, and thereby improving their productivity, scalability, and flexibility and making an agile deployment of services easier [8, 10-14]. Cloud ERP adoption also makes better use of the IT resources available, enabling access to data and services system functionalities.

To achieve the expected results of ERP adoption, it is necessary to choose the package that best suits the firm's requirements [41]. However, no single ERP commercial solutions can meet all business needs and the specific particularities of any adopter firm [17, 26]. Likewise, ERP system selection is a difficult and highly complex undertaking, owing to the great number of ERP vendors and packages available in the market, the limitation in available resources, the continuous improvements and upgrading in IT, the existence of interdependences and incompatibilities between the old and new hardware and software systems, the complexity of the business environment, and decision makers' lack of knowledge and experience for system selection decision making methods [42, 43]. This has led to the development of numerous studies which support the ERP system selection process in a better and more structured way. The next section examines these studies in detail.

3. ERP selection studies

Choosing the most suitable ERP package from among a large number of options in the market is a complex and uncertain process [26]. With this in mind, decision makers with limited money, time, and resources have to consider multiple functional and non-functional criteria of different degrees of importance [42]. The need of supporting this task has encouraged the appearance of many advanced methodologies in the ERP selection context.

Some studies about ERP package selection identify the most commonly used criteria and categorize or prioritize them [44-46]. Others mainly focus their efforts on providing frameworks, methodologies, and techniques to assess the available ERP packages and assist decision makers in their decision process [37, 47, 48].

Several frameworks and stage-based methodologies for the selection of ERP solutions can be found in the literature [49-55]. These studies set out the guidelines or sequence of activities that decision makers should carry out for selecting the right ERP solution [55]. For example, they present a high-level model of the ERP acquisition process, which is made up of six interrelated and iterative processes: planning, information search, selection, evaluation, choice, and negotiations.

In order to automate the process of ERP selection, new applications have also been developed [16, 56-60]. These tools assist decision makers in evaluating criteria and systems proposals, helping them to choose the best commercial ERP system. Multi-criteria decision-making approaches have been widely used to develop these decision support systems [61]. Furthermore, [58] introduce a fuzzy quality function deployment method to determine ERP selection criteria. Under another approach, [56] provide a fuzzy cognitive map-based tool which allows the assessment of possible scenarios about the ERP package selection process.

Additionally, other studies have proposed the use of diverse techniques for assessing ERP systems on the basis of the company’s requirements and expectations [2, 3, 60-66]. With this purpose in mind, [60] provide a fuzzy comprehensive appraisal method for facilitating a group decision process. [66], on the other hand, present a combined method based on the PIRCS process and the SMART multi-attribute analysis to evaluate ERP packages alternatives, while [64] prefer TOPSIS and PROMETHEE to rank them. In the same line, an ANP-based method has also been applied alone [61, 63] and later in combination with PROMETHEE [67]. Nevertheless, AHP has been the most commonly used technique for the assessment of ERP solutions [1-5].

Unfortunately, it is noteworthy that these methods based on pairwise comparisons are very time consuming and consequently can only be used when the number of alternatives is small.

In our case study, many services and functionalities offered by ERP cloud vendors are not well known, and therefore require a more detailed analysis. Accordingly, we preferred to use a two-step analysis, where the first step is a pass or reject decision of the vendor and the second step is a ranking of the ERP system. The additional first step is a typical sorting problem with two classes. As no technique is able to solve a problem having qualitative and quantitative criteria and several decision-makers simultaneously, we developed GAHPSort. The next section describes it.

4. Sorting methods

4.1 Introduction

Several multi-criteria methods have been proposed to assign actions to predefined classes [68]. We usually distinguish three main families.

The first set of methods, referred to as nominal classification methods, handles classification problems where there is no preference order for the predefined groups; i.e., the relationships are symmetric. Most of these methods are based on the computation of a similarity, indifference, or closeness degree between the actions to be classified and the reference actions or central profiles defining the classes, such as PROAFTN [69], filtering procedures [70], TRINOMFC [71], and CLOSORT [72].

The second family of methods, called the sorting methods, is defined for classification problems where the classes are completely ordered (i.e., there is a complete preference structure from the best to the worst in the groups which are given by the decision maker). In this case, the classes are defined either by limiting profiles or by one or several reference actions (also called central profiles), such as Electre-Tri [73, 74], Electre-Tri-nC [75], FlowSort [76], PromSort [77], Theseus method [78], AHPSort [9], and ELECTRE-SORT [79].

The third family is the ordered clustering or unsupervised ordered classification methods. These methods focus on the automatic discovering of groups of similar objects within the dataset. The groups, also called clusters, are not predefined. The clusters are such that elements from one cluster are very different (distant) from elements of another cluster. Only a few multi-criteria clustering methods have been proposed [80-82].

FlowSort-GDSS [83] has been the first method developed for group sorting. This method is based on the outranking philosophy. It treats problems where the performance of the alternatives with each criterion is given. In this paper, we propose a new sorting method for group decisions: GAHPSort, an extension based on the AHP methodology. In this kind of problems, the performance table is not known a priori but qualitatively evaluated with pairwise comparisons.

4.2 GAHPSort

GAHPSort is a new sorting method used to assign alternatives to predefined classes by a group of decision makers. The classes are defined in an ordinal way based on decision makers' preferences. This means that classes are ordered from the most to the least preferred. GAHPSort is based on 10 steps:

A) Problem definition.

1) The group of h decision makers DM_s, S = 1,…, h agrees on the goal, criteria c_j, j = 1,…, m and alternatives a_k k = 1,…, l of the problem.
2) The group of decision makers defines the classes C_i, $i=1,…,n$, where n is the number of classes. The classes are ordered and have a label (e.g., excellent, good, medium, bad)
3) Each decision maker DM_s defines the profiles of each class. This can be done with limiting profiles lp_{ijs}, which indicates the minimum performance needed for each criterion j to belong to a class C_i according to DM_s, or with central profiles cp_{ijs}, which is given by a typical example of an element belonging to the class C_i for the criterion j according to DM_s. For each decision maker, we need m· (n -

1) limiting profiles or $m \cdot n$ central profiles to define all n classes.

