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Cloud provider selection a complex multicriteria problem

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Abstract. *Cloud provider* (CP) selection problem is a complex decision-making problem that involves multiple criteria, often in conflict with one another. The purpose of the paper is to present a brief survey on CP selection problem and to formulate a group decision approach and a multi-objective model for CP selection. Starting from this model several single-objective models are derived. The objective functions are cost, evaluation risk and performance. A numerical example for the trade-off model is analyzed. Five scenarios are discussed, and a matrix of CPs ranks for each scenario is computed.

Key-words: Cloud computing, evaluation divergence, evaluation risk, group decision, multi-objective model, provider selection.

1. Introduction

Cloud computing is one of the most innovative technology of the last decades and it is expected to be at the forefront of all technologies in 2021 and beyond. The term was coined by Amazon in 1960s. It comes from the cloud symbol that is often used to represent the telephone network and internet connections in diagrams and flowcharts. In 2020 the market size of the global cloud computing was estimated at USD 219 billion. This market is expected to grow from USD 250.04 billion in 2021 to USD 791.48 billion in 2028 at a CAGR (Compound Annual Growth Rate) of 17.9% in the forecast period cf. [1].

The introduction of emerging information technologies, such as *Artificial Intelligence and Machine Learning*, has enabled the cloud industry growth. The COVID-19 pandemic has forced a huge number of people, such as businessmen, managers, and employees, to use the remote working. This trend is expected to continue in the long term. The pandemic is likely to induce one of the most serious workplace transformations. When the cloud technology appeared, it was seen only as a secure online storage solution. Most of the people did not perceive the full potential of this technology. In a short time period, cloud computing has revolutionized the business world and human activities. In the last decade, a huge number of companies have started to adopt cloud computing by moving their activity in cloud. This has made the cloud service providing industry one of the fastest-growing high-tech sectors of today.

Cloud Computing offers users great advantages in terms of cost and reliability compared to the traditional computing models, which use a dedicated in-house infrastructure. Organizations rely on the cloud to serve more complex and dynamic needs of their activities. As the time goes by, more services and improved experiences are now available to every organization that is willing and ready to explore this technology to its fullest potential. After the introduction of online storage solutions, cloud computing provided various other services, such as IaaS (*Infrastructure as a Service*), SaaS (*Software as a Service*), PaaS (*Platform as a Service)*, and FaaS (*Function as a Service*).

A cloud service provider, or *cloud provider* (CP), is an organization that offers services to the consumer at different levels of features and characteristics. Its services are components of cloud computing such as IaaS, SaaS or PaaS. Most of cloud providers use their own data centers and computer resources. Frequently used subscription models for cloud services are of type "pay-as-you-go" (or "pay-per-use") and the customers are charged by CPs only for the resources they consume. Cloud computing technology and services are provided either by large or small specialized companies.

According to a recent survey (AWS vs Azure vs Google Cloud Market Share 2021: What the Latest Data Shows - ParkMyCloud), the cloud market is dominated in 2021 by several major CPs: Amazon Web Services (32% of the market), Microsoft Azure (19%), Google Cloud (7%), Alibaba (6%) IBM Cloud, Oracle Cloud, Dell Technologies/VMware, SAP, Cisco, and Hewlett Packard Enterprise.

The main benefits of using cloud computing are:

- **Cost reduction:** Cloud computing technology helps cloud users to mitigate the capital expenditure by avoiding huge investments in equipment and software licensing and maintenance, and in training their own people. Overprovisioning (paying for more services than are needed) is avoided and the users are ensured that they will not run short on capacity they need;
- **Improved uptime** (the time period over the system is operational);
- **Real-time collaboration:** Real-time updates for data platforms and applications make possible flexible collaboration for all the users;
- **Scalable features:** Cloud systems are able to scale to company's needs;
- **Remote and mobile access:** The use of cloud systems makes remote and mobile access possible. Consequently, the set of locations where the users can work can be expanded;
- **Security monitoring:** Cloud providers use constant monitoring in their systems;

- **Disaster recovery and data management:** The cloud systems save the latest version of data and application updates in order to easily create backups. This function is very important since it improves data management capabilities. In the case of a security breach, this function makes data recovery easier.

