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CLOUD SERVICE PROVIDER SELECTION USING MULTI-CRITERIA DECISION MAKING METHODS

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Abstract

Cloud computing offers various services to cloud users, including IaaS, PaaS and SaaS. These services are selected according to cost, availability, performance etc. The selection of a suitable cloud service becomes a complex decision-making problem for a cloud service user because of multiple alternatives and criteria. Multi-criteria decision making is a sub-field in operation research that deals with the techniques to solve such selection problems. This paper presents cloud provider selection problem for IaaS and PaaS using multi-criteria decision-making techniques. Paper presents four case studies for IaaS and PaaS cloud provider selection. In these case studies we have taken different alternatives and criteria depending on that application. Results of Simple Additive Weighting (SAW), Weighted Product Method (WPM), Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIKOR, PROMETHEE and Data Envelopment Analysis (DEA) techniques are compared. The ranking suggested by different MCDM methods are different but in majority cases first ranked alternative is same.

***Keywords:* Cloud service provider selection, multi-criteria decision making.**

1. INTRODUCTION

Nowadays cloud computing technology is one of the key technologies required in the field of ICT development. Cloud computing provides the services which includes storage, servers and software on the Internet with flexibility, on demand allocation and pay per use model. It offers a way to store, retrieve and process data on a network of servers. Many cloud service providers offer various cloud services to the consumers. There is tremendous demand for cloud computing and its services such as IaaS, PaaS and SaaS. Infrastructure as a service (IaaS), is the lowest service model in the technology stack which offers infrastructure resources as a service, such as raw data storage, processing power and network capacity. Platform as a service (PaaS) is the service model that offers the services as operation and development platforms to the consumer. To develop and run his own applications, users can use this platform supported by cloud based infrastructure.

Multi-Criteria Decision Making (MCDM) is a process that allows to make decisions in the presence of multiple and usually conflicting criteria. The problems of MCDM can be broadly classified into two categories namely multiple attribute decision making (MADM) and multiple objective decision making (MODM). Multi-criteria decision making plays a critical role in many real-life problems. It is impossible to determine the "best" decision making method for a given selection problem and selection of the "best" decision making method is a decision making problem itself. Multi-criteria decision making methods are applied to solve different problems such as selecting land mining detection strategies (De Leeneer & Pastijn, 2002), personnel selection (Dursun & Karsak, 2010), supplier selection and evaluation (Ho et al., 2010), selection of equipment for construction of hilly road (Phogat & Singh, 2013), parting curve selection and evaluation (Quang et al., 2013), material selection (Jahan & Edwards, 2013), pipe material selection in sugar industry (Anojkumar et al., 2014).

Every cloud computing service provider offers a different set of solutions for each business. Before choosing a vendor, user needs to take time in deciding the type of data or applications that go into the cloud, the amount of money that is to be spent on the cloud applications, the type of support they need from the vendor based on human resources and the payment terms. Users find themselves in a difficult situation on cloud service to select which best suits their needs. Various criteria come into light while selecting cloud services like business requirements, cost, data security, technology advancements, support, certification and standards and reliability.

Objectives of paper are,

- Formulate IaaS and PaaS provider selection problem
- Apply and compare different multi-criteria decision making methods to solve cloud provider selection problems

The next section briefly describes related work. Section 3 describes multi-criteria decision making methods. Case study, results and discussion are presented in section 4. To end, section 5 presents conclusions of our work.

2. RELATED WORK

This section comprises various previous works using MCDM methods for selection problems in cloud computing.

Lo et al., (2010) proposed that QoS based service selection can be efficiently done using multiple criteria decision making methods. TOPSIS was used to find the best alternatives from the available web services. This paper was primarily focused on a group of people with fuzzy opinions on selection of QoS based service. A set of predefined variables were used to evaluate the weights of each criterion and the ratings of the alternatives and the available alternatives of web services can be ordered according to group preference. Godse & Mulik, (2009) used analytical hierarchy process (AHP) technique for prioritizing the product features and expert-led scoring of the products. The objective is to find the most suitable SaaS product. Various criterions were used and their weights were calculated, accordingly, the best alternative was found out from a set of alternatives. Saripalli & Pingali, (2011) proposed a MADMAC framework for cloud adoption which consists of three decision areas referred to as the cloud switch, cloud type and vendor choice. An altered version of wide-band Delphi method is put forward for assessing the relative weights for each attribute with accordance to their workload. Relative ranks are calculated using these weights. Simple Additive Weighting (SAW) method is used to generate value functions for all the alternatives, and finally ranked according to their values to choose the best alternative. Yiming & Yiwei, (2011) solved the decision problem with multi-objective to select the best SaaS vendor selection for enterprise. They used the AHP method to find an effective approach for enterprises to choose the best SaaS vendor. This paper primarily focused on building hierarchy models, analyzing and calculating the attributes to finally come up with the best vendor to choose. Zia urRehman et al., (2012) proposed a method to find the best cloud service provider from the thirteen alternatives by using MCDM techniques. Various criterions and outperforming services were used compared for the cloud selection. The results obtained by using each technique are compared to find out how the choice of a particular MCDM method affects the result of Decision making process in IaaS cloud service selection. Sun et al., (2013) proposed consumer centered cloud service selection method based on AHP theory. The main objective of this paper is to select the most qualified customer centered cloud service from available services. The most qualified service is selected on the basis of the highest value of the cloud service. In this paper, the author takes one case study on the medical service cloud environment. Suppose that the user is a stroke patient, who wants to select a cloud service from a cloud platform for health medical rehabilitation. There are three kinds of cloud service providing stroke rehabilitation therapy in cloud platforms. Users can access cloud platforms to select desired medical cloud service according to their personal preference and the demand of treatment.