B) Evaluations.

4) Each decision maker DM_s evaluates pairwise the importance of the criteria c_j and derives their weight w_{js} with the eigenvalue method of the AHP.

$$\mathbf{A_s} \cdot \mathbf{w_s} = \lambda_s \cdot \mathbf{w_s} \tag{1}$$

where $\mathbf{A_s}$ is the comparison matrix for DM_s

$\mathbf{w_s}$ is the priorities/weights vector for DM_s

λ_s is the maximal eigenvalue for DM_s

5) Each decision maker DM_s compares in a pairwise comparison matrix a single alternative a_k with each limiting profile lp_{ijs} or central profile cp_{ijs} for each criterion j.

6) From the comparison matrices of each decision maker, DM_s derives the local priority p_{kjs} for the alternative a_k and the local priority p_{ijs} of the limiting profiles lp_{ijs} or central limiting profiles cp_{ijs} with the eigenvalue method (1).

C) Aggregation.

7) Aggregate the weighted local priorities for each DM_s, which provides a global priority p_{ks} for the alternative a_k (2) and a global priority lp_{is} for the limiting profile or cp_{is} for the central profiles (3).

$$p_{ks} = \sum_{j=1}^{m} p_{kjs} \cdot w_{js} \tag{2}$$

$$lp_{is} \text{ or } cp_{is} = \sum_{j=1}^{m} p_{ijs} \cdot w_{js} \tag{3}$$

D) Assignment to classes.

8) For each DM_s, the comparison of p_{ks} with lp_{is} or cp_{is} is used to assign the alternative a_k to a class C_i.

a. Limiting profiles:

If limiting profiles have been defined, the alternative a_k is assigned to the class C_i which has the lp_{is} just below the global priority p_{ks} (Figure 1).

$$
\begin{aligned}
&p_{ks} \geq lp_{1s} && \Rightarrow \quad a_k \in C_1 \\
&lp_{2s} \leq p_{ks} < lp_{1s} && \Rightarrow \quad a_k \in C_2 \\
&\ldots \\
&p_{ks} < lp_{n-1s} && \Rightarrow \quad a_k \in C_n
\end{aligned}
\tag{4}
$$

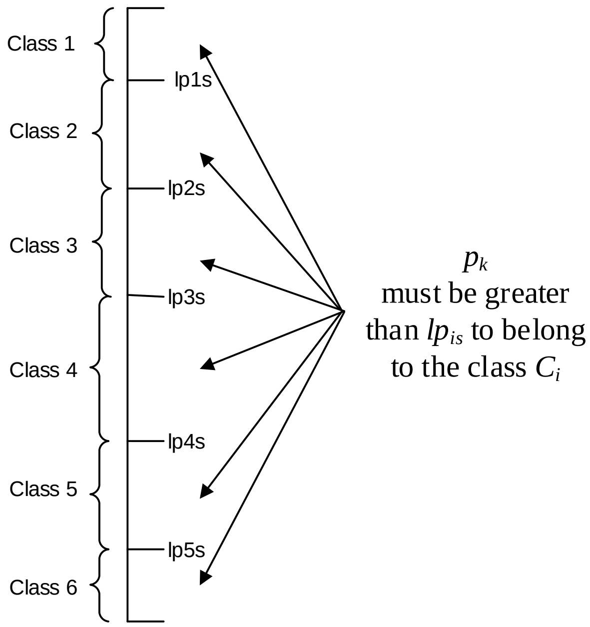

Figure 1. Sorting with limiting profiles

b. Central profiles:

If the decision maker has difficulties defining a limiting profile, he or she can define a typical example of a class: the central profiles cp_{is}. The limiting profiles are deduced by $(cp_{is} + cp_{i+1s})/2$. The alternative a_k is assigned to the class C_i which has the nearest central profile cp_{is} to p_{ks} (Figure 2). In the case of an equal distance between two central profiles, the optimistic assignment vision allocates a_k to the upper class, whilst the pessimistic assignment vision allocates a_k to the lower class.

$$
\begin{array}{ll}
p_{ks} \geq cp_{1s} & \Rightarrow a_k \in C_1 \\
cp_{2s} \leq p_{ks} < cp_{1s} \text{ AND } (cp_{1s} - p_{ks}) < (cp_{2s} - p_{ks}) & \Rightarrow a_k \in C_1 \\
cp_{2s} \leq p_{ks} < cp_{1s} \text{ AND } (cp_{1s} - p_{ks}) = (cp_{2s} - p_{ks}) & \Rightarrow a_k \in C_1 \text{ in the optimistic vision} \\
cp_{2s} \leq p_{ks} < cp_{1s} \text{ AND } (cp_{1s} - p_{ks}) = (cp_{2s} - p_{ks}) & \Rightarrow a_k \in C_2 \text{ in the pessimistic vision} \\
cp_{2s} \leq p_{ks} < cp_{1s} \text{ AND } (cp_{1s} - p_{ks}) > (cp_{2s} - p_{ks}) & \Rightarrow a_k \in C_2 \\
\ldots & \\
p_{ks} < cp_{ns} & \Rightarrow a_k \in C_n
\end{array}
\tag{5}
$$

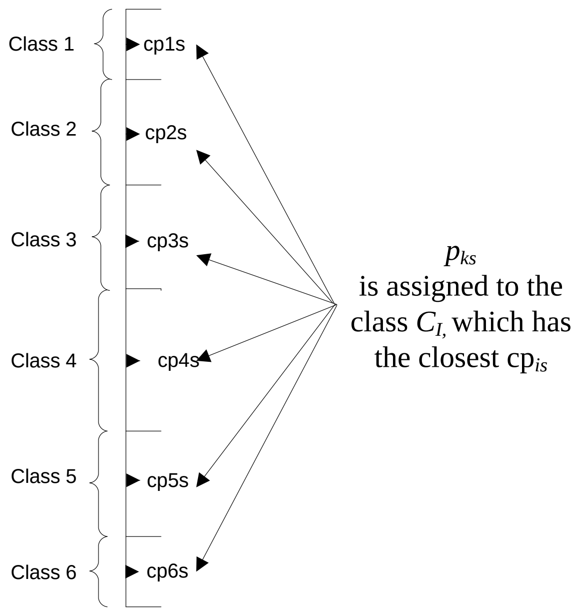

Figure 2. Sorting with central profiles

E) Group aggregation.