Due to the ever more growing number of CPs and the growing variety of services in their offerings, the competition in the cloud market is continuously increasing. In order to increase their market shares, the cloud providers are under pressure to reduce their operational costs and to provide the latest and most performant technology to end users/customers. Nowadays, CPs offer various levels in the *Quality of Service* (QoS) of cloud services. Also, customers may choose between various pricing models for cloud services.

The existence of many CPs in the market raises a question: "When does a CP performs better compared to others with respect to the specific needs and settings of the customer?", Consequently, the customer has to evaluate the set of CPs that are available in the market and to choose a CP that best fits his/her performance and cost needs. The evaluation and selection process involves various parameters. Sometimes, when the number of CPs, the number of services provided, and the number of criteria is high the customer has to solve a complex decision problem whose solution can hardly be obtained with mere judgment or intuition.

How can a customer choose a CP? An answer to this question could help potential customers to choose a service that best fits their performance needs and budget limits and CPs to bring into the market advantageous offerings for cloud customers. For example, cloud customers may choose a cloud service for storage intensive applications and another cloud service for computation intensive applications. Since a large variety of cloud services with varying characteristics are available in the cloud market, it is difficult to select an optimal cloud service that satisfies customer requirements. The cloud service has to cope with business strategies that usually have several objectives which sometimes are in conflict with one another. In order to compare CPs, customers need to use a set of measurable criteria against which service providers are to be compared and a method to rank them based on these criteria.

The paper aims at presenting a survey on CP selection problem and to formulate a group decision approach and a multi-objective model for CP selection. Starting from this model, several single-objective models are formulated. Objective functions are cost, evaluation risk, and performance. A numerical example for the trade-off model is analyzed. Five scenarios are considered and a matrix of CPs ranks for each scenario is computed.

2. Literature review

There are several available criteria, metrics and methods that are used to select IT products and services [2]. The CP selection problem is a special case of the more general vendor selection problem. It is a complex decision-making problem since:

- It involves multiple criteria, often in conflict with one another;

- Sometimes, the problem becomes more complicated since uncertainty and imprecision show up in the decision-making process of selection. More precisely CP evaluation data (QoS and user feedbacks) have many times an uncertain and incomplete nature.

Because of the above features obtaining an accurate CPs ranking remains an open research challenge. Existing literature that focuses on the CP selection problem provides several decision frameworks and selection criteria that a customer can take into account.

Several approaches have been explored for CPs ranking and selection. The main approaches are the following:

- *Multi-criteria decision-making methods* (MCDM) that include *Multi-Attribute Decision Making* (MADM) methods and combinations of some MADM methods. Some of these MADM methods are: *Analytic Hierarchy Process* (AHP), *Analytic Network Process* (ANP), S*imple Additive Weight* (SAW), *Technique for Order of Preference by Similarity to Ideal Solution* (TOPSIS), *ÉLimination et Choix Traduisant la REalité* (ELECTRE), *Multi-Attribute Utility Theory* (MAUT), *Preference Ranking Organization Method for Enrichment Evaluations* (PROMETHEE).

- Optimization-based methods that aim to find optimal services which can maximize or minimize one criterion or several criteria and meet service provision constraints. Optimization techniques include, among others, dynamic programming, linear programming, integer programming, and greedy algorithms.

A state-of-the-art for the CP selection problem that contains papers published before 2014 can be found in [3]. A recent review on the CP selection problem based on QoS (Quality of Service) criteria can be found in [4].

2.1. MCDM methods

MCDM is a term that denotes the set of methods that exist for helping people make decisions according to their preferences, in cases where there is more than one conflicting criterion cf. [4] and [5]. It can be viewed as a complex decision-making supporting tool that involves both quantitative and qualitative factors. In recent years, several MCDM techniques and approaches have been proposed for choosing the optimal alternative.

A systematic approach was developed in [7] to evaluate CPs and to rank the selection criteria for all the cloud levels. An AHP-based model was used, and seven IT executives gave evaluations to cloud levels. A case study was analyzed for a large publishing company that has recently implemented a cloud-based solution. The application of AHP shows that it can be used to improve the selection process (reduction of decision time, better structured decision process, or comprehensible results).

