Journal of Theoretical and Applied Information Technology
30th April 2021. Vol.99. No 8

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

HYBRID APPROACH CRITIC-TOPSIS FOR CLOUD SERVICE SELECTION

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ABSTRACT

Recently, Cloud computing is an ideal solution to complete business processes of most enterprises. The number of cloud services providers has increased, and consequently the number of cloud services and offerings has increased. The said issue is how choosing the best suitable cloud service adequate to business requirements. The aim of this paper is to provide a novel MCDM approach that gives accurate and reliable results for cloud service selection based problem. This paper proposes a hybrid MCDM (CRITIC-TOPSIS) approach to select best cloud service. CRITIC method used for determining weights of criteria objectively, furthermore, TOPSIS method used for ranking six virtual dedicated servers (VDS silver, VDS Gold, Cloud4You, SMART8, SMART16, QUAD SMART) based on 4 criteria (Dedicated CPU cores, Dedicated RAM , Storage HDD , Price/month). To approve the validity and robustness of the proposed hybrid approach, sensitivity analysis was conducted through sum experiments as different scenarios. Proposal's result was compared to another hybrid approach result, which used Entropy weighting method to determine the weights of criteria and TOPSIS to rank alternatives. More MCDM methods were applied (Classical TOPSIS, PROMETHEE-||, weighted sum product, weighted sum model), then this experimental results compared with the two hybrids and approved validity of CRITIC-TOPSIS approach.

Key words: *MCDM, Cloud Computing, CRITIC, TOPSIS, Entropy, PROMETHEE-||, Weighted Sum Product, Weighted Sum Model.*

1. INTRODUCTION

Cloud computing (CC) has become increasingly popular due to its introducing cost effective resources as a services (e.g., networks, servers, storage, applications, and services) over the network [12]. CC is a powerful invention which helps enterprises to achieve a competitive advantage. When an enterprise wants to adopt cloud services, this means that it faces a real challenge. The said issue is how to identify the best cloud service among set of feasible services. Therefore, enterprises restore to solving their matter through decision making methods. The selection process determined based on number of criteria which make it a multi criteria decision making (MCDM) problem. There are many attempts by researchers and scientists to help enterprises select cloud services. Some researches like [13], [14] used qualitative criteria, so they integrate analytic hierarchy process (AHP) with TOPSIS to convert criteria relative importance to numerical values and assign weights to criteria subjectively but paper [24] used cloud services selection problem based on quantitative criteria and also used AHP to assigning weights. Assigning weights subjectively which be influenced by decision makers' preferences leads to time consuming, and a lot of inconsistency especially when there is no agreement between decision makers. And when these preferences based on wrong information, this can cause results inaccuracy. So we prefer to assigning weights to criteria objectively. With the Objective weighting methods especially quantitative criteria in which criteria weights are derived from information gathered in each criterion through mathematical models without any consideration of decision makers' opinions. Objective weighting methods includes entropy; mean weight, standard deviation, and criteria importance through inter criteria (CRITIC) [4]. Many of existing researches of cloud services selection based problem e.g. [25], [26], [27] used Entropy-TOPSIS approach. Practically, there was found some lack of reliability in its results. This paper aim to develop a novel hybrid approach which uses CRITIC method for assigning weights to criteria objectively and TOPSIS method for ranking alternatives. Then we applied other MCDM methods (classical TOPSIS, weighted sum product (WSP), weighted product model (WPM), and PROMETHEE-||. and these experimental results compared with the two hybrids results to prove accuracy and reliability of our proposal result. The robustness of proposed approach was approved by applying sensitivity analysis through six experiments of interchanging criteria as different scenarios. The rest of this paper is organized as follow: Section 2 consists of related work of cloud services selection based problem with MCDM methods. Section 3 presents the proposed methodology to help enterprises choose the best suitable cloud service to achieve its goals. In section 4, a discussion of results of the hybrid approach. Section 5 validates results of the hybrid approach by comparing the hybrid approach results with the results of other five MCDM methods by using sensitivity analysis. Section 6 contains conclusion, limitation and future work.