9) There are three scenarios:

a) All *S* decision makers assign a_k to the same class C_i. Then, a_k is unanimously assigned to C_i.

b) The majority of the decision makers assign a_k to the class C_i. Then, a_k is majorly assigned to C_i.

c) Half of the decision makers assign a_k to the class C_i and the other half to C_{i+1}.

a. *Limiting profiles*:

We separate the decision makers into two sets: the set x assigning a_k to C_i and the set y assigning a_k to C_{i+1}. Then, we calculate the sum of the distances for the set x between p_{ks} and lp_{is}. Similarly, we calculate the distance for the set y between p_{ks} and lp_{is}. If the sum of the distances is larger for the set x, then a_k is assigned to C_i or otherwise to C_{i+1}.

In the case of equal sums, the optimistic assignment vision allocates a_k to the upper class, whilst the pessimistic assignment vision allocates a_k to the lower class.

$$\sum_{s=1, s\in x}^{h}(p_{ks} - lp_{is}) > \sum_{s=1, s\in y}^{h}(lp_{is} - p_{ks}) \text{ then } a_k \in C_i$$

$$\sum_{s=1, s\in x}^{h}(p_{ks} - lp_{is}) < \sum_{s=1, s\in y}^{h}(lp_{is} - p_{ks}) \text{ then } a_k \in C_{i+1} \quad (6)$$

$$\sum_{s=1, s\in x}^{h}(p_{ks} - lp_{is}) = \sum_{s=1, s\in y}^{h}(lp_{is} - p_{ks}) \text{ then } a_k \in C_i \text{ (in the optimistic vision)}$$

$$\sum_{s=1, s\in x}^{h}(p_{ks} - lp_{is}) = \sum_{s=1, s\in y}^{h}(lp_{is} - p_{ks}) \text{ then } a_k \in C_{i+1} \text{ (in the pessimistic vision)}$$

b. *Central profiles*:

We calculate the sum of the distances for all decision makers between p_{ks} and cp_{is} and between p_{ks} and cp_{i+1s}. If the sum of the distances is smaller between p_{ks} and cp_{is}, then a_k is assigned to C_i or otherwise to C_{i+1}.

$$\sum_{s=1}^{h}|p_{ks} - cp_{is}| < \sum_{s=1}^{h}|p_{ks} - cp_{i+1s}| \text{ then } a_k \in C_i \quad (7)$$

$$\sum_{s=1}^{h}\left|p_{ks}-cp_{is}\right| > \sum_{s=1}^{h}\left|p_{ks}-cp_{i+1s}\right| \text{ then } a_k \in C_{i+1}$$

$$\sum_{s=1}^{h}\left|p_{ks}-cp_{is}\right| = \sum_{s=1}^{h}\left|p_{ks}-cp_{i+1s}\right| \text{ then } a_k \in C_i \text{ (in the optimistic vision)}$$

$$\sum_{s=1}^{h}\left|p_{ks}-cp_{is}\right| = \sum_{s=1}^{h}\left|p_{ks}-cp_{i+1s}\right| \text{ then } a_k \in C_{i+1} \text{ (in the pessimistic vision)}$$

10) Repeat processes 5) to 9) for each alternative to be classified.

4.3 Number of pairwise comparisons

The high number of comparisons is a well-known problem of AHP [84]. In fact, with *l* alternatives, $\frac{l \cdot (l-1)}{2}$ pairwise comparisons are necessary for each criterion considered. The increase in the number of comparisons is quadratic. For *m* criteria, the total number of pairwise comparisons is:

$$\boldsymbol{m \cdot \frac{l \cdot (l-1)}{2}} \tag{8}$$

In AHPSort, the number of comparisons is calculated as following. The *b* limiting or central profiles need first to be compared with each other: $\frac{b \cdot (b-1)}{2}$. Then, the *l* alternatives are compared to the *b* profiles. Finally, this is repeated for all *m* criteria:

$$m \cdot \left[\frac{b \cdot (b-1)}{2} + (b \cdot l)\right] \tag{9}$$

The number of comparisons is smaller in AHPSort compared to AHP if the number of alternatives *l* is much larger than the number of classes, which is normally the case. However, it is to be noted that they are two different methods. AHP is a ranking method and AHPSort is a sorting method. They cannot be interchangeable.

5. Case study

The proposed multi-criteria group decision making approach has been applied to a cloud-based ERP system selection in a Spanish firm. This company inspects and controls the appliance of a wide variety of standards and industrial regulations. At the same time, it promotes the region's industrial development.

5.1 Description of the whole cloud ERP selection process

The company has decided to adopt a cloud-based ERP system in order to improve the data integration and to operate more efficiently. A team has developed this preliminary study to support the final decision. This study is not described here because it is not the focus of this paper. The team consisted of three decision makers (DM_s) with a wide range of ERP experience and was joined by the authors acting as facilitators for Stages 1 and 2 (Figure 3). They are employees of the case study company. Table 1 introduces the decision makers' profiles. The authors collected the decision preferences and selection criteria of the DM_s to determine the most appropriate cloud-based ERP system for their implementation. The data were collected through personal interviews.

Table 1. Decision makers' profiles

Characteristics	**DM_1**	**DM_2**	**DM_3**
Position	Project manager	IT analyst	IT technician
Work experience	12 years	12 years	15 years
Industry	Public sector	Public sector	Public sector
Familiarity with ERP solutions for	10 years	10 years	15 years
Academic background	IT engineer	BA degree	IT engineer

The full decision workflow process is depicted in Figure 3. There is a great variety of methodologies for selecting the most suitable ERP package described in the literature (Section 3). These should be adapted to the requirements, issue, and individual features of each selection process. Due to the high number of alternatives and criteria, we decided to use a two-stage selection process. The first stage is a pre-qualification stage where cloud ERP vendors are sorted with GAHPSort into two classes: accepted or rejected. Subsequently, in the second stage, we assessed the cloud ERP solutions provided by the accepted vendors with ANP. Sections 5.1.1 and 5.1.2, respectively, describe both stages.