3. MULTI-CRITERIA DECISION MAKING METHODS

This section presents seven MCDM methods investigated in this paper for cloud service provider selection. The methods are classified in three categories.

- Attribute Based Techniques (e.g. AHP, TOPSIS)
- Alternative Based Techniques (e.g. PROMETHEE, ELECTRE)
- Data Envelopment Analysis (DEA)

3.1 Simple Additive Weighting (SAW)

In SAW, weight is given to each criterion. Alternative scores are normalized using linear normalization. After that normalized alternative scores are multiplied with weights of each criterion. Finally add these multiplied scores and we get the global score of each alternative and its ranking (Rao, 2007).

3.2 Weighted Product Method (WPM)

Triantaphyllou, (2000) stated that the Weighted Product Method was developed by Bridgman in 1922. Mateo, (2012) stated that the Weighted Product Method is similar to the Weighted Sum method. The main difference is that instead of addition in this model there is multiplication. Alternatives are compared with one another by multiplying a number of ratios, one with each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion.

3.3 Analytical Hierarchy Process (AHP)

In AHP problems are structured into three levels viz. objective (goal) is at the top level, criteria at the intermediate level and alternatives at the bottom level. AHP generates a weight for each criterion according to the decision maker's pair wise comparisons of the criteria. Then AHP normalizes the alternative scores because different criteria have different units. Finally, the AHP combines the weights of each criterion and the normalized alternatives scores, we get the global score of each alternative and it's ranking. AHP investigated in assessment of sustainable housing affordability (Mulliner et al., 2016), selection of suppliers in manufacturing industries (Nallusamy et al., 2016), risk assessment in PPP projects (Valipour et al., 2018) and sustainability engineering (Stojčić et al., 2019).

3.4 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Idea behind this method is to choose an alternative which have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. The positive ideal solution maximizes the beneficial criteria and minimizes non-beneficial criteria, whereas the negative ideal solution maximizes the non-beneficial criteria and minimizes the beneficial criteria. TOPSIS is presented in optimization of multiple responses (Rao & Venkatasubbaiah, 2016), selection of web service (Serrai et al., 2017).

3.5 VIKOR

This method concentrates on ranking and selecting the best solution from a set of alternatives, which are associated with multi-conflicting criteria. Moreover, it makes it easy for the decision makers to reach the final decision by finding the compromise solution (closest to the ideal) of a problem. VIKOR determines the positive-ideal solution as well as negative ideal solution in the search place. Positive-ideal solution provides the best value of alternatives under measurement criteria, whereas a negative-ideal solution provides the worst value of alternatives under measurement criteria. The closeness of alternatives assessed value to the ideal scheme is used to arrange the precedence of the schemes. Hence VIKOR is popularly known as a multi-criteria decision making method based on idea point technique which is proposed by Opricovic & Tzeng, (2007). VIKOR is used in many applications such as best vendor selection for conducting the recycled material based on hybrid MCDM model (Hsu et al., 2012), concept selection in an agile environment (Vinodh et al., 2013), material selection (Jahan & Edwards, 2013), selection of web service (Serrai et al., 2017), distribution strategy selection for an e-tailer (Titiyal et al., 2019).

3.6 PROMETHEE

PROMETHEE method is all about mutual comparison of each alternative pair with respect to each of the selected criteria. Evaluation table is considered to be the starting point of the method. The alternatives are evaluated on the different criteria. The implementation of PROMETHEE requires two additional types of information, namely,

- Information on the relative importance (i.e., the weights) of the criteria considered.
- Information on the decision-makers preference function, which user uses when comparing the contribution of the alternatives in terms of each separate criterion.

This method is most useful where groups of people are working on complex tasks, especially those with several multi-criteria, involving a lot of human perceptions and judgments, where decisions have long-term impact. This method has advantages when important elements of the decision are difficult to quantify or compare, or where collaboration among departments or team members are constrained by their different specializations or perspectives.

