Trustworthy Cloud Service Provider Selection using Multi Criteria Decision Making Methods

Supriya M*, Sangeeta K, G K Patra

Abstract—**Cloud Computing is a specialized form of Distributed computing in which the resources such as storage, processors, memory etc. are completely abstracted from the consumer. The number of Cloud Service Providers (CSPs) who offer computing as a service has increased in recent times and often the customers need to interact with unknown service providers to carry out transactions. In such an open and anonymous environments, trust helps to build consumer confidence and provides a reliable environment for them. A trust based ranking system could also help them to choose between the services as per their requirement. In this paper, multi criteria decision making methods have been used to rank the service providers based on their infrastructure parameters. A combination of analytic and fuzzy method gives a better trust estimate as compared to an analytic method alone.**

Index Terms—**Multiple Criteria Decision Making, Cloud Service Provider Selection, Fuzzy.**

I. Introduction

Distributed systems, or distributed computing, has spawned many familiar technologies across the years, including Grid Computing, Utility Computing, Cloud Computing, application service provision (ASP) and Web 2.0. Among these, Cloud Computing is a specialized form in which the underlying resources, such as storage, processors, and memory, are completely abstracted from the consumer. It has emerged as a paradigm to provide on demand resources to the customers, which may include access to infrastructure/application services on a subscription basis. Cloud Service Provider (CSP) facilitates many types of services among which Infrastructure as a Service (IaaS), Software as a Service (SaaS) and Platform as a Service (PaaS) are the basic types. Consumers utilize these services to simplify application utilization, store, and share, protect content, and enable access from any web-connected device. The range of computing services, thus offered helps enterprises by reducing capital and operational expenditure [1].

The number of CSPs who offer computing as a utility has increased exponentially in the recent years providing more options for the customers to choose from. This rapid growth of public cloud offerings allows the customers to interact with unknown service providers to carry out tasks or transactions [2]. In such a scenario, a rating or a ranking system could help them to choose between the services as per their requirement. If an appropriate service provider is not selected, serious problems such as low-quality services and service non-fulfillment may occur. Thus, the selection of a suitable service provider by reasoning and assessing the possible risks in carrying out transactions is necessary for providing a safe and trustworthy environment. A proper and secure trust management evaluation that is in place would help to minimize the risks posed by different malicious agents.

Trust is the estimation of competency of a resource provider in completing a task based on dependability, security, ability, and availability in the context of a distributed cloud environment. It helps to build consumer confidence in such open and often anonymous environments and provides a reliable atmosphere for customers or businesses to carry out transactions with cloud providers. This also enables them to select the best resources in the heterogeneous cloud infrastructure. Therefore service levels of different CSPs need to be evaluated in an objective way to ensure quality, reliability and security of an application. These cloud services that exist at three levels of the cloud model, namely; IaaS, PaaS, and SaaS have to be evaluated using an efficient trust management model.

A survey paper on trust and trust management in cloud computing proposed by Firdhous *et. al.* [3] analyzes the trust management models proposed for cloud computing like Cuboid trust, Eigen trust, Bayesian network based trust, etc. with special emphasis on their capability, applicability, and implementabilty in practical heterogeneous cloud environment and also emphasizes the need for a trust evaluation model. Sun *et. al.* [4] have proposed a trust management model to evaluate the direct and recommended trust measurements based on fuzzy set theory; which provides a helpful measure for the computation of direct trust, connection of recommended trust, and incorporation of trust chain. However, it does not completely measure the trust degree and the model has not been tested practically. For infrastructure as a service, Alhamad *et. al.* [5] developed a Sugeno fuzzy inference model to find the trust rating for cloud based online services using scalability, availability, security, and usability as parameters, measures for which are obtained from the opinions of Cloud Computing experts and

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cloud users. These measures are not a direct estimation of the available infrastructure resources.

As the data centers in the cloud computing environment are geographically distributed and owned by different individuals, a multi agent based quantitative trust framework is developed, which helps the user find trustworthy service providers in a cloud environment using the recommendations provided by acquaintances with an element of subjectivity [6]. Another framework named SMICloud proposed by Garg *et. al*. [7], [8] allows the cloud user to find the appropriate cloud provider based on his essential and non-essential requirements. The Cloud Service Measurement Initiative Consortium (CSMIC) [9] parameters are used here to rate the Quality of CSPs using Analytical Hierarchical Process (AHP) as a tool which allows to translate the evaluations (both qualitative and quantitative) made by the decision maker into a multi criteria ranking. AHP is a Multi Criteria Decision Making (MCDM) methodology which has been used in e-commerce, transport problem, portfolio selection, and choice of the best suppliers [10], [11], [12], [13].

Technique for Ordering Preference by Similarity to Ideal Solution (TOPSIS) is another popular Multi Criteria Decision Making method which uses the concept of shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS) to determine the best alternative. Fuzzy TOPSIS has been used to rank the web services available in the market [14]. The Fuzzy TOPSIS method considers both the qualitative and quantitative aspects used in the selection of an appropriate industrial robotic system based on economic and technical attributes [15], [16]. A review for service selection for cloud computing using MCDM methods discussed in [17] does not use quantitative trust estimates for ranking various CSPs.

This study uses various MCDM methods to get a quantitative estimate of trust for various service providers based on the CSMIC parameters which are in turn estimated from the measures of their defining attributes. A comparison of the methods suggests an integration of qualitative and quantitative decision making into one unified framework to help customers choose service providers as per their priorities. Problem description and the various MCDM approaches are discussed in sections II to VIII. Performance evaluation of MCDM methods is described in sections IX and X. The paper is concluded in section XI.