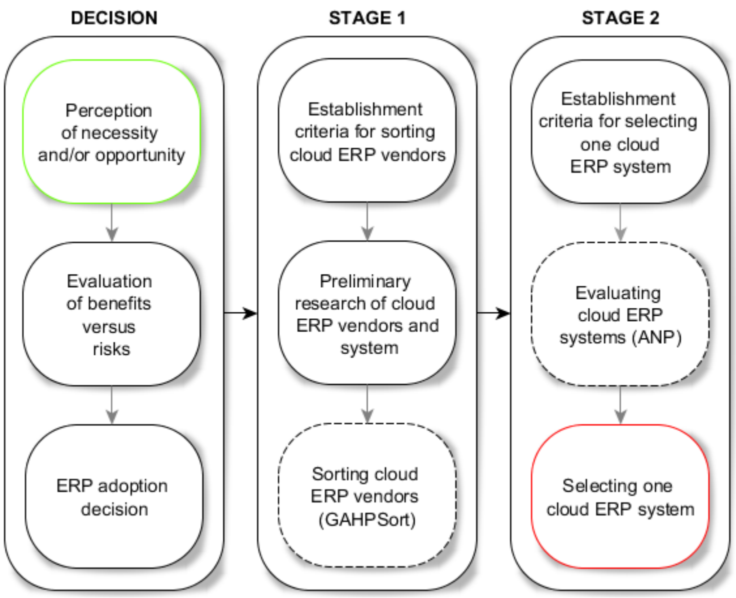

Figure 3. Steps in the cloud ERP system selection

5.1.1 Stage 1: sorting cloud-based ERP vendors

One of the most critical points in the selection process is the establishment of the criteria for sorting cloud-based ERP vendors. Indeed, a wrong choice of the ERP vendor would negatively affect the success of the process [22]. In order to support this task, we carried out an extensive literature review of ERP vendor selection criteria. We searched all the databases available to us, which were the ScienceDirect, IEEE-Xplore, Emerald Management Xtra and SpringerLink databases. We applied the following rules in all the searches:

1. The articles have to contain the terms (“ERP” AND “Vendor selection”) OR (“Enterprise Resource Planning” AND “Vendor selection”) in the title, abstract, keywords or text.
2. The articles have to clearly identify the vendor selection criteria.
3. The articles have to be written in English.
4. The time horizon was not limited to the last 15 years.

Altogether 15 articles were found in the search. Most of the vendor selection criteria are identified by several articles. Hence, we checked them and removed duplicates. The criteria identified were grouped under the same umbrella without changing their initial meaning (e.g., “Maintenance ability” encompasses the following criteria: “Vendor support for maintaining and updating the system”, “Maintenance support services”, and “Upgrade ability”). The preliminary list was made up of seven criteria. Subsequently, the three decision makers reviewed all the criteria identified. They had the possibility to add or remove criteria not considered relevant for this study. Only one criterion was added and two were removed (“Range of solutions” and “ERP vendor reputation”).

Table 2 summarizes the resulting list of criteria used to evaluate the cloud-based ERP vendors.

Table 2. Criterion weighting comparison

Sorting Criterion	**Source**	**DM$_1$**	**DM$_2$**	**DM$_3$**	**Aggregate weight**
Experience	[22, 41, 43, 45, 54, 64, 85]	0.088	0.052	0.046	0.059
Implementation ability	[4, 59, 63, 64]	0.220	0.194	0.181	0.199
Maintenance ability	[4, 21, 22, 43, 55, 64]	0.391	0.410	0.468	0.423
Support services	[4, 22, 41, 45, 49, 54, 60, 63, 64, 66, 85]	0.227	0.274	0.215	0.242
Successful outcomes in similar firms	[54]	0.051	0.046	0.068	0.054
ERP national market share	Suggested by the decision makers	0.022	0.024	0.023	0.024
Inconsistency ratio		0.13	0.05	0.09	0.06

The following step consisted in compiling a list of suitable cloud ERP vendors (i.e., the alternatives). This preliminary research also required the identification of the cloud-based ERP systems supplied by each pre-selected vendor. To do this, the project team checked diverse sources of information, such as vendors' websites, databases, cloud ERP market reports, and specialized magazines, among others. They initially selected eleven vendors.

In order to sort the cloud-based ERP vendors, we applied a multi-criteria decision-making methodology called GAHPSort, which is described in Section 4.2. Figure 4 shows the elements in the GAHPSort hierarchy. The top level contains the aim of the decision problem. Elements in the middle levels are the criteria defined for sorting the cloud ERP vendors. The third level shows the 11 cloud ERP vendors, which are the alternatives to the problem.