2. RELATED WORK

The problem of selecting a cloud service has attracted the attention of many researchers and scientists for helping enterprises to identifying best suitable service. Researchers contributed to introduce many integration of MCDM methods. In this section we will mention many of contributions in this field.

Table .A. Related work

Reference	Date	Contribution
[22]	2016	Proposed empirical study which integrated CRITIC and Entropy weighting to assigning weights to quantitative criteria and TOPSIS method for ranking alternatives. In context of the evaluation of regional disparities and determination of weights of regional indicators and regional disparities assessment.
[20]	2017	In this paper, The TOPSIS method expanded by using the Minkowski Distance to rate and classifies Cloud Service Providers (CSPs) then compared E-TOPSIS results with classical TOPSIS result.
[13]	2017	Proposed approach which integrated AHP and TOPSIS. Used AHP method to assigning weights to qualitative criteria and TOPSIS method for ranking alternative of a set of cloud service providers.
[14]	2017	Introduced an Analytical Hierarchy (AHP) process combined with Fuzzy-TOPSIS for selecting cloud services and validating results in comparison to another method, and agreed on its robustness with sensitivity analysis.
[26]	2017	Proposed an Extended TOPSIS (E-TOPSIS) approach by varying the parameter p in the Minkowski distance. Presented in a case study for CSPs evaluation An analysis of E-TOPSIS solutions and the CSPs order change relative to parameter p variation is realized. A comparison of the E-TOPSIS solutions with TOPSIS solution is presented.
[24]	2018	Introduced hybrid multi-criteria decision-making model to select best cloud services. The proposed methodology assigns various ranks to cloud services based on the quantified quality-of-service parameters using a novel extended Grey Technique for Order of Preference by Similarity to Ideal Solution integrated with analytical hierarchical

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

		process.
[25]	2018	Applied Entropy Weight method and TOPSIS power and SLA method to find the physical machine. That optimize energy consumption, number of VM migration and SLA violation.
[18]	2019	This paper determines a hybrid renewable energy source (HRESs) for a rural community using technical, economic, and techno-economic criteria, which combines the importance of criteria by linking the criteria (CRITIC) and (TOPSIS) as a solution method.
[19]	2019	Designed an improved Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method based selection technique for choosing trustworthy Cloud Database Servers (CDSs). The selection technique utilizes multi attribute decision making approach for selecting trustworthy CDSs.
[27]	2020	Proposed Heterogeneous QoS-Based Cloud Service Selection Approach Using Entropy Weight and GRA-ELECTRE III
[16]	2020	Developed a framework for selecting cloud services for a neutrosophic environment using single-value neutrosophic group theory (SVNS) and (TOPSIS) for ranking alternatives of cloud services providers.
[12]	2020	Here, paper focused on cloud services security evaluation based problems. Integrated subjective weights (fuzzy DEMATEL) with objective weights (Entropy method) then TOPSIS to rank alternatives.

3. RESEARCH METHODOLOGY

In this paper, CRITIC weighting method was merged with TOPSIS method to select best virtual dedicated server as a cloud infrastructure as a service type. CRITIC method used to assign weights to criteria objectively. Then we used TOPSIS method for ranking alternatives as shown in figure 1

Detailed steps of research methodology:

3.1. Construct Decision Matrix and Data Description:

This research concentrates on infrastructure as a service (IaaS) of cloud computing. Decision matrix has real data which gathered from real offers of three cloud companies (Server4You), (Cloud4You), (Cherry servers).Decision matrix has a set of six virtual dedicated servers and four criteria. The six servers are VDS silver (A1), VDS Gold (A2), Cloud 4 you (A3), SMART8 (A4), SMART16 (A5), and QUAD SMART (A6). The four criteria are Dedicated CPU cores (C1), Dedicated RAM (GB) (C2), Storage HDD (TB) (C3), and Price/month ($) (C4), as in table 1.

3.2. CRITTIC Method for Criteria Weight Determination:

The criteria importance through inter-criteria correlation (CRITIC) method is based on the standard deviation. It uses correlation analysis to measure contrasts between criteria [4], [22].