II. PROBLEM DESCRIPTION

Ranking of CSPs is based on the Key Performance Indicators suggested by CSMIC [9], [18] called Service Measurement Index (SMI) which help the organizations measure the cloud-related business services based on their specific business and technology requirements. The indicators considered in the trust estimation of CSPs are Accountability, Agility, Assurance, Performance, Financial, Security and Privacy, and Usability. Estimates for five of these parameters are obtained from the infrastructure attributes listed in Table I against the various service providers. The non-quantifiable subjective estimates like Security and Usability can be obtained and consolidated from a survey. For the comparison of services, four infrastructure CSPs were considered: Gogrid, Rackspace, Amazon EC2 and Cloudflare. These service providers and their various plans have been abbreviated as CSP1, CSP2, CSP3, ... CSP7.

Table I shows that attributes like number of virtual machines (VM), data centers (DC) and storage space (SS) contribute to Agility estimation, while Finance is determined from the VM cost, storage cost and transfer cost. Likewise, the other CSMIC parameters are estimated from the inputs described in Table I. Table II lists two additional attributes viz. Total cost (TC) and DC Processing time (DCPT) obtained from the Cloud Analyst after simulating the cloud environment with the values provided in Table I [18]. The Total cost obtained from Cloud Analyst is taken as an estimate for the Finance parameter while the DC Processing time contributes to measure Performance.

TABLE I
INFRASTRUCTURE ATTRIBUTES CORRESPONDING TO VARIOUS PLANS OF CSPs

CSP and Server type	Agility			Financial			Performance		Security			Usability		
	No of VM (VM)	No of DC (DC)	Storage Space in TB (SS)	VM Cost/hr($) (VMC)	Storage Cost / GB($) (SC)	Transfer Cost/ GB($) (Tfr.C)	No. of Processors (NP)	RAM In GB (RAM)	Physical Security (PS)	Internal Security (IS)	Network Security (NS)	Understan dability (Un)	Easability (Es)	Flexibility (Fl)
CSP1	8	3	1	0.5553	0.15	0.29	8	12	0.84	0.89	0.86	0.9	0.8	0.85
CSP2	12	3	0.934	1.666	0.15	0.29	12	48	0.75	0.8	0.9	0.95	0.9	0.9
CSP3	2	8	0.219	1.068	0.1	0.18	2	8	0.85	0.9	0.82	0.9	0.85	0.9
CSP4	6	8	0.6	1.694	0.1	0.18	6	32	0.79	0.85	0.9	0.84	0.87	0.9
CSP5	12	8	0.292	2.083	0.1	0.18	12	32	0.8	0.85	0.87	0.87	0.85	0.9
CSP6	2	6	0.16	0.06	0.15	0.20	2	1.7	0.87	0.79	0.9	0.85	0.9	0.84
CSP7	2	4	0.5	1.76	0.17	0.25	2	8	0.8	0.75	0.85	0.7	0.78	0.8

TABLE II
ADDITIONAL ATTRIBUTES TO THE MODEL

	TC	DCPT
CSP1	65.84	0.96
CSP2	252.47	1.06
CSP3	76.14	3.25
CSP4	333.07	0.91
CSP5	807.77	1.06
CSP6	10.8	0.99
CSP7	53.04	16.01

Although, all the parameters listed in Table I contribute to trust estimation for IaaS, a customized trust estimation suited to users' requirement will provide a good judgment. For a user not keen on Security, trust estimation can be done by assigning less weightage to Security. This motivates the need to develop a hierarchical trust estimation model which ranks the CSPs based on users' necessity. If the customer's emphasis is on Finance, then a higher weight can be assigned to this parameter and proportionate weights to other parameters. Such a trust model has been named as Finance based hierarchical model. Likewise, the models which obtain trust estimates giving more weightage to Performance and Security have been named as Performance based and Security based hierarchical models respectively.

So, the problem addressed in this work is the trust estimation and ranking of service providers based on varying user requirements. The MCDM methods used to estimate trust are AHP, Fuzzy based AHP, TOPSIS and Fuzzy based TOPSIS; which are described in the following sections.

III. AHP BASED RANKING

AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology [19], where alternatives are ranked using the pairwise comparison of multiple criteria. In this study, the alternative selection is analogous to the selection of service provider and the criteria relate to the various infrastructure parameters. Each criterion represented as a vector when multiplied by its weight provides the trust estimate of each alternative corresponding to that criterion. The relationship between the attributes, the criteria and the final decision is represented at various levels of AHP in Fig.1. This figure represents the attributes and contributing parameters listed in Tables I and II. The attributes like number of VM, DC, SS, and VMC, etc. correspond to the lower level of AHP, whereas the CSMIC parameters used for trust estimation namely; Agility, Finance, Performance, Security and Usability contribute to the middle level of the AHP hierarchy. The objective continues to be the choice of a best service provider as per the users' requirement.

During the first iteration, Relative Service Ranking Vector (RSRV) is computed for each attribute at the leaf level, which further leads to Relative Service Ranking Matrix (RSRM) [8]. In the second iteration, the relative ranking between the service providers are computed using the RSRM associated with each CSMIC parameter. Table III shows the RSRM of VM obtained from the pairwise comparison of VM values of various CSPs shown in (1). The RSRV corresponding to VM shown in (2) is the eigenvector of the matrix represented in Table III. Likewise the eigenvectors for DC and SS in (3) and (4) are also obtained from the pairwise comparison matrices of DC and SS respectively.