One of the most used MADM method is TOPSIS. In [8], the TOPSIS method was extended by using the *Minkowski distance*. An *Extended TOPSIS* (E-TOPSIS) approach was proposed by varying the parameter p in the *Minkowski distance*. The applicability of the proposed E-TOPSIS approach was illustrated in a case study for CPs evaluation and ranking in relation to a set of *Service Measurement Index* (SMI) criteria. In [9], a MCDM approach for CPs ranking, based on SAW and TOPSIS methods was proposed. For the two methods, the same normalization process used to bring the arrays of the evaluation matrix to compatible units and to transform all the criteria in ones of the same type (benefit criteria) was used. In order to make the TOPSIS method compatible with the SAW method, a modified TOPSIS method was used. A case study of the proposed approach for CSPs ranking was studied. An analysis of the obtained solutions was realized.

In [10] a hybrid multi-criteria decision method was proposed to evaluate and rank CPs based on *Smart data* (a term frequently used in association with the data produced by embedded smart sensors in an *Internet of Things* setting). Interdependencies and relations between the CPs performances were taken into account. The hybrid method has two stages: (i) clustering CPs using the k-means algorithm in order to consolidate CPs with similar features and (ii) application of the *DEMATEL-ANP* method for clusters ranking and making a final decision. The method used takes into account the existing workloads of the company and assigns weights to a set of criteria. It uses the k-means algorithm for obtaining a clustering for the CPs.

In [4], a new QoS-aware selection model designed and implemented as a simulation tool was developed. It had a three-level representation scheme that was used for obtaining a systematic representation of QoS attributes. The ranking of cloud services based on various QoS attributes was made using two MCDM models, the AHP model and the SAW model. The proposed model was rigorously evaluated through a number of experiments with data about widely used commercial CPs. Unlike other reported approaches, the proposed framework extracted cloud service information from various sources: information from CPs, performance data from third-party monitoring tools, and user reviews. The use of several sources of information ensures the credibility and correctness of CPs selection. The simulation results show that the proposed model improves, simplifies and ensures the credibility of the CPs selection process.

2.2. MCDM methods that include uncertainty, imprecision and incomplete data

The decision-making process for selecting a CP may incorporate uncertainty, imprecision and incomplete data. In order to solve the problem of CP selection, "fuzzy" and "rough" MADM methods have been used. Examples of methods are: fuzzy or rough AHP, ANP, TOPSIS, SAW.

In [11], a new group decision approach that took into account the uncertainty to solve the problem of selection of the best CP was proposed. Imprecise evaluations of cloud experts and uncertainty were handled with the help of rough sets. The approach is based on a combination of the rough AHP method and the SAW method. The paper [12] proposed a fuzzy group MADM method based on a combination of the fuzzy SAW method with a maximizing set and minimizing set defuzzification method. The last method was based on triangular fuzzy numbers and was applied for CPs ranking.

The aim of the authors of [13] was to use a *Neutrosophic Multi-Criteria Decision Analysis* (NMCDA) approach [14] for estimating the quality of cloud services. Ambiguous and incompatible information which usually exist in the performance estimation process was handled with the help of triangular neutrosophic numbers. A model based on the *Neutrosophic AHP Process* (NAHP) was built. Its aim was to provide performance estimation for CPs and to improve the QoS by creating a strong competition between CPs. Another neutrosophic method that can be used for CPs selection is *Multimoora* [15]. A multicriteria framework for CPs selection based on an extension of the *Matter Element Method* can be found in [16]. The approach from [17] can be adapted for the CPs selection problem.

In [18], a *virtual machine* (VM) provisioning framework was proposed with the aim to provision the VMs from a well-suited CP in hybrid cloud. A MCDM method was used for obtaining weights for each decision-making input criteria.

2.3. Weighting methods

In MCDM approaches, the weights of the criteria reflect the relative importance of the criteria in the decision-making process. A critical problem in most MCDM methods is to obtain the weights of the criteria by subjective, objective or a combination of weighting methods.