3.2.1. Normalize the decision matrix as in table 2.

$r_{ij}=\frac{x_{ij}-Xj^{worst}}{Xj^{best}-Xj^{worst}}$/ Where r_{ij} is the data of the i-th evaluating alternative on the criterion (1)

3.2.2. Calculate standard deviation σj for each criterion which quantifies the contrast intensity of the corresponding criterion, see table3.

3.2.3. Determine the symmetric matrix (S) of n*n with element r_{ik} as a generic element, which is the linear correlation coefficient between the vectors x_i and x_k, as in table 4.

3.2.4. Calculate measure of the conflict created by criterion j with respect to the decision situation defined by the rest of criteria$\sum_{k=1}^{m}(1-r_{ik})$, as in table 5.

Journal of Theoretical and Applied Information Technology
30th April 2021. Vol.99. No 8

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

3.2.5. Determining the quantity of the information in relation to each criterion, see table 5.

c_j= σj*$\sum_{k=1}^{m}(1 - r_{ik})$ (2)

3.2.6. Determining the objective weights result by normalizing these values to unity according to the following equation, see table 5.

$w_j = \frac{c_j}{\sum_{k=1}^{m} c_j}$ (3)

3.2.7. CRITIC method Results:
The criterion dedicated RAM (C2) has the highest weight and the dedicated CPU cores criterion (C1) has a lower weight. The storage HDD criterion (C3) was ranked second in importance and the price criterion (C4) was the third, as shown in figure 2.

3.3. TOPSIS Method for Ranking Alternatives

TOPSIS method is based on the determination of the best alternative nearest to the ideal solution (with the shortest Euclidean distance) and farthest from the negative ideal solution [22], [6], [7], see table 6:

3.3.1. Normalize decision matrix $r_{ij} = \frac{x_{ij}}{\sqrt{\sum_j^n x_{ij}}}$ (4)

3.3.2. Calculate weighted normalized matrix $Vj = w_j * x_{ij}$ (5)

3.3.3. Identifying ideal (best and worst) value
Vj^+: indicates the ideal(best) value
Vj^-: indicates the ideal(worst) value

3.3.4. Calculate Euclidean distance from ideal best and worst

$S_I^+ = \left[\sum_{j=1}^{m}(Vj - \mathrm{Vj}^+)^2\right]^{0.5}$ (6)

$S_i^- = \left[\sum_{j=1}^{m}(Vj - \mathrm{Vj}^-)^2\right]^{0.5}$ (7)

3.3.5. Calculate performance score (the relative closeness from the ideal solution), The relative closeness of the i-th alternative Ai is expressed as:

$p_i = \frac{s_i^-}{s_I^+ + s_i^-}$ (8)

3.3.6. Ranking the alternatives in descending order, see figure 3.

4. CRITIC-TOPSIS Results:

QUAD SMART (A6) was ranked the best server, and Cloud4You (A3) server was ranked the worst. The second is SMART16, the third is VDS Gold, the fourth is SMART78 and the fifth is VDS silver, as shown in figure 3.