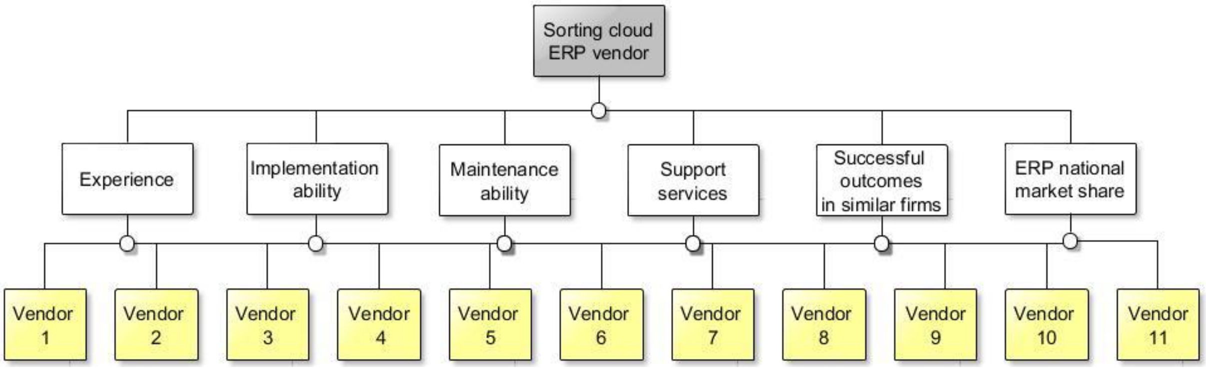

Figure 4. Hierarchical structure to sort ERP vendors

Table 3 shows the limiting profile established by each decision maker. Then, they carried out the criteria pairwise comparisons between each alternative and the limiting profiles in a questionnaire. Appendix A shows an extract. This is based on the widely-accepted nine-point scale which is inspired from the original scale suggested by Saaty (1977). We have adapted each point scale meaning according to the GAHPSort mechanism. Table 4 explains them. Crisp numbers were used to measure the limits and the weights of criteria. Notwithstanding, these could also be estimated using fuzzy numbers [86]. Yet, as a long debate is open on the validity of Fuzzy AHP [87, 88], we prefer use the traditional crisp numbers.

Table 3. Limiting profiles for each decision maker

Id	Criteria	Description	Limiting profile		
			DM_1	DM_2	DM_3
Sor1	Experience	At least …. years in the ICT industry	10	10	10
Sor2	Implementation ability	Projects do not exceed .... cost limits	20%	10%	20%
Sor3	Maintenance ability	▪ Basic requests are resolved within …. hours of receipt	4	4	3
		▪ Complex requests are resolved within …. days of receipt	7	3	3
Sor4	Support services	Geographic proximity (within a radius of … km).	200	200	200
Sor5	Successful outcomes in similar firms	At least successful outcomes in …. sector firm	1	1	1
Sor6	ERP national market share	At least …. ERP national market share	5%	5%	5%

Table 4. GAHPSort 1-9 scale and its meaning

Comparison scale	Definition	Explanation
1	Equal to limit profile	Alternative *k* meets the minimum performance needed to belong to class *I* with limiting profiles *lpijs* for criterion *j*
3	Weakly over limit profile	Alternative *k* weakly exceeds the minimum performance needed to belong to class *i* with limiting profiles *lpijs* for criterion *j*
5	Strongly over limit profile	Alternative *k* strongly exceeds the minimum performance needed to belong to class *i* with limiting profiles *lpijs* for criterion *j*
7	Very strongly over	Alternative *k* very strongly exceeds the minimum performance

	limit profile	needed to belong to class *i* with limiting profiles *lpijs* for criterion *j*
9	Extremely over limit profile	Alternative *k* extremely exceeds the minimum performance needed to belong to class *i* with limiting profiles *lpijs* for criterion *j*
2, 4, 6, 8	Intermediate values	
1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9	Opposite case	These intensities are assigned when the alternative *k* does not exceed the minimum performance needed to belong to class *i* with limiting profiles *lpijs* for criterion *j*

Table 2 also summarizes the weight of the criteria calculated with the eigenvalue method of the AHP. These values indicate the relative importance given to each criterion in the entire sorting exercise. The weights provided by each decision maker are aggregated by taking the average. Maintainability was considered the most important criterion in the assessment of ERP vendors. It achieved a global weight of 0.423. It is about 2 to 20 times greater than the other criteria. In second place are support services (0.242). These two criteria add up to 66.5% of the total global weight. Those results underline the company's concern to have a properly maintained ERP system, as evidenced in previous ERP post-implementation studies [89, 90]. The inconsistency ratio was 0.06. The maximum accepted upper value for the inconsistency ratio is 0.1 [91], and for that reason the DM_s' answers can be considered as sufficiently consistent.

Then, decision makers compared pairwise each cloud-based ERP vendor with the limiting profile in each criterion in a questionnaire. Once all the comparisons were performed, we computed the priorities of each alternative and limiting profile with Expert Choice. However, as this software is not designed primarily for sorting exercises [92], it requires a file for each cloud-based ERP vendor. Hence, we created a total of 11 files with Expert Choice — one for each alternative. The expertise of the three decision makers is considered equivalent, and they receive the same weight for the overall aggregation of their priorities. Therefore, the overall priority is calculated as an average of the decision makers' priorities.

Table 5 lists the results of the sorting exercise. The 11 ERP vendors were ranked in a descending order according to their overall priority. It is worth noting that the sum of the priorities of the limiting profile(s) and the alternative(s) is always 1. When we have only two classes, the alternative is in the upper class (accepted) if it has a global priority higher than 0.5. Figure 5 depicts the results obtained in the cloud-based ERP vendor sorting stage. Seven alternatives reached a higher value compared to the limiting profile score. These cloud-based ERP vendors progressed to the next evaluation stage.

Table 5. Cloud-based ERP vendors' priorities

	Sor1	Sor2	Sor3	Sor4	Sor5	Sor6	Priority DM_1	Priority DM_2	Priority DM_3	Overall priority

Vendor 2	0.889	0.857	0.8	0.889	0.5	0.875	0.814	0.816	0.8	0.811
Vendor 1	0.9	0.875	0.5	0.889	0.5	0.875	0.660	0.655	0.626	0.647
Vendor 3	0.9	0.111	0.847	0.558	0.75	0.889	0.636	0.597	0.631	0.625
Vendor 4	0.442	0.25	0.75	0.833	0.5	0.167	0.619	0.619	0.619	0.614
Vendor 5	0.9	0.1	0.879	0.152	0.875	0.9	0.534	0.532	0.586	0.548
Vendor 8	0.675	0.442	0.515	0.614	0.442	0.442	0.243	0.655	0.741	0.524
Vendor 11	0.591	0.43	0.534	0.534	0.409	0.397	0.195	0.613	0.742	0.508
Vendor 10	0.558	0.442	0.442	0.519	0.454	0.409	0.192	0.443	0.803	0.468
Vendor 9	0.5	0.333	0.409	0.5	0.343	0.369	0.247	0.507	0.528	0.424
Vendor 7	0.5	0.333	0.369	0.534	0.424	0.424	0.243	0.443	0.634	0.421
Vendor 6	0.386	0.442	0.386	0.442	0.386	0.369	0.227	0.670	0.395	0.412