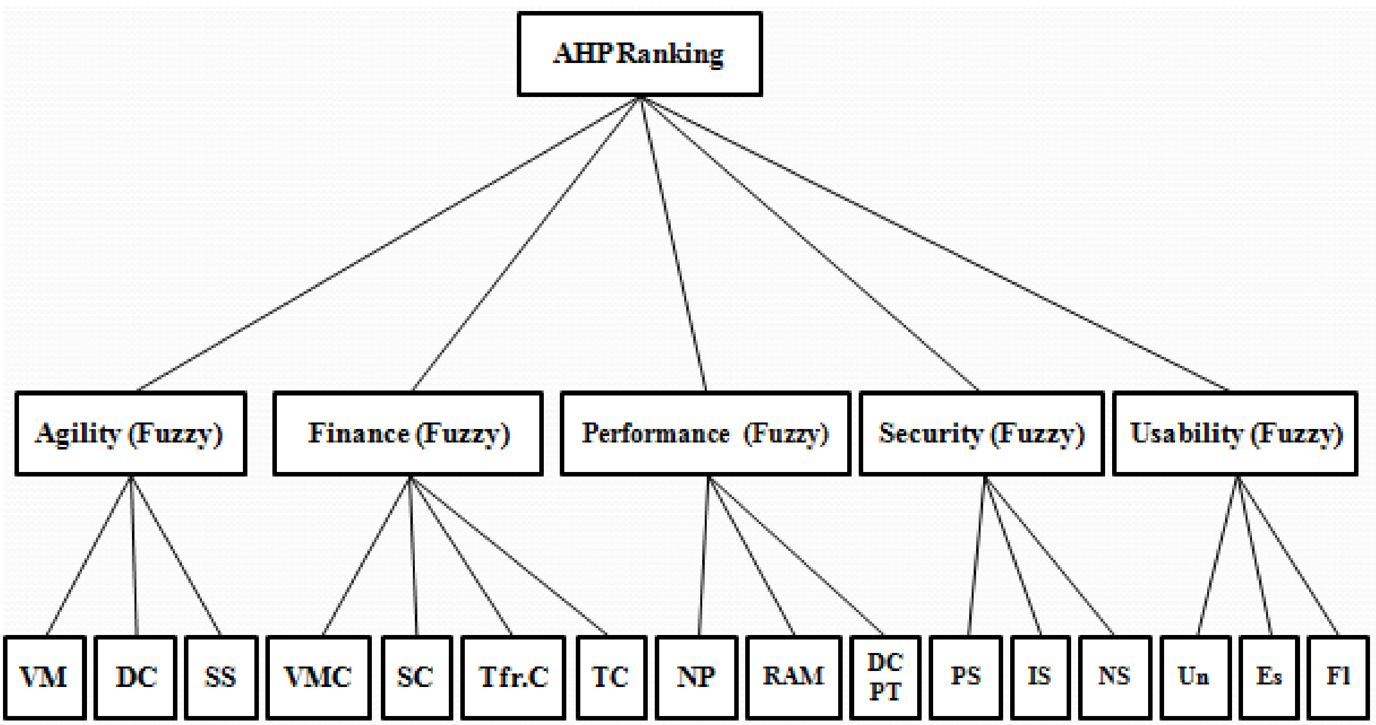

Fig 1 AHP Hierarchy

$$VM = (8 \quad 12 \quad 2 \quad 6 \quad 12 \quad 2 \quad 2) \tag{1}$$

$$RSRV(VM) = (0.182 \quad 0.273 \quad 0.0455 \quad 0.136 \quad 0.273 \quad 0.0455 \quad 0.0455) \tag{2}$$

$$RSRV(DC) = (0.075 \quad 0.075 \quad 0.2 \quad 0.2 \quad 0.2 \quad 0.15 \quad 0.1) \tag{3}$$

$$RSRV(SS) = (0.27 \quad 0.252 \quad 0.0591 \quad 0.162 \quad 0.0788 \quad 0.0432 \quad 0.135) \tag{4}$$

The matrix of eigenvectors corresponding to the VM, DC and SS is shown in Fig 2 when multiplied by the relative weights (0.4667, 0.3333, 0.2) leads to the RSRV for Agility.

TABLE III
PAIRWISE COMPARISON OF VM AVAILABLE WITH 7 SERVICE PROVIDERS

	CSP1	CSP2	CSP3	CSP4	CSP5	CSP6	CSP7
CSP1	1	0.667	4	1.333	0.667	4	4
CSP2	1.5	1	6	2	1	6	6
CSP3	0.25	0.167	1	0.333	0.167	1	1
CSP4	0.75	0.5	3	1	0.5	3	3
CSP5	1.5	1	6	2	1	6	6
CSP6	0.25	0.167	1	0.333	0.167	1	1
CSP7	0.25	0.167	1	0.333	0.167	1	1

Fig 2 explains this RSRV computation for Agility where the weight vector is derived from the relative importance of the attributes using the AHP scale [20]. Likewise, RSRVs for the other CSMIC parameters, Finance, Performance, Security and Usability obtained from their contributing attributes at the leaf level are listed in Table IV.