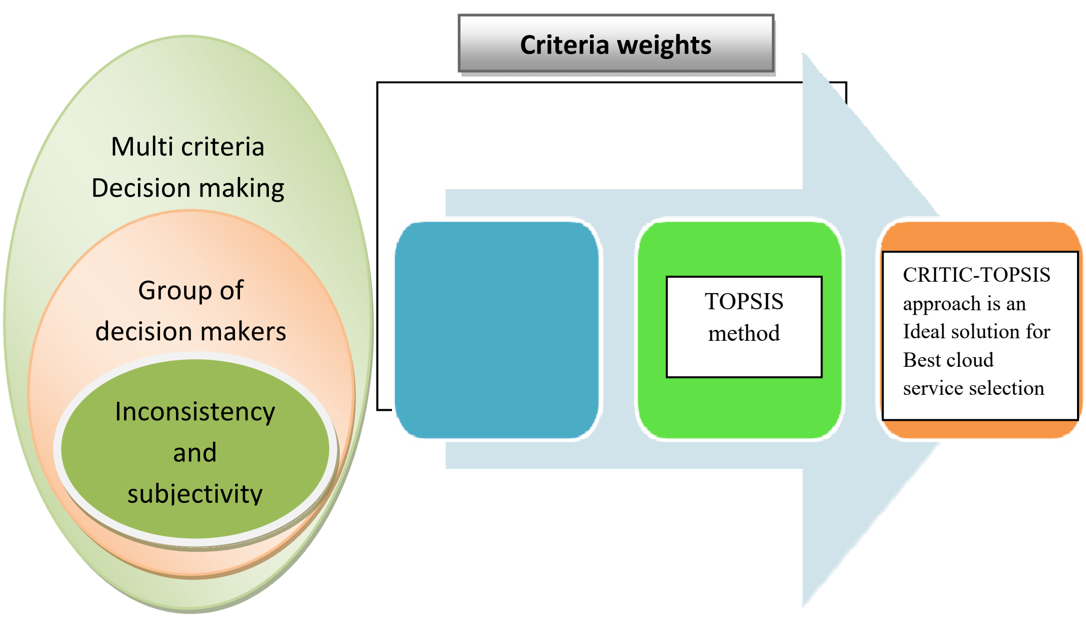

Figure (1) Research Methodology

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 1: Decision Matrix of Virtual Dedicated Servers

dIndex	Cloud company	Server name	Dedicated CPU cores(C1)	Dedicated RAM (GB) (C2)	Storage HDD(TB) (C3)	Price/month ($) (C4)
A1	Server4You[1]	VDS silver	2	8	0.5	19.99
A2		VDS Gold	2	16	1	29.99
A3	Cloud4You[2]	-	3	16	1	145.22
A4	Cherry servers[3]	SMART8	2	8	2	55
A5		SMART16	2	16	2	61
A6		QUAD SMART	4	16	3	69
Best			4	16	3	19.99
worst			2	8	0.5	145.22
$Xj^{best} - Xj^{worst}$			2	8	2.5	125.23

Table 2: Normalized Decision Matrix (r_{ij})

Criteria / Index	Dedicated CPU cores	Dedicated RAM (GB)	Storage HDD(TB)	Price/month($)
1	0	0	0	0
2	0	1	0.2	0.079853
3	0.5	1	0.2	1
4	0	0	0.6	0.2796
5	0	1	0.6	0.3275
6	1	1	1	0.3914

Table 3: Standard Deviation of Criteria

Criteria	C1	C2	C3	C4
σj	0.41833	0.516398	0.36697	0.353575

Table 4:.symmetric matrix S (r_{ik})

Criteria	C1	C2	C3	C4
C1	1	0.46291	0.586264	0.50275
C2	0.46291	1	0.281439	0.452593
C3	0.586264	0.281439	1	0.109457
C4	0.50275	0.452593	0.109457	1

Table 5: CRITIC Method Results for Weight Determination

Criteria	$(1 - r_{ik})$						
	C1	C2	C3)	C4	$\sum_{k=1}^{m}(1 - r_{ik})$	c_j	w_j
C1	0	0.53709	0.413736	0.49725	1.448076	0.60577	0.20441
C2	0.53709	0	0.718561	0.547407	1.803058	0.931096	0.314196
C3	0.413736	0.718561	0	0.890543	2.02284	0.74232	0.25045
C4	0.49725	0.547407	0.890543	0	1.9352	0.68424	0.23089