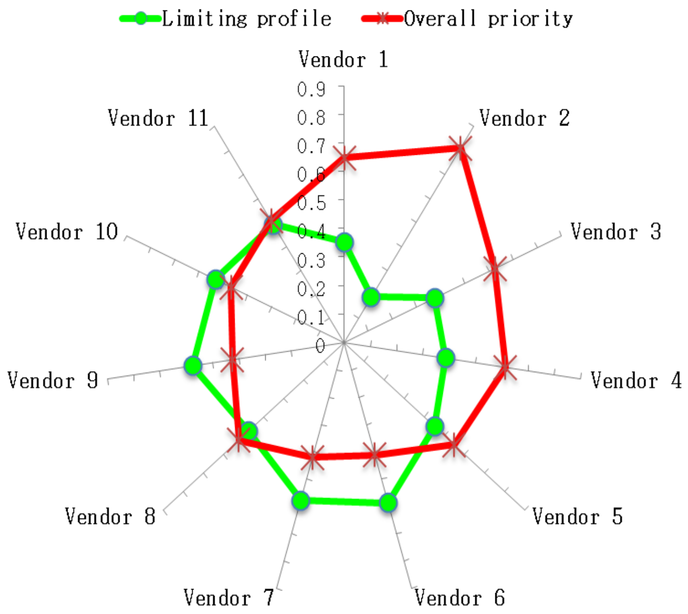

Figure 5. Limiting profile cloud-based ERP vendors radar chart

5.1.2 Stage 2: selecting the cloud-ERP system

After the ERP vendors have been qualified in the first sorting stage, the second stage aims to select their commercial package that best meets the company's requirements and expectations.

Our first step was to identify the criteria used in the literature to evaluate the ERP packages by companies. We consulted the same database as Stage 1, but applied the following constraints:

1. The publications have to contain the terms [("ERP" OR "Cloud") AND ("System selection")] OR [("Enterprise Resource Planning" OR "Cloud") AND ("System selection")] in the title, abstract, keywords or text.
2. The articles have to identify the ERP system selection criteria clearly.
3. The articles have to be written in English.
4. The time horizon was limited to the last 15 years.

We found 24 articles which identified criteria in the ERP system selection, but only one dealt with cloud ERP packages [50]. This presents a network model made up of six criteria related to system and software quality for evaluating SaaS ERP applications. As in Stage 1, we checked the criteria identified and removed duplicates. The preliminary list contained a total of twenty-four criteria. The group of decision makers checked the criteria identified. They added the criteria "Multilingual", "Monthly cost", "Customization cost" and "Business process reengineering cost". They excluded the criteria "Portability", "Software prestige", "Compatibility with other systems", and "Used by customers and suppliers" because they do not apply to their company. In order to increase their readability, the criteria were grouped into four categories: system, adoption, cost, and time. The full classified list of criteria is given in Table 6.

Table 6. Cloud-based ERP systems evaluation criteria

Category	Id	Criteria	Source
Sel1 - System	Sel1.1	Customization	[21, 22, 41, 44, 45, 49, 50, 54, 56, 62-64, 66, 93]
	Sel1.2	Maintainability	[22, 45, 50, 55, 57-59, 64, 85]
	Sel1.3	Reliability	[4, 21, 41, 43, 44, 50, 55-60, 62, 63, 85]
	Sel1.4	Security	[22, 45, 54, 55, 62, 64]
	Sel1.5	Usability	[4, 21, 22, 44, 45, 50, 55, 57-60, 62, 64, 85]
	Sel1.6	Functionality	[21, 41, 43, 44, 54, 57-60, 62, 63, 85, 93]
	Sel1.7	Multilingual	Suggested by the decision makers
Sel2 - Adoption	Sel2.1	Local support	[64]
	Sel2.2	Fit with organizational systems	[21, 41, 43, 55, 56, 62, 64]
	Sel2.3	Ease of implementation	[22, 43, 55, 62, 64, 85]
	Sel2.4	Ease of learning	[44, 54]
	Sel2.5	Fit with organizational procedures	[49, 50, 54-56, 64]
	Sel2.6	Quality documentation support	[22]
	Sel2.7	External parties support	[21, 41, 43, 55, 56, 62, 64]

Sel3 - Cost	Sel3.1	Initial cost	[4, 21, 41, 43-45, 50, 55, 56, 62, 63, 66, 85]
	Sel3.2	Training cost	[41, 43-45, 56, 63, 66, 85]
	Sel3.3	Monthly cost	Suggested by the decision makers
	Sel3.4	Customization cost	Suggested by the decision makers
	Sel3.5	Upgrading cost	[4, 41, 43-45, 55, 56, 62, 64, 66, 85]
	Sel3.6	BPR cost	Suggested by the decision makers
Sel4- Time	Sel4.1	Implementation time	[44, 54]
	Sel4.2	Training time	[49, 50, 54-56, 64]

The next step was to evaluate the seven cloud-based ERP solutions issued from the sorting stage. As criteria have independencies, we used the ANP method [94]. Unlike AHP, ANP does not use a hierarchical structure but a network to face a complex decision problem [95]. It represents the problem through the identification of the criteria, sub-criteria, and available alternatives collocated into clusters (Figure 6).