TABLE IV
RESULTS AFTER FIRST ITERATION OF THE AHP

	Agility	Finance	Performance	Security	Usability
CSP1	0.1639	0.0907	0.0978	0.1469	0.1417
CSP2	0.2028	0.1709	0.1903	0.1389	0.1541
CSP3	0.0997	0.0899	0.0861	0.1455	0.1476
CSP4	0.1625	0.1708	0.1152	0.1442	0.1457
CSP5	0.2098	0.2948	0.1634	0.1429	0.146
CSP6	0.0798	0.0543	0.0356	0.1455	0.1464
CSP7	0.0815	0.1286	0.3117	0.1359	0.1272

The second iteration repeats the above process for the CSMIC parameters stated in Table IV, which corresponds to the middle level of the hierarchy in Fig 1. Now, the eigenvector for each CSMIC parameter is obtained from its pairwise comparison matrix. The RSRM is then constructed from the RSRVs of each parameter and is multiplied by the weight vector to obtain a trust value for each service provider. The weight vector here is defined for the case where Performance is the priority. It can be modified for varying user priorities. Fig 3 therefore shows the trust estimates obtained from a Performance based model. These trust values obtained using the AHP process are given in (5).

	VM	DC	SS
CSP1	0.182	0.075	0.27
CSP2	0.273	0.075	0.252
CSP3	0.0455	0.2	0.0591
CSP4	0.136	0.2	0.162
CSP5	0.273	0.2	0.0788
CSP6	0.0455	0.15	0.0432
CSP7	0.0455	0.1	0.135

X

Weights
0.4667
0.3333
0.2

=

Agility
0.1639
0.2028
0.0997
0.1625
0.2098
0.0798
0.0815

Fig 2 RSRV Computation for Agility

	Agility	Finance	Performance	Security	Usability
CSP 1	0.164	0.0907	0.0978	0.147	0.141
CSP 2	0.203	0.171	0.19	0.139	0.153
CSP 3	0.0997	0.0899	0.0861	0.146	0.146
CSP 4	0.163	0.171	0.115	0.144	0.144
CSP 5	0.21	0.295	0.163	0.143	0.145
CSP 6	0.0798	0.0543	0.0356	0.146	0.145
CSP 7	0.0815	0.129	0.312	0.136	0.126

x

Weights
0.259
0.185
0.333
0.111
0.111

=

Trust Estimate
0.1238
0.1799
0.1035
0.1441
0.1952
0.0749
0.178

Fig 3 Trust Value Estimation for Performance based Model using AHP

$$Trust\ values\ using\ AHP\ (Performance\ based\ model) = (0.1238 \quad 0.1799 \quad 0.1035 \quad 0.1441 \quad 0.1952 \quad 0.0749 \quad 0.178) \tag{5}$$

IV. FUZZY-AHP BASED RANKING

In undefined environments, the Fuzzy AHP method provides decision makers, a systematic method for comparing and weighting of the multiple criteria and alternatives. This too follows a hierarchical structure similar to Fig 1 with the difference that parameter estimation now utilizes a range of values. Thus, in the first iteration, the CSMIC parameters are estimated using the Sugeno Fuzzy Inference System (FIS) [21], [22] instead of the AHP mechanism, the results of which are shown in Table V. This is analogous to the RSRM obtained by the AHP mechanism in Fig 3. In the second step, trust estimates for service providers are once again obtained using the AHP mechanism as described in section III. For the Performance based model, the CSMIC parameters iss assigned the following weights:

$$(0.259 \quad 0.185 \quad 0.333 \quad 0.111 \quad 0.111) \tag{6}$$

as described in Fig 3 so that the trust estimates obtained can be compared with those obtained using AHP.

TABLE V
RESULTS AFTER FIRST ITERATION OF THE FUZZY AHP

	Agility	Finance	Performance	Security	Usability
CSP1	0.5	0.484	0.509	0.497	0.259
CSP2	0.5	0.272	0.996	0.323	0.511
CSP3	0.251	0.694	0.296	0.438	0.488
CSP4	0.525	0.473	0.644	0.489	0.486
CSP5	0.506	0.266	0.883	0.488	0.485
CSP6	0.249	0.706	0.28	0.497	0.42
CSP7	0.183	0.25	0.00285	0.297	0.00056

The trust estimation mechanism and the values so obtained from this Fuzzy based AHP method is shown in Fig 4. The final trust values are given in (7).

	Agility	Finance	Performance	Security	Usability
CSP 1	0.154	0.112	0.141	0.164	0.0978
CSP 2	0.0865	0.199	0.276	0.107	0.193
CSP 3	0.221	0.078	0.082	0.145	0.184
CSP 4	0.15	0.114	0.178	0.161	0.183
CSP 5	0.0846	0.204	0.245	0.161	0.183
CSP 6	0.224	0.0767	0.0775	0.164	0.159
CSP 7	0.0795	0.217	0.000786	0.0981	0.000187

x

Weights
0.259
0.185
0.333
0.111
0.111

=

Trust Estimate
0.1522
0.1889
0.1287
0.1752
0.1836
0.1269
0.0433

Fig 4 Trust Value Estimation for Performance based Model using Fuzzy-AHP

$$Trust\ values\ using\ Fuzzy - AHP\ model\ (Performance\ based\ model) = (0.1522 \quad 0.1889 \quad 0.1287 \quad 0.1752 \quad 0.1836 \quad 0.1269 \quad 0.0433) \tag{7}$$