3.7 Data Envelopment Analysis (DEA)

Data envelopment analysis (DEA), occasionally called frontier analysis, was first put forward by (Cooper et al., 2000). It is a performance measurement technique which can be used for evaluating the relative efficiency of alternatives for given decision making situations. DEA is an extreme point method and compares each alternative with only the 'best' alternative. A fundamental assumption behind an extreme point method is that if a given alternative'A' is capable of producing Y(A) units of output with X(A) inputs, then other alternatives should also be able to do the same if they were to operate efficiently. Similarly, if alternative 'B' is capable of producing Y(B) units of output with X(B) inputs, then other alternatives should also be capable of the same production schedule. Alternatives 'A', 'B' and others can then be combined to form a composite or virtual alternative with composite inputs and composite outputs. The heart of the analysis lies in finding the 'best' virtual alternative for each real alternative. For a given MCDM problem, alternatives (A1, A2,…AN) and different attributes affecting the selection of an alternative are identified. Attributes are divided into two groups: (1) outputs: attributes for which higher values are desirable or beneficial attributes and (2) inputs: attributes for which lower values are desirable or non-beneficial attributes.

4. RESULTS AND DISCUSSION

This section presents case studies, results and comparison between selected seven MCDM methods.

4.1 IaaS Selection Case Study 1

Cloud services (IaaS) selection among 13 services and employed 4 criteria for service selection using MCDM is investigated. In this case study two cloud providers viz. AWS EC2 and Joyent are considered. There are 6 instance types of AWS EC2 and 7 instance types of Joyent considered for comparison. Zia ur Rehman et al. (2012) presented the case study. The measured criteria values are based on CCU (Cloud Harmony Compute Unit) which is an aggregate of several different performance benchmarks. The evaluation matrix is based on a study done by cloud harmony and this decision matrix is used as an input for MCDM techniques. Each criterion has its own specific units. In this case study, four criteria are considered for finding the best IaaS cloud provider. Out of them 'Cost' is a non-beneficial criteria and CPU performance, Memory performance & IO performance are beneficial criteria's. All the criteria are considered as equally important. The weight of each criterion is the same i.e. 0.25.

Table 1. Results of IaaS case study 1

SAW	WPM	AHP	TOPSIS	VIKOR	PROMETHEE
1	1	1	1	1	1
7	12	7	7	8	8
2	7	2	8	3	7
13	8	13	10	7	3
8	13	8	12	10	4
12	10	12	11	4	9
10	11	10	13	9	10
3	3	3	4	12	2
9	2	9	3	11	12
11	4	11	2	13	11
4	9	4	5	5	13
6	5	6	9	2	5
5	6	5	6	6	6

Table 1 shows the comparison of SAW, WPM, AHP, TOPSIS, VIKOR and PROMETHEE. In this case study there is one non-beneficial criterion. DEA method is not applicable for this case study because it requires at least two beneficial and non-beneficial criteria. All methods rank "Alternative 1"as the best alternative. SAW and AHP suggested "alternative 5" as the worst alternative. All remaining methods suggested "alternative 6" as worst alternative. SAW and AHP give exactly the same ranking but other methods give different rankings. This problem is solved using equal weightage but it has been applied in different application areas viz. Education and Scientific. In each application area the relative importance of each criterion can be different so their weights are also different.

4.2 IaaS Selection Case Study 2

In this case study, 11 cloud providers and 15 criteria are considered. All criteria have been taken are considered as equally important. Weights of each criterion are calculated by AHP method.

- Alternatives: Amazon EC2, BitRefinery, GoDaddy, GoGrid, Hosting.com, NephoScale, OpSource, Rackspace, ReliaCloud, Softlayer, Terremark.
- Criteria: Pricing, Price/Month(US$), SLA, Data Centers, Certifications, ScaleUp, ScaleOut, Support, Monitoring, APIs, FreeTier,Oss, Instance Types, Data Transfer out(/GB), Data Transfer in (/GB).
- Beneficial Criteria: Pricing, SLA, Data Centers, Certifications, ScaleUp, ScaleOut, Support, Monitoring,

APIs, FreeTier, Oss, Instance Types.
- Non-beneficial Criteria: Price/Month (US$), Data Transfer out (/GB), Data Transfer in (/GB).

Table 2. Results of IaaS Case Study 2

SAW	AHP	TOPSIS	PROMETHEE	DEA
8	8	1	8	3
7	7	8	7	1
5	5	7	11	2
1	1	10	10	8
2	2	5	5	7
10	10	6	1	10
11	11	2	2	5
3	3	3	9	6
6	6	9	3	9
4	4	4	4	4
9	9	11	6	11

In this case study, SAW, AHP, PROMETHEE ranked "alternative 8" as a best alternative. TOPSIS ranked "alternative 1" as a best alternative (see table 2). For this case study DEA is applicable because it contains more than two beneficial and non-beneficial criteria and it suggests "alternative 3" as a best alternative. SAW and AHP show the same ranking order.