In [19], a MCDM method called *best-worst method* is combined with a method based on Markov chains for solving the cloud service selection. In [20], a survey on the criteria weighting methods was made. Also, a new *Group Decision Support* approach for QoS criteria analysis and weighting was proposed. The approach was based on a hybrid method which is a combination of a subjective weighting method called DEMATEL method and an objective weighting method called *Shannon method*. In [21] a new decision-making framework based on the hybrid DANP method (*DEMATEL based on ANP*) for obtaining the criteria weights in the process of selection of a CP was proposed. The hybrid DANP method is a combination of DEMATEL method and ANP method. The applicability of the decision-making framework was illustrated using a case study.

In [22], an *Improved Interval-Valued Intuitionistic Fuzzy Sets-Weighted Aggregate Sum and Product Assessment* (IIVIFS-WASPAS) method was used for the identification of *Trustworthy CPs* (TCPs). The approach used the integrated objective and subjective weight assessment method and the IVIFSWASPAS method to determine the importance of QoS attributes and to rank the TCPs.

2.4. Optimization-based methods

Mathematical programming

An approach of the CP selection problem based on portfolio selection theory can be found in [23]. The authors use the exponential loss distributions and one-sided risk measures. In [24], a mathematical programming model based on the ranked voting method with discrimination of efficient candidates is used for solving the CP selection. In [25], the CP selection problem in the case of multiple CPs is formulated as a linear programming problem. A numerical example that shows the reduction of usage costs compared with the costs of a single CP is developed. In [26], CP selection and ranking is made by using a linear programming model. The aim of the paper is to use both quantifiable and non-quantifiable QoS parameters to provide an appropriate service that satisfies almost all the requirements of cloud customers. As a result a dynamic ranking and selection of cloud services was obtained. In [27], two CP selection models for cloud storage services that minimize the total cost of usage were developed. The models select multiple CP that meet the user requirements and take unavailability into account. Both models are formulated as integer linear programming problems. In [28], a dynamic programming-based approach for cloud instance type selection and optimization was developed.

Multi-objective mathematical programming

Multi-objective optimization methods aim to optimize several objectives of the system or the environment. A multi-objective optimization model for CP selection was proposed in [29]. For solving the model authors use a combination of multi-objective evolutionary approach and a decision-making method called AHP. In [30], an optimization model with two main objective functions, one for objective assessment and the other for subjective assessment was developed for CP selection. Objective assessments were obtained from QoS values and subjective assessments were obtained from the feedback of previous users as training information. NSGA-II (*Non-dominated Sorting Genetic Algorithm II*) method is used for solving the model.

In [31], a multi-objective optimization model for cloud service selection was proposed. The approach for solving the model is based on a multi-objective particle swarm optimization algorithm. In [32], a multi-objective optimization problem for the cloud brokering with bundles was formulated. The novelty of the presented problem lies in considering services which can be sold in bundles. *Bundling* is a common business practice, in which a set of services is sold at a lower price than the sum of individual service prices included in it. A broker gathers information about services from various providers and at the same time, collects the data about the needs and specific requirements of the potential customers, with the final goal of finding the best match.

2.5. Decision Support Systems

Decision Support Systems (DSS) play a significant role in every sector of economy, both in the professional and private life. With the advancements of technology and information communication, decision-making at the right and appropriate time is a challenging issue for many domains. Taking decision on the right and appropriate time can ultimately lead the business into success and contribute to human well-being. When more than one person take part in decision-making, we use multi-participant DSS [33]-[34]. As described in [35], modern DSSs can use cloud services.

DSS have been also used for solving the CP selection problem. For example, in [36], a decision support system named *ClouDSS* was proposed. It employs various MCDM methods with the aim of optimizing cloud service selection decisions. In [36], the main components of ClouDSS are presented, the employed cloud service selection process is described in order to highlight the associated tasks. Both objective and subjective evaluation approaches are included. Applicability of the proposed system is proved through a case study.

In [37], a DSS that supports decision-makers in choosing the most suitable IaaS cloud providers is presented. Input data used for the alternatives definition were composed by well-known CPs, websites, related forum, and domain experts. The set of alternatives in this study was composed by 40 IaaS CPs (*Leaseweb, Google Cloud*, and so on). The information about the CPs alternatives was collected from recent reports published on *Gartner, Glassdoor*, and *Forrester* websites. In order to evaluate the efficiency and effectiveness of the DSS for the CP selection problem for software producing companies four case studies have been analyzed. The case studies and experts confirm that the approach increases insight into the selection process and reduces the time and cost of the decision-making process.