V. COMPARISON OF AHP AND FUZZY-AHP METHODS

The trust estimates obtained from the AHP and Fuzzy-AHP mechanism are given in (5) and (7) respectively. For a Performance based model, AHP rates CSP5, CSP2 and CSP7 as the top three service providers. A direct comparison of the Performance attributes of these three service providers indicates an inconsistency in the ranking above. This deviation can be explained as follows:

The attributes which contribute to Performance are - Number of Processors (NP), RAM availability (RAM) as listed in Table I and the DC Processing Time (DCPT) listed in Table II. So a service provider rated highest based on Performance should provide a high NP, high RAM and low DCPT. A look into Tables I and II shows that CSP2 has (NP-12, RAM-48, DCPT-1.06) while CSP5 has (NP-12, RAM-32, DCPT-1.06). Since both have the same NP and DCPT values, the provider with higher RAM should be ranked better than the provider with lower RAM. Thus, as per the values of attributes contributing to Performance, rank of CSP2 > rank of CSP5. But, AHP shows a rank reversal due to the inability of the mechanism to handle a mix of high/low measure of attributes. The Fuzzy based AHP mechanism on the other hand clearly ranks CSP2 as a better service provider than CSP5.

This comparison is further strengthened by a similar deviation observed in the ranking of top three service providers. The top three service providers from AHP are CSP5, CSP2, and CSP7 while the Fuzzy AHP ranks the top three service providers as CSP2, CSP5, and CSP4. This deviation in identifying the third best service provider can also be justified by the inability of AHP to capture a mix of high and low values of attributes. Once again as seen in Tables I and II, the Performance attributes for CSP7 are (NP-2, RAM-8, DCPT-16.01) while for CSP4 are (NP-6, RAM-32, DCPT-0.91). CSP4 is definitely better in the Performance as compared to the remaining unranked service providers.

This leads to a conclusion that the Fuzzy AHP mechanism correctly captures the behavior of Performance attributes thus leading to correct estimates of trust values with higher variance.

VI. TOPSIS BASED RANKING

TOPSIS developed by Hwang and Yoon in 1981 [23], views the decision making problem with *m* alternatives, as a geometric system with *m* points in the *n*-dimensional space. The method is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. TOPSIS defines an index called similarity to the positive-ideal solution and the remoteness from the negative-ideal solution using which the method chooses an alternative that has a maximum similarity to the positive-ideal solution. The structure of alternative performance matrix in TOPSIS is shown in Table VI [23].

TABLE VI
STRUCTURE OF THE ALTERNATIVE PERFORMANCE

	Criterion 1	Criterion 2	……	Criterion n
Alternative 1	x_{11}	x_{12}	……	x_{1n}
Alternative 2	x_{21}	x_{22}	……	x_{2n}
…	…	…	……	…
…	…	…	……	…
…	…	…	……	…
Alternative m	x_{m1}	x_{m2}	……	x_{mn}

where x_{ij} is the rating of the alternative *i* with respect to criterion *j*. The similarity indices of the attributes at leaf level of Fig 1 are first computed. These values have been listed in Table VII (A), where the alternatives correspond to service providers and the criteria are VM, DC and SS. The TOPSIS process proceeds as follows:

i) The normalized decision matrix (r_{ij}) for Agility as in Table VII (B) is obtained from the similarity indices using

$$r_{ij} = \frac{x_{ij}}{\sqrt{\Sigma(x_{ij})^2}}\ for\ i = 1\ to\ m\ and\ j = 1\ to\ n \tag{8}$$

where, *m* represents the set of service providers and *n* represents the attributes/criteria used in the model. Likewise, the normalized decision matrix is obtained for other CSMIC parameters too.

TABLE VII (A)
INPUT TABLE FOR AGILITY

	VM	DC	SS
CSP1	8	3	1
CSP2	12	3	0.934
CSP3	2	8	0.219
CSP4	6	8	0.6
CSP5	12	8	0.292
CSP6	2	6	0.16
CSP7	2	4	0.5

TABLE VII (B)
NORMALIZED TABLE FOR AGILITY

	VM	DC	SS
CSP1	0.4	0.185	0.615
CSP2	0.6	0.185	0.575
CSP3	0.1	0.494	0.135
CSP4	0.3	0.494	0.369
CSP5	0.6	0.494	0.18
CSP6	0.1	0.371	0.098
CSP7	0.1	0.247	0.308

ii) A weighted normalized decision matrix $v_{ij} = w_j r_{ij}$ is obtained by multiplying the normalized matrix(r_{ij}) with the weights(w_j). Although, decision makers can define weights directly, they can also be obtained from pairwise comparisons of AHP mechanism. For example, the weighted normalized decision matrix in Table VIII has been obtained by multiplying the normalized decision matrix for Agility shown in Table VII (B) with the weights computed using AHP shown in Fig 2.