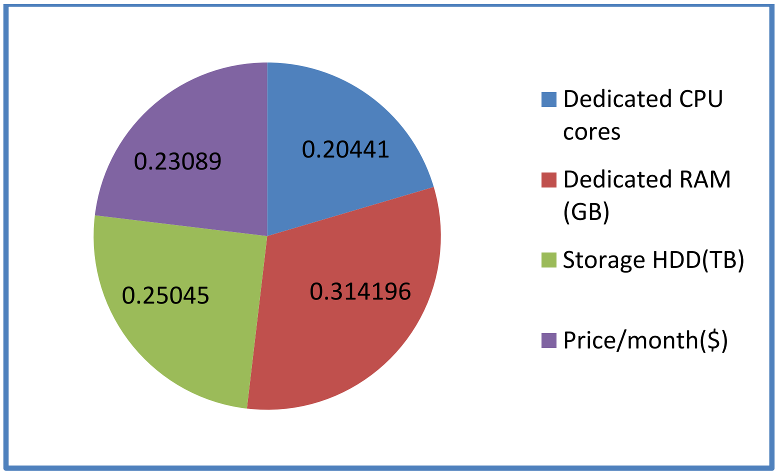

Figure 2: Objective Weights of Criteria

Table 6: Hybrid (CRITIC-TOPSIS) for Ranking Alternatives

Index		Normalized decision matrix (x_{ij}) (3.3.10)											
W_j		0.20441	0.314196	0.25045	0.23089	Weighted normalized decision matrix(Vj)(3.3.2)							
servers	criteria	C1	C2	C3	C4	C1	C2	C3	C4	Si^+ (3.3.4)	Si^- (3.3.4)	p_i (3.3.5)	Rank
A1		0.312348	0.235702	0.1139606	0.1085790	0.0638471	0.0740566	0.0285414	0.02506981	0.17299199	0.157054861	0.475856	5
A2		0.312348	0.471405	0.227921	0.1628957	0.0638471	0.1481136	0.0570828	0.037610988	0.13140608	0.164872378	0.556477778	3
A3		0.468522	0.471405	0.227921	0.7887867	0.095771	0.1481136	0.0570828	0.182122961	0.196770475	0.085546408	0.30301556	6
A4		0.312348	0.235702	0.455843	0.298742	0.0638471	0.0740566	0.114165879	0.06897654	0.121437673	0.141893143	0.5388398	4
A5		0.312348	0.471405	0.455843	0.331332	0.0638471	0.1481136	0.114165879	0.07650125	0.0999003	0.154828718	0.607817406	2
A6		0.624695	0.471405	0.683764	0.374785	0.1276939	0.1481136	0.171124869	0.08653411	0.0614643	0.19764478	0.762786008	1
Vj^+ (3.3.3)						0.1276939	0.1481136	0.171124869	0.02506981				
Vj^- (3.3.3)						0.0638471	0.0740566	0.0285414	0.182122961				

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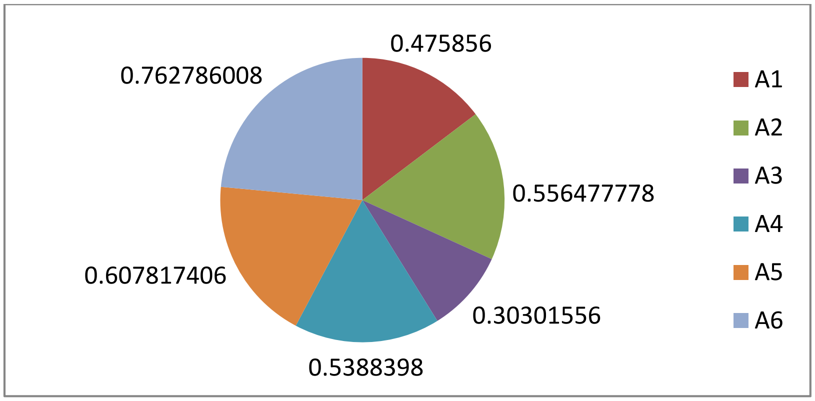

Figure 3: Ranking Virtual Servers by CRITIC-TOPSIS

5. VALIDATION OF RESULTS

Our proposal validated by using a comparison between its results and results of another hybrid approach Entropy-TOPSIS and other four MCDM methods: (Classical TOPSIS, PROMETHEE-‖, weighted sum product, weighted sum model) as in section 5.1, and sensitivity analysis as in section 5.2.

5.1. Comparing CRITIC-TOPSIS Result with Results of MCDM Methods:

Five MCDM methods conducted on the same decision matrix in table.1 to validate and confirm the preference of the hybrid approach, Entropy-TOPSIS, classical TOPSIS, Weighted sum product, weighted product model, PROMETHEE-‖, were applied. And a comparison of results introduces.

5.1.1. Classical TOPSIS method
Classical TOPSIS steps are explained before in section 3.3, and see classical TOPSIS calculations and results in table 7, and 8.