3. Criteria for ranking CPs

When evaluating the performances of potential cloud providers, the organizations should consider several criteria. In their turn, CPs can be characterized by several features. The analysis of these features led to the development of QoS standards for CPs. A well-known QoS standard for CPs developed by *Cloud Services Measurement Initiative Consortium* (CSMIC) is the *Service Measurement Index* (SMI) [38]. The SMI defines a framework and method for the calculation of a relative index, which may be used to compare IT Services against one another, or to track services over time.

The SMI cloud quality criteria can be qualitative or quantitative. A selection of the more important criteria is presented below.

- **Cost.** The cost is usually based on a "pay-per-use" model. Cost is often considered one of the main reasons that makes customers to adopt a cloud service platform;
- **Performance.** CPU speed, memory read and write, storage, network, response time etc.
- **Data management features.** These features include: data availability, minimized redundancy, data accuracy, consistency and relevance, file consistency, data retrieval, data integrity etc;
- **Physical location of the servers.** The location of servers may be an important factor in the CPs selection when customers want to store sensitive data;
- **Reliability.** Reliability is very important since cloud customers want their data to be accessible any time. A typical cloud storage provider's SLA, for example, specifies precise levels of service – such as 99.9% uptime;
- **Security.** Security is a very important issue for most Internet-based services [39]. Data theft, hacking into data, and the fear of industrial espionage are well-known problems. Organizations should avoid using cloud services for sensitive functions such as research and development, or those involving critical business data. At the same time, e-mails that are exchanged without end-to-end encryption between companies expose them to significant security vulnerabilities. Organizations such as *Cloud Security Alliance* (https://cloudsecurityalliance.org) offer certification to those CPs that meet the security criteria;
- **Reputation.** In general. reputation is an evaluation of the organization about performing a task or service. Cloud customers require a certified system to guarantee the safety of their data, investment, and services. Reputation is gained through the trust which might be obtained either through self-experience or from previous and current users.

Most researchers agree that security and legal aspects, functionality coverage, cost, and abilities to interact with the provider are very relevant to a CP selection. In most cases, security and reliability are very important for the great majority of customers. The relative novelty of Cloud Computing brings up a number of legal challenges [40]. When a customer adopts cloud solutions, he/she must compare the costs of cloud services to those of the traditional (internal) solution within the company and check if considerable cost savings can result from it.

4. A multi-objective model for the CP selection problem

The input data in the cloud provider selection problem defined in the present paper are represented by:

1. a set of CPs and a set of criteria for which the CPs will be evaluated. The CPs will be ranked according to the set of criteria and to customer preferences;
2. a set of experts that evaluate the criteria for CPs selection and the CPs performance;

3. two sets of weights that show the importance of criteria.

The divergent evaluations of the experts generate the evaluation risk. A new indicator is introduced in order to measure this risk. The value of the indicator is non-negative. The higher the value of the indicator is, the higher the evaluation risk is. The smallest value of this indicator is zero. It corresponds to the case when all evaluations of the experts are the same. When the evaluations of the experts are divergent, the value of the indicator increases.

The group decision approach for the CP selection problem is illustrated in Figure 1.