TABLE VIII
WEIGHTED NORMALIZED TABLE FOR AGILITY

	VM	DC	SS
CSP1	0.187	0.061661	0.123
CSP2	0.28	0.061661	0.115
CSP3	0.047	0.16465	0.027
CSP4	0.14	0.16465	0.0738
CSP5	0.28	0.16465	0.036
CSP6	0.047	0.123654	0.0196
CSP7	0.047	0.082325	0.0616

iii) Assuming J to be the set of favorable attributes/criteria and J' to be the set of negative attributes/criteria, the positive and the negative ideal solutions $A^*$and A' are determined by

Positive ideal solution.

$$A^* = \{v_1{}^*, v_2{}^*, \ldots\ldots, v_n{}^*\}\ \text{where}$$
$$v_j{}^* = \{\max(v_{ij})\ if\ j \in J;\ \min(v_{ij})\ if\ j \in J'\} \tag{9}$$

Negative ideal solution

$$A' = \{v_1{}', v_2{}', \ldots\ldots, v_n{}'\}\ \text{where}$$
$$v_j{}' = \{\min(v_{ij})\ if\ j \in J;\ \max(v_{ij})\ if\ j \in J'\} \tag{10}$$

The positive ideal solution computed for Agility is defined by a high value of VM, DC and SS. These values are denoted in **bold** in the respective columns of Table IX. The negative ideal solution corresponding to the least values of attributes are denoted in *italics*.

TABLE IX
POSITIVE AND NEGATIVE IDEAL SOLUTION COMPUTED FOR AGILITY

	VM	DC	SS
CSP1	0.187	*0.061661*	**0.123**
CSP2	**0.28**	*0.061661*	0.115
CSP3	*0.047*	**0.16465**	0.027
CSP4	0.14	**0.16465**	0.0738
CSP5	**0.28**	**0.16465**	0.036
CSP6	*0.047*	0.123654	*0.0196*
CSP7	*0.047*	0.082325	0.0616

iv) The separations S_i^* and $S_i^{'}$ defined below provide an estimate of the deviations of each v_{ij} from v_j^* and $v_j{'}$ respectively and are represented in Tables X and XI.

$$S_i^* = \sqrt{\sum (v_j^* - v_{ij})^2} \; where \; i = 1, 2, \dots m \tag{11}$$

$$S_i^{'} = \sqrt{\sum (v_j^{'} - v_{ij})^2} \; where \; i = 1, 2, \dots m \tag{12}$$

TABLE X
SEPARATIONS FROM POSITIVE IDEAL SOLUTION FOR AGILITY

	VM	DC	SS	S_i^*
CSP1	0.008712	0.0106069	0	**0.139**
CSP2	0	0.0106069	6.4E-05	**0.103**
CSP3	0.054452	0	0.009216	**0.252**
CSP4	0.019603	0	0.0024206	**0.148**
CSP5	0	0	0.007569	**0.087**
CSP6	0.054452	0.0016807	0.0106916	**0.259**
CSP7	0.054452	0.0067774	0.00377	**0.255**

TABLE XI
SEPARATIONS FROM NEGATIVE IDEAL SOLUTION FOR AGILITY

	VM	DC	SS	$S_i^{'}$
CSP1	0.019603	0	0.0106916	**0.174**
CSP2	0.054452	0	0.0091012	**0.252**
CSP3	0	0.0106069	5.476E-05	**0.103**
CSP4	0.008712	0.0106069	0.0029376	**0.149**
CSP5	0.054452	0.0106069	0.000269	**0.256**
CSP6	0	0.0038432	0	**0.062**
CSP7	0	0.000427	0.001764	**0.047**

v) The above values of S_i^* and $S_i^{'}$ are used to compute the similarity index C_i^* as follows:

$$C_i^* = \frac{S_i^{'}}{(S_i^* + S_i^{'})} \quad 0 < C_i^* < 1 \tag{13}$$

$$Similarity\ Index\ (Agility) = (0.556 \quad 0.71 \quad 0.29 \quad 0.502 \quad 0.746 \quad 0.193 \quad 0.156) \tag{14}$$

The higher values of C_i^* correspond to the service providers rated high in Agility. Similarly, the indices are obtained for the remaining CSMIC parameters. In iteration two, steps (i) to (v) are repeated at the higher level of Fig 2 with the inputs listed in Table XII. The weights at this level are considered (0.259, 0.185, 0.333, 0.111, 0.111) which are once again taken from the AHP calculation shown in Fig 3.

TABLE XII
RESULTS AFTER FIRST ITERATION OF TOPSIS

	Agility	Finance	Performance	Security	Usability
CSP1	0.556	0.849	0.74	0.765	0.566
CSP2	0.71	0.587	0.991	0.368	1
CSP3	0.29	0.792	0.596	0.692	0.723
CSP4	0.502	0.526	0.782	0.571	0.617
CSP5	0.746	0.115	0.886	0.563	0.652
CSP6	0.193	0.923	0.628	0.575	0.68
CSP7	0.156	0.692	0.047	0.257	0

The final trust values of the service providers based on Performance are listed in (15).

$$Trust\ values\ using\ TOPSIS\ (Performance\ based\ model) = (0.61 \quad 0.786 \quad 0.462 \quad 0.668 \quad 0.867 \quad 0.424 \quad 0.094) \tag{15}$$

VII. FUZZY-TOPSIS BASED RANKING

In Fuzzy-TOPSIS, the iteration at first level uses the Sugeno FIS to get an estimate of Agility, Finance, Performance, Security, and Usability, the results of which are shown in Table V. The second iteration starts from Table V and repeats the steps (i) to (v) of the TOPSIS method to get the final trust values. Results so obtained from the Performance based model are:

$$Trust\ values\ using\ Fuzzy - TOPSIS\ (Performance\ based\ model) = (0.555 \quad 0.928 \quad 0.321 \quad 0.679 \quad 0.899 \quad 0.3 \quad 0.225) \tag{16}$$