5.1.2. Weighted Sum Product [10], table 9:

5.1.2.1. Normalization:
Linear normalization for beneficial criteria:
$x_{ij}\sim = \frac{x_{ij}}{x_{ij}{}^{max}}$ (9)

Linear normalization for non-beneficial criteria: $x_{ij}\sim = 1 - \frac{x_{ij}}{x_{ij}{}^{max}}$ (10)

5.1.2.2. Weighted normalized decision matrix $=\sum_{j=1}^{n} w_j x_{ij}\sim$ (11)

5.1.3. Weighted Product Model [10], see table 10:

5.1.3.1. Normalization done with help of previous equation (9), (10).

5.1.3.2. Weighted normalized decision matrix Ai= $\prod_{x_{ij}} w_j$ (12)

5.1.4. PROMETHEE-‖ [8]:
The PROMETHEE is an outranking method for ranking a finite set of alternative actions when multiple criteria, which are often conflicting, and multiple decision-makers are involved [9].

5.1.4.1. Normalize the decision matrix, see table 11.

Beneficial criteria
$r_{ij} = \frac{[x_{ij} - \min(x_{ij})]}{[\max(x_{ij}) - \min(x_{ij})]}$ (13)

Non beneficial criteria
$r_{ij} = \frac{[\max(x_{ij}) - x_{ij}]}{[\max(x_{ij}) - \min(x_{ij})]}$ (14)

5.1.4.2. Calculate the evaluative differences of i^{th} alternative with respect to other alternatives

5.1.4.3. Calculate the preference function p_j(a, b), see table 12.

p_j(a, b)=0 if $r_{aj} <= r_{bj}$
D (m_a-m_b) <=0 (15)
p_j(a, b)= (r_{aj}-r_{bj}) if $r_{aj} > r_{bj}$
D (m_a-m_b) >0 (16)

5.1.4.4. Calculate the aggregated preference, see table 13

$\prod(a,b) = \left[\sum w_j p_j(a,b)\right] / \sum_{j=1}^{n} w_j$ (17)

5.1.4.5. Determine the leaving and the entering outranking flows, see table 13:

a. Leaving(positive) flow for a^{th} alternative,
$\varphi^{+} = \frac{1}{m-1} \sum_{a=1}^{m} \prod(a,b)$ (a!=b) (18)

b. Entering (negative) flow for a^{th} alternative,
$\varphi^{-} = \frac{1}{m-1} \sum_{b=1}^{m} \prod(b,a)$ (a!=b) (19)

Journal of Theoretical and Applied Information Technology
30th April 2021. Vol.99. No 8

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

5.1.4.6. Calculate the out ranking flow for each alternative, see table 13.

$$\phi = \phi^{+} - \phi^{-} \qquad (20)$$

5.1.5. Entropy Method For Weight Determination:

Entropy, in information theory, is a criterion for the amount of uncertainty, represented by a discreet probability distribution [4], [6], in which broad distribution represents more uncertainty. When the difference of the value among the evaluating objects on the same indicator is high, while the entropy is small, it illustrates that this indicators provides more useful information, and the relative weight of this indicator would be higher and vice versa[22].

5.1.5.1. Normalize the decision matrix (R).

$r_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$ where r_{ij} is the data of the i-th evaluating alternative on the criterion (21)

5.1.5.2. Compute entropy(h_j).

In the n criteria, m evaluating alternatives evaluation problem, the entropy of j-th criterion is defined as:

$$e_j = -h\sum_{i=1}^{m} r_{ij} ln r_{ij}, \text{ j=1, 2, 3, ..m} \qquad (22)$$

$$h = \frac{1}{ln(m)} \qquad (23)$$

$$h = \frac{1}{\ln(6)} = 0.55811$$

5.1.5.3. Calculate weight vector of j-th criterion as:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)}, \text{ j=1, 2, 3… n} \qquad (24)$$

Table 7: (Classical TOPSIS) Normalization Using Equation (4)