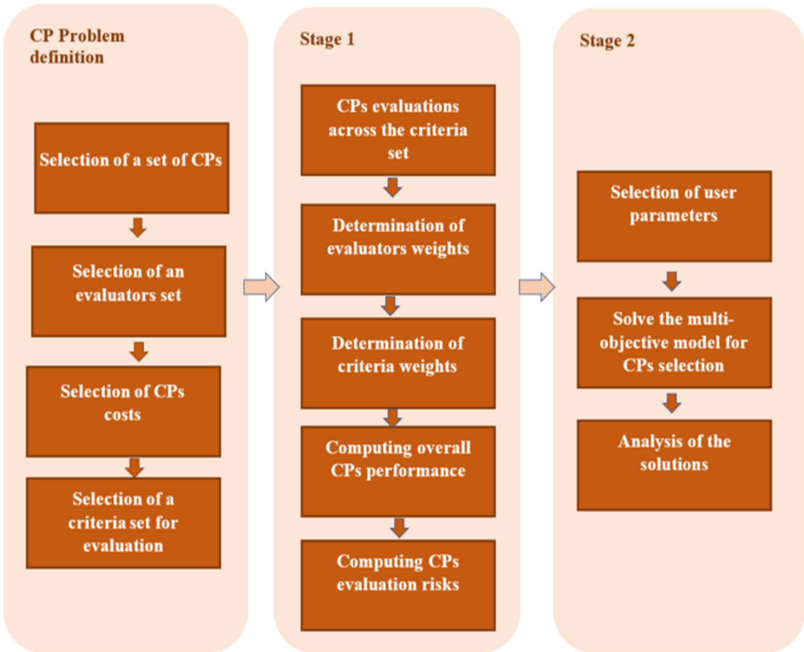

Fig. 1. The group decision approach for the CP selection problem.

In stage 1 of the group decision approach, the CPs performance and the related evaluation risk are calculated based on a multi-attribute group decision making method.

The input data in stage 1 is included in Table 1.

The group of evaluators selects the criteria for the evaluation of CPs and the related measurement scale.

Each evaluator evaluates each CP with regard to each of the criteria.

The input data in the MOCPS model are:

1. n = the number of CPs
2. m = the number of criteria based on which the CPs are evaluated
3. k = the number of expert evaluators
4. Criteria set: $C = \{C_1, C_2, ..., C_m\}$,
5. CPs set: $A = \{A_1, A_1, ..., A_n\}$,

6. The set of evaluators $E = \{E_1, E_2, ..., E_k\}$,

7. a_{ijr} = the score obtained by A_i for criterion C_j as a result of the evaluation made by expert E_r. The scores are given using a scale.

8. $w_{1,j,r}$ = the weight that shows the degree of confidence in the evaluation of expert E_r for criterion C_j. We suppose that $\sum_{r=1}^{k} w_{1,j,r} = 1$ for every $j = 1, 2, , m$

9. $w_{2,j}$ = the importance of the evaluation after criterion C_j in the overall evaluation

10. $\mu_{i,j} = \sum_{r=1}^{k} w_{1,j,r} a_{i,j,r}$ is the score of A_i for criterion C_j.

11. $\sigma_{i,j}$ = the evaluation risk after criterion C_j for A_i.

$$\sigma_{i,j} = \sum_{r=1}^{k} w_{1,j,r} \left(a_{i,j,r} - \mu_{i,j}\right)^2$$

12. c_i = the cost of selecting A_i

13. $x_i = \begin{cases} 1 & \text{if } A_i \text{ is selected} \\ 0 & \text{if } A_i \text{ is not selected} \end{cases}$

14. $q_{i,r}$ = the weighted score given by expert E_r for A_i. $q_{i,r}$ = $\sum_{j=1}^{m} w_{1,j,r} a_{i,j,r}$

15. p_i = the weighted score obtained by A_i. $p_i = \sum_{r=1}^{k} q_{i,r}$

16. v_i = the overall evaluation risk for A_i. $v_i = \sum_{j=1}^{m} w_{2,j} \sigma_{i,j}$. We suppose that $\sum_{j=1}^{m} w_{2,j} = 1$

4.1. The multi-objective model for CPs selection

Decision problem P: choosing the CP that best meets the following requirements:
– minimize the cost
– minimize the evaluation risk
– maximize the overall score of cloud provider
– meet the constraints- meet the constraints

The mathematical formulation of the multi-objective model for CPs selection is presented below:

$$\begin{cases} \min\left(\sum_{i=1}^{n} c_i x_i\right) \\ \min\left(\sum_{i=1}^{n} v_i x_i\right) \\ \max\left(\sum_{i=1}^{n} p_i x_i\right) \\ \sum_{i=1}^{n} x_i = 1 \\ x_i \in \{0, 1\}, \quad i = 1, 2, \ldots, n \end{cases}$$

Starting from the above model one can define several single-objective models.