VIII. COMPARISON OF TOPSIS AND FUZZY TOPSIS METHODS

The trust estimates obtained from the TOPSIS and Fuzzy-TOPSIS methods are given in (15) and (16) respectively. For a Performance based model, TOPSIS rates CSP5, CSP2 and CSP4 as the top three service providers, while the ranking obtained using the Fuzzy-TOPSIS method is CSP2>CSP5>CSP4. A direct comparison of the Performance attributes of all the service providers from Tables I and II indicates the same as in the above ranking. Though, top three ranking of the service providers is preserved in both the methods, there is a deviation observed between the ranking of CSP2 and CSP5. TOPSIS ranks CSP5 better than CSP2, but as in case of AHP and Fuzzy-

AHP, a closer look at the Performance related attributes clarifies that the ranking of CSP2 should have been better than CSP5, which is captured by the Fuzzy-TOPSIS method.

IX. PERFORMANCE EVALUATION OF MCDM METHODS

The trust estimates for the Performance based model listed in Table XIII, obtained from the four MCDM methods, namely; AHP, Fuzzy-AHP, TOPSIS, and Fuzzy-TOPSIS are now analyzed for their consistency, sensitivity, complexity and reduction in dimension of service providers [20].

TABLE XIII
RESULTS OF PERFORMANCE BASED MODEL

	AHP	Fuzzy-AHP	TOPSIS	Fuzzy-TOPSIS
CSP1	0.1238	0.1522	0.61	0.555
CSP2	0.1799	0.1889	0.786	0.928
CSP3	0.1035	0.1287	0.462	0.321
CSP4	0.1441	0.1752	0.668	0.679
CSP5	0.1952	0.1836	0.867	0.899
CSP6	0.0749	0.1269	0.424	0.3
CSP7	0.178	0.0433	0.094	0.225

- *Consistency:* Consistency, in our context, means obtaining a trust estimate for infrastructure facilities which is inline with the input parameters listed in Tables I and II. As per the attribute values listed in the above tables, CSP2 should have a larger trust value than CSP5 for Performance based trust estimation. This ranking is captured precisely by the Fuzzy AHP and Fuzzy TOPSIS methods as seen in Table XIII whereas in the other two methods, rank reversal is observed. Thus, combining Fuzzy inference with MCDM helps to achieve consistency.
- *Sensitivity:* Sensitivity is analyzed by observing the change in trust value brought out by a small change in the Performance attributes in Table I. This is achieved by changing the Number of Processors (NP) of CSP4 from 6 to 9. The modified trust estimates for various CSPs are now listed in Table XIV.

TABLE XIV
SENSITIVITY OF PERFORMANCE BASED MODEL

	AHP	Fuzzy-AHP	TOPSIS	Fuzzy-TOPSIS
CSP1	0.1225	0.1508	0.609	0.556
CSP2	0.1779	0.1862	0.784	0.927
CSP3	0.1032	0.1279	0.463	0.323
CSP4	0.1504	0.1825	0.693	0.75
CSP5	0.1935	0.1813	0.866	0.901
CSP6	0.0745	0.1262	0.426	0.302
CSP7	0.1776	0.0433	0.095	0.229

The trust values of CSP4 here show a nominal increase from its trust values listed in Table XIII. This increase in the trust value substantially modifies the trust values of the competing CSPs. Thus, all the methods respond well to small changes in input.

- *Complexity:* The AHP mechanism uses the power iteration for computation of eigenvalues which is of order $O(n^3)$, where n is the number of service providers. Computation cost here increases with the number of service providers as also the number of attributes. Another disadvantage of this method is that, addition or removal of any attribute, calls for repetition of the entire computation from the leaf level.
  The Fuzzy-AHP method brings down the complexity of AHP by replacing the iteration at leaf level with the FIS. The FIS considered here uses a maximum of 125 rules, for each parameter estimation, which takes linear time compared to the AHP computation at leaf level.
  TOPSIS updates the matrix entries and has a computational complexity of $n \ x \ p$ where n is the number of service providers and p is the number of attributes applicable to each level. Once again, Fuzzy-TOPSIS brings down the number of computations at the leaf level.
  Thus, parameter estimation using FIS helps in improving the computational efficiency.
- *Reduction in dimension of service providers:* Any decision making method is expected to preserve the ranking when the number of alternatives is increased or decreased. To test this, the trust estimates obtained in Table XIII for seven providers were compared with trust estimates for fourteen service providers [21] using all the MCDM methods. The seven providers considered in this study are the subset of the fourteen providers [21]. The trust estimates for the fourteen CSPs obtained from all MCDM methods are listed in Table XV.

TABLE XV
RESULTS OF FOURTEEN SERVICE PROVIDERS – PERFORMANCE BASED MODEL

	AHP	Fuzzy-AHP	TOPSIS	Fuzzy-TOPSIS
CSP1	0.0662	0.0753	0.615	0.555
CSP2	0.0997	0.0938	0.784	0.935
CSP3	0.0597	0.0634	0.459	0.321
CSP4	0.0805	0.087	0.655	0.678
CSP5	0.1112	0.091	0.871	0.898
CSP6	0.0399	0.0625	0.423	0.303
CSP7	0.1185	0.0213	0.079	0.213
CSP8	0.0494	0.061	0.469	0.436
CSP9	0.0703	0.0813	0.611	0.73
CSP10	0.0618	0.0676	0.544	0.467
CSP11	0.045	0.0708	0.456	0.386
CSP12	0.0523	0.0811	0.505	0.503
CSP13	0.0669	0.0644	0.556	0.56
CSP14	0.0523	0.0786	0.669	0.699