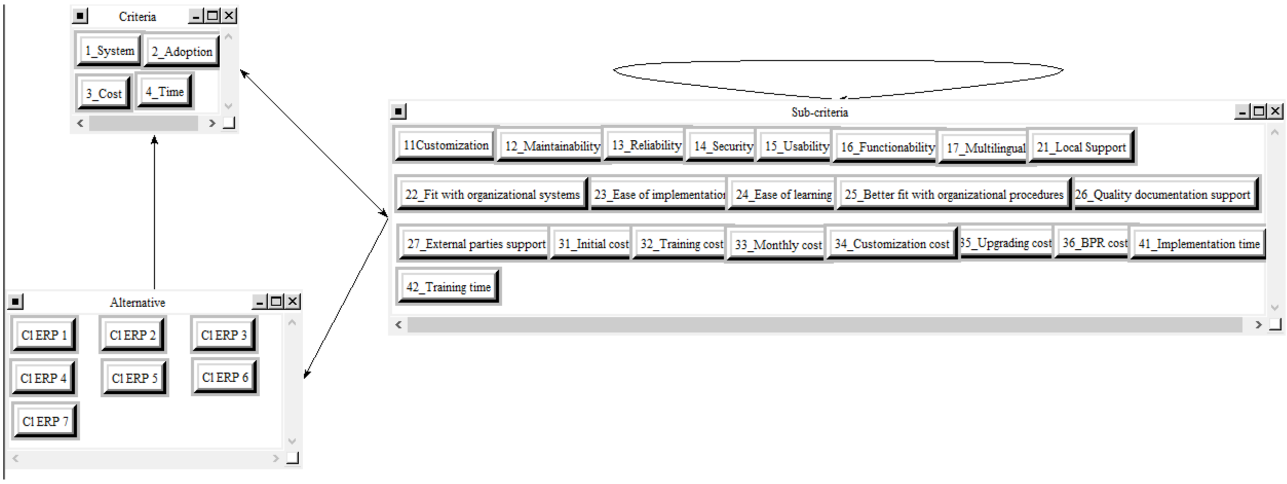

Figure 6. Network structure to select one cloud-based ERP system

As the criteria are not independent, the decision makers marked the dependencies in the influence matrix (Appendix B) where the left column influences the top row. For example, a good customization has a positive influence on a good maintainability, functionality, fit for organizational procedures, customization costs and implementation time.

Following the ANP technique, the elements in a cluster are pairwise compared by assigning evaluations. In order to take into account interdependencies (Appendix B), further questions need to be asked. For example, customization influences maintainability or functionality more and by how much. The decision makers used the nine-point scale suggested by [7] to answer these questions. The whole process can be computed using any mathematical software with some programming function. For our exercise, the Super Decision software was used. The consistency ratio remained below 0.1 for all the matrices. All the decision makers received the same weights, and therefore the aggregate weight is simply given by an average of the scores of the decision makers.

Table 7 shows the weight of the criteria, together with the relative weight of each sub-criterion. The criteria were sorted in a descending order according to their value. “System” is the most important criterion with close to half of the total weight. “Security” is the most important sub-criterion with an aggregate weight of

0.13. This is 1.4 to 16.6 times greater than the weight of the other criteria. This result is in line with previous studies where security has been highlighted as a major concern in cloud computing [4, 96, 97]. The aggregate weights show that the three out of four first sub-criteria belong to the system-related criteria. This is quite understandable, because a cloud-based ERP system not meeting the system requirements will not work properly.

Table 7. Weight of the criteria and sub-criteria

Criteria	Sub-Criteria	DM_1	DM_2	DM_3	Aggregated weight
System		**0.190**	**0.501**	**0.639**	**0.444**
	Customization	0.005	0.019	0.018	0.014
	Maintainability	0.006	0.065	0.039	0.037
	Reliability	0.029	0.091	0.113	0.078
	Security	0.059	0.134	0.197	0.13
	Usability	0.032	0.109	0.110	0.084
	Functionality	0.012	0.032	0.047	0.03
	Multilingual	0.002	0.014	0.007	0.008
Adoption		**0.686**	**0.107**	**0.144**	**0.312**
	Local support	0.041	0.004	0.006	0.017
	Fit with organizational systems	0.179	0.004	0.008	0.064
	Ease of implementation	0.096	0.036	0.037	0.056
	Ease of learning	0.046	0.065	0.065	0.059
	Better fit with	0.107	0.005	0.012	0.041

	organizational requirements				
	Quality documentation support	0.021	0.015	0.017	0.017
	External parties support	0.017	0.010	0.023	0.017
Cost		**0.084**	**0.323**	**0.147**	**0.185**
	Initial cost	0.002	0.015	0.007	0.008
	Training cost	0.036	0.060	0.039	0.045
	Monthly cost	0.008	0.065	0.028	0.033
	Customization cost	0.140	0.078	0.064	0.094
	Upgrading cost	0.003	0.051	0.027	0.027
	BPR cost	0.054	0.026	0.019	0.033
Time		**0.040**	**0.068**	**0.070**	**0.059**
	Implementation time	0.083	0.060	0.062	0.068
	Training time	0.022	0.043	0.056	0.04

Table 8 lists the evaluation results of each decision maker, as well as the overall score and ranking of the seven cloud-based ERP alternatives. All DMs preferred cloud ERP 2. Hence, as shown in Table , the team concluded that the organization should adopt cloud ERP 2.

Table 8. Cloud-based ERP packages ranking

	DM_1 Score	**DM_2 Score**	**DM_3 Score**	**Overall Score**	**Overall Ranking**
Cloud ERP 1	0.132	0.16	0.145	0.146	4
Cloud ERP2	0.277	0.257	0.238	0.257	1

Cloud ERP 3	0.168	0.162	0.194	0.175	3
Cloud ERP 4	0.081	0.085	0.072	0.079	7
Cloud ERP 5	0.181	0.162	0.207	0.183	2
Cloud ERP 6	0.081	0.09	0.073	0.081	5
Cloud ERP 7	0.079	0.083	0.071	0.078	6

6. Discussion

In our case study, the company had no previous experience in structured decision making, therefore they hired us as facilitators. Their time was also limited and hence they asked us to structure the problem as much we could. For this reason, we compiled in advance a list of criteria. However, we only found one article which is specifically dealing with cloud ERP packages selection [50]. This presents a network model made up of six criteria related to system and software quality for evaluating SaaS ERP applications. These criteria could be applied to both on-premise ERP selection and cloud ERP selection. This confirms that the criteria are very similar. In our study, the DMs added five specific criteria (“Multilingual”, “Monthly cost”, “Customization cost” and “Business process reengineering cost”). Notwithstanding, the main differences lie in the weight of the criteria.