4.2. The minimum cost model

Decision problem: choosing the CP that has a minimum cost when the evaluation risk is smaller than a given bound ρ and the overall score of the CP is greater than a given bound θ.

$$\begin{cases} \min\left(\sum_{i=1}^{n} c_i x_i\right) \\ \sum_{i=1}^{n} v_i x_i \leq \rho \\ \sum_{i=1}^{n} p_i x_i \geq \theta \\ \sum_{i=1}^{n} x_i = 1 \\ x_i \in \{0,1\}, \quad i = 1,2,\ldots,n \end{cases}$$

Here ρ and θ are user parameters.

Let $\rho_1 = \underset{1\leq i\leq n}{min}(v_i), \rho_2 = \underset{1\leq i\leq n}{max}(v_i), \theta_1 = \underset{1\leq i\leq n}{min}(p_i), \theta_2 = \underset{1\leq i\leq n}{max}(p_i)$. Then ρ and θ should be chosen as follows: $\rho \in [\rho_1, \rho_2]$ and $\theta \in [\theta_1, \theta_2]$.

4.3. The minimum risk model

Decision problem is: choosing the CP that has a minimum evaluation risk when the cost is smaller than *M* and the overall score of the CPs is greater than a given bound θ.

$$\begin{cases} \min\left(\sum_{i=1}^{n} v_i x_i\right) \\ \sum_{i=1}^{n} c_i x_i \leq M \\ \sum_{i=1}^{n} p_i x_i \geq \theta \\ \sum_{i=1}^{n} x_i = 1 \\ x_i \in \{0,1\}, \quad i = 1,2,\ldots,n \end{cases}$$

Here M and θ are user parameters.

Let $c^{min} = \underset{1\leq i\leq n}{min}(c_i), c^{max} = \underset{1\leq i\leq n}{max}(c_i), \theta_1 = \underset{1\leq i\leq n}{min}(p_i), \theta_2 = \underset{1\leq i\leq n}{max}(p_i)$. Then, *M* and θ should be chosen as follows: $M \in \left[c^{min}, c^{max}\right]$ and $\theta \in [\theta_1, \theta_2]$.

4.4. The trade-off model

Decision problem: choosing the CP that minimizes a linear combination of objective functions.

$$\begin{cases} \min\left(\alpha_1\left(\sum_{i=1}^{n} c_i x_i\right) + \alpha_2\left(\sum_{i=1}^{n} v_i x_i\right) - \alpha_3\left(\sum_{i=1}^{n} p_i x_i\right)\right) \\ \sum_{i=1}^{n} x_i = 1 \\ x_i \in \{0,1\}, \quad i = 1,2,\ldots,n \end{cases}$$

Here, $\alpha_i \in [0,1], i = 1,2,3$ and $\alpha_1 + \alpha_2 + \alpha_3 = 1$. Parameters α_i show how important are the objective functions in the optimization model.

The solution of the trade-off is simple. Let us denote

$b_i = \alpha_1 c_i + \alpha_2 v_i - \alpha_3 p_i, i = 1,2,\ldots,n.$

The best CP for the trade-off model is A_s where $b_s = \underset{1\leq i\leq n}{min}(b_i)$. One can rank CPs with the help of the vector **b** $= (b_1, b_2, \ldots, b_n)$. Let τ be a permutation of the set $\{1,2,,n\}$ such that $b_{\tau(1)} \leq b_{\tau(2)} \leq \ldots \leq b_{\tau(n)}$. A ranking of CPs from the best CP to the worst CP is the following $A_{\tau(1)}, A_{\tau(2)}, \ldots, A_{\tau(n)}$.

5. A numerical example

In this section, a numerical example for the trade-off model is presented. Let us consider a set of $n = 10$ CPs, $m = 7$ criteria and $k = 5$ experts. We shall consider equal weights, that is $w_{1,j,r} = 1/k$ for every $r = 1, 2, \ldots, k$ and $w_{2,j} = 1/m$ for every $j = 1, 2, \ldots, m.$ The matrix $\sum = (\sigma_{i,j})$ is displayed in Table 1.