TABLE XVI

RANKING OF SERVICE PROVIDERS DERIVED FROM TABLE XIII AND TABLE XV

Rank	AHP		Fuzzy-AHP		TOPSIS		Fuzzy-TOPSIS	
	From Table XIII	From Table XV	From Table XIII	From Table XV	From Table XIII	From Table XV	From Table XIII	From Table XV
1	CSP5	CSP7	CSP2	CSP2	CSP5	CSP5	CSP2	CSP2
2	CSP2	CSP5	CSP5	CSP5	CSP2	CSP2	CSP5	CSP5
3	CSP7	CSP2	CSP4	CSP4	CSP4	CSP4	CSP4	CSP4
4	CSP4	CSP4	CSP1	CSP1	CSP1	CSP1	CSP1	CSP1
5	CSP1	CSP1	CSP3	CSP3	CSP3	CSP3	CSP3	CSP3
6	CSP3	CSP3	CSP6	CSP6	CSP6	CSP6	CSP6	CSP6
7	CSP6	CSP6	CSP7	CSP7	CSP7	CSP7	CSP7	CSP7

From Tables XIII and XV, the ranking of the seven service providers discussed in this paper are listed in Table XVI. It is observed that except for AHP, all the three methods preserve the ranking even on reducing the dimension.

Thus, relative comparison of the MCDM methods indicates Fuzzy-TOPSIS as the better method for cloud services ranking.

X. TRUST ESTIMATION USING MCDM METHODS FOR VARYING USERS' PRIORITY

In the previous sections, a comparison of the trust estimates of seven providers was made for a Performance based model, where the Performance parameter was weighted high, relative to other parameters, and for a user whose requirement was to select a service provider with best Performance, CSP2 was recommended as the best choice.

The hierarchical model can also help the user to make a judicious choice based on Cost or Security too; rather it can be used to rate service providers as per users' requirements by assigning suitable weights to the relevant parameters. Results presented in this section, provide the trust estimation of service providers for varying users' priority. In particular, results are tabulated for Finance and Security based hierarchical models which are obtained by defining suitable weight vectors.

The weight vector corresponding to the Performance based model used in Fig 3, has a highest value for Performance parameter and can be modified as per the user requirement. So, for Finance and Security based models, the weights derived using AHP scale are

$$(0.185 \quad 0.333 \quad 0.259 \quad 0.111 \quad 0.111)\ and$$
$$(0.161 \quad 0.169 \quad 0.225 \quad 0.289 \quad 0.164) \tag{17}$$

in which the Finance and Security parameters have higher weights relative to other parameters. These vectors are used to obtain the Finance and Security based trust estimates for the seven service providers and these values are listed in Table XVII.

In case of the Finance based model, as per the input, CSP2 > CSP5, so CSP2 should have a higher trust estimate. This ranking is captured appropriately in the Fuzzy-AHP and the Fuzzy-TOPSIS methods, while a rank reversal is observed in the AHP and TOPSIS methods.

Interestingly, CSP5 is rated as the highly preferred service provider based on Security parameter from all the MCDM methods. But, the trust values obtained from the Fuzzy-TOPSIS method have a higher variance which enables clear differentiation between the service providers.

TABLE XVII

TRUST ESTIMATES FOR VARYING USERS' PRIORITY

	Finance based model				Security based model			
	AHP	Fuzzy-AHP	TOPSIS	Fuzzy-TOPSIS	AHP	Fuzzy-AHP	TOPSIS	Fuzzy-TOPSIS
CSP1	0.1178	0.1509	0.457	0.536	0.1293	0.1508	0.624	0.568
CSP2	0.1761	0.1676	0.655	0.921	0.1696	0.1689	0.651	0.798
CSP3	0.1031	0.1485	0.395	0.295	0.1168	0.1428	0.559	0.427
CSP4	0.1489	0.1699	0.603	0.637	0.1462	0.173	0.638	0.708
CSP5	0.2113	0.1642	0.874	0.912	0.1854	0.1759	0.761	0.908
CSP6	0.0744	0.1475	0.343	0.274	0.096	0.1435	0.483	0.418
CSP7	0.1679	0.0501	0.174	0.399	0.1651	0.0528	0.097	0.258

Table XVIII lists the variance of the trust estimates obtained from different methods. It is evident that the variance is maximum in the Fuzzy-TOPSIS method for all models, due to which it is able to capture the best service provider unambiguously.

TABLE XVIII
VARIANCE OBTAINED FROM MCDM METHODS

	Performance based model	Finance based model	Security based model
AHP	0.002	0.0022	0.001
FUZZY-AHP	0.0025	0.0018	0.0018
TOPSIS	0.0675	0.0531	0.0463
FUZZY-TOPSIS	0.0836	0.073	0.0541

XI. CONCLUSION

This study compares various trust estimation methods using MCDM process to rank CSPs offering infrastructure as a service. The trust estimation of service providers uses CSMIC parameters prioritized based on Performance, Finance and Security criteria. The trust values obtained show that Fuzzy-TOPSIS based ranking mechanism is consistent in ranking the service providers by capturing the information precisely from the infrastructure parameters. It also reduces the computational complexity and brings higher variance in the trust estimates, thus facilitating the choice of the best service provider suitable to users' priority.

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