Depending on the circumstances, there are of course alternative ways to proceed. For example, a steering committee could take part in identifying the cloud ERP system criteria and monitoring the system selection process. In this case, the composition of the participants is very important. The steering committee should bring together a heterogeneous group of participants [98]. This means a group of people who are familiar with the various enterprise system packages but who work in different corporate functions (IT, purchasing, sales, manufacturing, and so on) and represent as much as possible the hierarchy of the company (senior managers, supervisors, general employees, professional employees without supervisory responsibility, etc).

The internal participants are also known as key-users. They outline how the future application should work during the implementation process. Their early and active involvement favors the subsequent training, use and acceptance of the technology when operative [99]. [52] even reveals a higher ERP key-user satisfaction and a greater perceived ERP success. The key-users' role is thus critical to achieve a successful system adoption. The active involvement of competent external expertise has been also observed as a critical factor for getting successful ERP initiatives [100, 101]. They should prove its added-value and recognized knowledge of the problem, as well as an absence of conflicts of interest.

In order to support the steering committee in the cloud ERP selection, this study highlights the importance of carrying out a screening of cloud technology vendors. In this way, GAHPSort helped the DMs to reduce the initial number of alternatives by following the company requirements in a consensual manner.

During the entire cloud ERP selection process, all the participants' opinions should be considered equally important. This will help to attain consensus decision-making. In our case, the DMs' background clearly influenced the weight given to the different criteria. As Table 7 shows, the system-related criterion is considered the most relevant in the cloud-based ERP selection process and receives a weight 2 to 8 times greater than the other criteria. It is important to note that DM_1, who is a project manager, is more concerned with the "Adoption" criterion, whilst DM_2 and DM_3, the two technical people, considered the "System" criterion to be of high importance. Because of DM1 identifying that criterion in second place, the "System" cluster obtained the greatest aggregated weight in the overall ANP form. This highlights that the ANP approach is appropriate to select an agreed cloud ERP in the second stage.

As previously mentioned, the main differences between on-premise and cloud ERP selection were not reflected in the criteria, but rather in the weight of the criteria. This is revealed when we compare our results with the findings of previous studies about on-premise ERP selection with ANP (i.e., [63]). The aggregate weight of criteria (Table 7) also indicates a lower relevance of cost criteria and time criteria in cloud ERP selection ERP. These reached the first highest and the fourth highest weights (out of 7) respectively in [63]. In the same line, [102] indicates cloud ERP adoption reduces costs in comparison with on-premise ERP, although they also remark an increase of risks related to the security system and integration. This is also shown in our ANP results (Table 7). Hence, cloud ERP selection requires a more careful analysis of system and adoption criteria.

7. Conclusions

In order to attain the expected benefits derived from cloud-based ERP adoption, the choice of the most suitable ERP package from among the large number of options on the market is a critical decision. Over the last several decades, on-premise ERP selection has been well-studied in the literature. These advances cannot be extrapolated to cloud ERP selection due to the very distinct technology environment in which they operate. Moreover, cloud ERP market and services are still unfamiliar to companies which requires deeper analysis. Accordingly, our work has presented a combined approach of GAHPSort and ANP for selecting the package that best satisfies the adopter company's requirements and expectations. We have illustrated the applicability of the methodology through a real case study of the cloud-based ERP selection.

The selection process was divided into two stages. The first phase consisted in sorting cloud-based ERP vendor candidates with the new methodology: GAHPSort. This innovative sorting technique is based on AHP concepts and therefore keeps their advantages. Moreover, it makes collaborative decision making easier and, at the same time, it reduces the high number of pairwise comparisons. In addition, GAHPSort allows for defining a limiting profile for each decision maker, which can be of assistance in a screening stage. In our case study, "Maintenance ability" and "Support services" are the most important criteria in the assessment of ERP vendor candidates.

In the second stage, the decision makers evaluated cloud-based ERP packages which progressed from the sorting phase. The multi-criteria decision-making tool ANP was used in order to take into account the interactions between criteria. The findings enabled us to prioritize the solutions and to determine which of the cloud-based ERP alternatives is the best choice. Additionally, the results highlight the main differences between on-premise and cloud ERP selection lie in the weight of the criteria more that the criteria themselves. It was found that the "Systems" criterion is the most important in the cloud-based system evaluation.

The approach proposed in this study can support practitioners' decision making during the entire cloud-based ERP selection process. However, ERP selection is only the first stage of a long process, and several further decisions are needed, such as selecting control procedures [103]. The GAHPSort is a generic method that can be applied in any other sorting process. In future works, we aim to extend the method to cases where there are independences between criteria.

Acknowledgements

The authors would like to thank the decision makers and their company that allowed us to test our methodology in their cloud-based ERP selection process.

Appendix A. Extract of the GAHPSort questionnaire

Circle one number per row below using the scale:

1 = Equal 3 = Moderate 5 = Strong 7 = Very strong 9 = Extreme

2, 4, 6, 8 are intermediate values

Question 1. Compare the relative performance of cloud ERP Vendor against the experience criteria for the sorting stage.

Vendor 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 4	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 6	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 7	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 8	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 9	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 10	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile
Vendor 11	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Limiting profile

[Postprint] Please cite as: López C, Ishizaka A, GAHPSort: a new group multi-criteria decision method for sorting a large number of the cloud-based ERP solutions, Computers in Industry, 92, 12-24, 2017

Appendix B. Influence matrix

	Customization	Maintainability	Reliability	Security	Usability	Functionality	Multilingual	Local support	Fit with organizational systems	Ease of implementation	Ease of learning	Fit with organizational procedures	Quality documentation support	External parties support	Initial cost	Training cost	Monthly cost	Customization cost	Upgrading cost	BPR cost	Implementation time	Training time
Customization		X				X						X						X			X	
Maintainability			X	X	X																	
Reliability					X																	
Security																						
Usability											X											X
Functionality					X						X						X					X
Multilingual					X																	
Local support										X		X									X	
Fit with organizational systems										X								X				
Ease of implementation																					X	
Ease of learning																X						X
Fit with organizational procedures																				X	X	
Quality documentation support											X										X	X
External parties support										X	X		X								X	X
Initial cost																						
Training cost																						
Monthly cost																						
Customization cost																						
Upgrading cost		X																				
BPR cost																						

Implementation time																		X				
Training time																X						

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