4.3 IaaS Selection Case Study 3

From Literature Review, we have compared 10 different IaaS cloud providers on the basis of 11 different criteria such as pricing policy, price, free trial, SLA, Data center locations, Features, Platforms, Operating Systems, Support, Rating and Client Interface. (cloudreviews.com)

- Alternatives: Amazon Web services, Windows Azure, Rackspace, Go Grid, Softlayer, Go Daddy, Cloud sigma, Vcloud express (Terremark), Visi, PeakColo
- Criteria: Pricing policy, Price, Free trial, SLA, Data Centers, Features, Platforms, Operating Systems, Support, Rating, Client interface
- Beneficial Criteria: Pricing policy, free trial, SLA, Data Centers, Features, Platforms, Operating Systems, Support, Rating, Client interface
- Non-beneficial Criteria: Price.

In this case study, starting price is only non-beneficial criteria and remaining all are beneficial criteria's. All criteria have been taken as equally important. Weights of each criteria is calculated by AHP method.

Table 3. Results of IaaS Case Study 3

SAW	AHP	TOPSIS	VIKOR	PROMETHEE
3	3	3	3	3
1	1	1	1	1
5	5	7	5	8
7	7	5	7	5
2	2	8	8	7
8	8	2	2	2
6	6	6	6	6
4	4	4	4	4
9	9	10	9	9
10	10	9	10	10

In this case study, all decision making methods except WPM shows "alternative 3" is the best choice, WPM is not applicable for this problem because input data in the form of 0 and 1 (see table 3). In this case study there is one non-beneficial criteria i.e. starting price. Hence DEA method is not applicable for this case study.

4.4 PaaS cloud selection case study

In this section we have taken PaaS cloud selection problem and solved using Multi-criteria decision making methods. In this case study, 23 PaaS cloud providers are compared on the basis of 7 criteria such as languages, features, databases, extensions, locations, versioning and remote file access to find out best PaaS cloud provider.

- Alternatives: Ortrabbit, Pagodabox, Appfog, AppHarbor, AWS Elastic Beanstalk, CatN, Cloudbees, CloudControl, CloudFoundry, Cloudify, Cloudways, CumuLogic, dotCloud, Google App Engine, Heroku, Jelastic, Longjump, Microsoft Windows Azure, Orchestra, Red Hat OpenShift, Relbit, Stackato, Uhuru
- Criteria: Languages, Features, Databases, Extensions, Locations, Versioning, Remote file access
- Beneficial Criteria: Languages, Features, Databases, Extensions, Locations, Versioning, Remote file access

In this case study, all criteria which are considered for calculating the best PaaS provider are beneficial. All criteria are considered as equally important.

Table 4. Results of PaaS case study

SAW	AHP	TOPSIS	VIKOR	PROMETHEE
2	2	2	2	2
7	7	7	7	7
16	16	21	16	16
21	21	16	21	15
15	15	15	15	8
8	8	8	8	21
18	18	13	18	4
13	13	18	13	13
1	1	1	1	18
20	20	3	4	1
4	4	5	20	3
5	5	4	5	10
3	3	20	3	20
10	10	9	10	9
9	9	11	9	12
19	19	19	19	19
11	11	10	11	5
22	22	22	22	22
12	12	14	23	11
14	14	12	12	14
23	23	23	14	6
6	6	6	6	23
17	17	17	17	17

In PaaS cloud provider selection problem, weighted product method is not applicable because some input data is in the form of 0. SAW, AHP, TOPSIS, VIKOR and PROMETHEE show "alternative 2" and "alternative 6" is best alternative and worst alternative respectively (see table 4). SAW and AHP give the same ranking order. In this case study there are no non-beneficial criteria so the DEA method is not applicable.

5. CONCLUSIONS

The selection decisions are complex, as a large number of alternatives with different criteria's are available for selection problems. Multi-criteria Decision Making Methods (MCDM)ranks the alternatives considering the criteria and weights. Paper presents results of Simple Additive Weighting (SAW), Weighted Product Method (WPM), Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIKOR, PROMETHEE and Data Envelopment Analysis (DEA) techniques to provider selection problems in cloud environment. Paper presents four cloud provider selection problems. Three case study are for provider selection problem for Infrastructure as a selection service (IaaS). The alternatives and criteria are different in each case study. We have compared the rankings obtained by various MCDM methods for different provider selection problems in cloud environments. The ranking suggested by different MCDM methods are different but in majority cases first ranked alternative is same. In future, we will use group decision making for calculating the weights of criteria. After calculating weights of criteria we will further solve these provider selection problems and compare the results given by MCDM methods.

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