Table 1. Matrix $\sum$

	C1	C2	C3	C4	C5	C6	C7
A1	6.59E-05	8.37E-05	9.67E-05	7.26E-05	7.63E-05	9.70E-05	9.19E-05
A2	8.60E-05	1.06E-04	1.19E-04	9.49E-05	1.18E-04	8.96E-05	1.07E-04
A3	6.59E-05	6.41E-05	9.38E-05	9.49E-05	8.31E-05	1.11E-04	1.00E-04
A4	1.09E-04	1.06E-04	7.64E-05	9.23E-05	7.63E-05	8.96E-05	1.07E-04
A5	7.59E-05	8.37E-05	6.34E-05	9.49E-05	5.60E-05	6.86E-05	6.48E-05
A6	4.84E-05	6.41E-05	4.30E-05	4.24E-05	5.60E-05	6.04E-05	6.48E-05
A7	6.59E-05	4.62E-05	5.85E-05	5.34E-05	7.63E-05	6.86E-05	4.76E-05
A8	1.09E-04	8.37E-05	1.12E-04	1.20E-04	1.07E-04	6.86E-05	1.00E-04
A9	9.70E-05	1.06E-04	9.67E-05	9.49E-05	8.39E-05	1.13E-04	8.47E-05
A10	1.34E-04	1.06E-04	9.67E-05	9.49E-05	1.26E-04	8.70E-05	8.47E-05

In Table 2, the vectors **c** = (c_i) , **v** = (v_i) and **p** = (p_i) display arrays of normalized values of costs, evaluation risks and performances.

Table 2. Vectors **c, v, p**

	c	**v**	**p**
A1	0.104167	0.000584	0.496629
A2	0.095139	0.000721	0.553626
A3	0.097222	0.000613	0.506482
A4	0.093750	0.000657	0.528094
A5	0.107639	0.000507	0.462642
A6	0.105556	0.000379	0.398543
A7	0.100694	0.000416	0.419392
A8	0.102083	0.000701	0.543021
A9	0.097222	0.000677	0.535288
A10	0.096528	0.00073	0.556277

In Table 3, five scenarios which correspond to 5 choices of the user parameters $(\alpha_1, \alpha_2, \alpha_3)$ are displayed

Table 3. Scenarios corresponding to choices of parameters $(\alpha_1, \alpha_2, \alpha_3)$

Parameters	S1	S2	S3	S4	S5
α_1	1	0	0.333	0.4	0.35
α_2	0	0	0.333	0.1	0.05
α_3	0	1	0.333	0.5	0.60

In Table 4, the CPs ranks in scenarios S1-S5 are displayed.

From the above table one can note that cloud providers A2 and A9 show the same rank in every scenario: 2 and 4, respectively. In scenarios S2-S5, the CPs ranks are the same.

Table 4. The CPs ranks in scenarios S1-S5

	S1	S2	S3	S4	S5
A1	8	7	7	7	7
A2	2	2	2	2	2
A3	4	6	6	6	6
A4	1	5	5	5	5
A5	10	8	8	8	8
A6	9	10	10	10	10
A7	6	9	9	9	9
A8	7	3	3	3	3
A9	4	4	4	4	4
A10	3	1	1	1	1

6. Conclusions

Over the last decades, the cloud computing market has witnessed a fast growth. The growth was stimulated by Artificial Intelligence and Machine Learning [41] and [42]. The literature on cloud computing has increased considerably during the last decades.

At present, in practice, since the number and variety of cloud services as well as the number of CPs are rapidly increasing, it has become a challenge for organizations to choose the best CP based on their requirements. The selection process of cloud services can be considered a multi-criteria decision analysis problem. Sometimes, the complexity of the selection process can be complicated since uncertainty, imprecision and incomplete data can be encountered in the decision that should be taken. The paper has presented a state-of-the art of research on CP selection problem that includes recent approaches. A group decision approach for solving the selection problem has been proposed. Within it, a group of experts make evaluations of CPs with respect to several criteria. A multi-objective model for CPs selection has been formulated. One of the objectives of the proposed model is the evaluation risk that measures the divergence degree of individual evaluations from various experts. Starting from this model, several single-objective models are formulated. A numerical example for the trade-off model is also analyzed. The proposed model can be further developed in order to include a weighting method that is a combination between a subjective and objective weighting methods.

New concepts and computing models have been recently reported. Sky computing is a new computing model where resources from multiple cloud providers are leveraged to create large scale distributed infrastructures [43]

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