	Decision matrix				Normalized decision matrix			
Index	C1	C2	C3	C4	C1	C2	C3	C4
1	2	8	0.5	19.99	0.3125	0.2357	0.11396	0.10858
2	2	16	1	29.99	0.3125	0.4714	0.2279	0.16289
3	3	16	1	145.22	0.46875	0.4714	0.2279	0.78878
4	2	8	2	55	0.3125	0.2357	0.45584	0.29874
5	2	16	2	61	0.3125	0.4714	0.45584	0.33133
6	4	16	3	69	0.625	0.4714	0.68373	0.37478
$\sqrt{\sum_{j}^{n} x_{ij}}$	6.4	33.94	4.3875	184.106				

Table 8: Weighted Normalized Decision Matrix and Classical TOPSIS Results Using Equation (5)

Index	Weighted normalized decision matrix				Sij^{+}	Si^{-}	Pi	Rank
1	0.07813	0.05893	0.02849	0.02715	0.172818	0.170046	0.495958	5
2	0.07813	0.11785	0.056975	0.040724	0.13883	0.169607	0.549892	3
3	0.117188	0.11785	0.056975	0.197196	0.2083975	0.076213	0.26778	6
4	0.07813	0.05893	0.11396	0.074685	0.12280312	0.14938	0.548822	4
5	0.07813	0.11785	0.11396	0.082833	0.11158	0.15445	0.580574	2
6	0.15625	0.11785	0.17094	0.093695	0.066545	0.33557	0.83451	1
Vj^{+}	0.15625	0.11785	0.17094	0.02715				
Vj^{-}	0.07813	0.05893	0.02849	0.197196				

Table 9: Weighted Sum Product Results

	Normalized decision matrix				Weighted normalized decision matrix					
Index	C1	C2	C3	C4	C1	C2	C3	C4	Sum	Rank
1	0.5	0.5	0.1667	0.86235	0.125	0.125	0.041675	0.507263	0.507263	6
2	0.5	1	0.3333	0.7935	0.125	0.25	0.083325	0.198375	0.6567	3
3	0.75	1	0.3333	0.0	0.1875	0.25	0.083325	0	0.520825	5
4	0.5	0.5	0.6667	0.62126	0.125	0.125	0.166675	0.155315	0.57199	4
5	0.5	1	0.6667	0.57995	0.125	0.25	0.166675	0.1449875	0.686662	2
6	1	1	1	0.52486	0.25	0.25	0.25	0.131215	.881215	1

Table 10: Weighted Product Model Results

Criteria / index	C1	C2	C3	C4	Product	Rank
1	0.840896	0.840896	0.638975	0.963653	0.4354007	5
2	0.840896	1	0.75982	0.94381	0.603028	3
3	0.9306	1	0.75982	0	0.0	6
4	0.840896	0.840896	0.90361	0.887807	0.557591	4
5	0.840896	1	0.90361	0.87267	0.663091	2
6	1	1	1	0.851159	0.851159	1

Table 11: Normalized Decision Matrix

Index	C1	C2	C3	C4
1	0	0	0	1
2	0	1	0.2	0.920147
3	0.5	1	0.2	0
4	0	0	0.6	0.72043
5	0	1	0.6	0.678523
6	1	1	1	0.608203

Table 12: Evaluation Differences of i^{th} Alternative with Respect to Other Alternatives and The Preference of Each Alternative.

	C1	C2	C3	C4	C1	C2	C3	C4	Sum
D(1-2)	0	-1	-0.2	0.079853	0	0	0	0.079853	0.0196325
D(1-3)	-0.5	-1	-0.2	1	0	0	0	1	0.25
D(1-4)	0	0	-0.6	0.27957	0	0	0	0.27957	0.069895
D(1-5)	0	-1	-0.6	0.321477	0	0	0	0.321477	0.08369
D(1-6)	-1	-1	-1	0.391797	0	0	0	0.391797	0.097949
D(2-1)	0	1	0.2	-0.079853	0	1	0.2	0	0.3
D(2-3)	-0.5	0	0	0.920147	0	0	0	0.920147	0.2300367
D(2-4)	0	1	-0.4	0.199717	0	1	0	0.199717	0.299929
D(2-5)	0	0	-0.4	0.241624	0	0	0	0.241624	0.060406
D(2-6)	-1	0	-0.8	0.311944	0	0	0	0.311944	0.077986
D(3-1)	0.5	1	0.2	-1	0.5	1	0.2	0	0.425
D(3-2)	0.5	0	0	-0.920147	0.5	0	0	0	0.125
D(3-4)	0.5	1	-0.4	-0.72043	0.5	1	0	0	0.375
D(3-5)	0.5	0	-0.4	-0.678523	0.5	0	0	0	0.125
D(3-6)	-0.5	0	-0.8	-0.608203	0	0	0	0	0
D(4-1)	0	0	0.6	-0.27957	0	0	0.6	0	0.15
D(4-2)	0	-1	0.4	-.199717	0	0	0.4	0	0.1
D(4-3)	-0.5	-1	0.4	0.72043	0	0	0.4	0.72043	0.2801075
D(4-5)	0	-1	0	0.041907	0	0	0	0.041907	0.010476
D(4-6)	-1	-1	-0.4	0.112227	0	0	0	0.112227	0.0280567

Journal of Theoretical and Applied Information Technology
30th April 2021. Vol.99. No 8

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

D(5-1)	0	1	0.6	-0.321477	0	1	0.6	0	0.4
D(5-2)	0	0	0.4	-0.241624	0	0	0.4	0	0.1
D(5-3)	-0.5	0	0.4	0.678523	0	0	0.4	0.678523	0.26963
D(5-4)	0	1	0	-0.041907	0	1	0	0	0.25
D(5-6)	-0.5	0	-0.4	0.07032	0	0	0	0.07032	0.1758
D(6-1)	1	1	1	-0.391797	1	1	1	0	0.75
D(6-2)	1	0	0.8	-0.311944	1	0	0.8	0	0.45
D(6-3)	0.5	0	0.8	0.608203	0.5	0	0.8	0.608203	0.47705
D(6-4)	1	1	0.4	-0.112227	1	1	0.4	0	0.6
D(6-5)	1	0	0.4	0.07032	1	0	0.4	0.07032	0.36758

Table 13: PROMETHEE-|| Results

Index	1	2	3	4	5	6	ɚ+	ɚ	Rank
1	-	0.01996325	0.25	0.0698925	0.08036925	0.097949	0.10363485	0.030136515	6
2	0.3	-	0.23003675	0.29992925	0.060406	0.077986	0.1936716	0.06467895	3
3	0.425	0.125	-	0.375	0.125	0	0.2096	0.05176515	4
4	0.15	0.1	0.2801075	-	0.01047675	0.02805675	0.1137282	0.040523615	5
5	0.4	0.1	0.26963075	0.25	-	0.01758	0.20744215	0.07867575	2
6	0.75	0.45	0.47705075	0.6	0.36758	-	0.52892615	0.48461175	1
ɚ−	0.405	0.15899265	0.30136515	0.31896435	0.1287664	0.0443144			

Table 14: Entropy Method for Weight Determination

Decision matrix					Normalized decision matrix (5.1.5.1)				$r_{ij} ln r_{ij}$ (5.1.5.2)			
Index	C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4
1	2	8	0.5	19.99	0.13333	0.1	0.052632	0.052578	-0.26865	-0.23026	-0.154971	-0.15486
2	2	16	1	29.99	0.13333	0.2	0.1052631	0.07888	-0.26865	-0.32189	-0.236978	-0.20034
3	3	16	1	145.22	0.2	0.2	0.1052631	0.38196	-0.32189	-0.32189	-0.236978	-0.36761
4	2	8	2	55	0.13333	0.1	0.2105263	0.14466	-0.26865	-0.23026	-0.32803	-0.27968
5	2	16	2	61	0.13333	0.2	0.2105263	0.16044	-0.26865	-0.32189	-0.32803	-0.29357
6	4	16	3	69	0.26667	0.2	0.3157895	0.181483	-0.35247	-0.32189	-0.364004	-0.30971

Journal of Theoretical and Applied Information Technology
30th April 2021. Vol.99. No 8

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

$\sum_{i=1}^{m} x_{ij}$	15	80	9.5	380.2					-1.74896	-1.74808	-1.08398	-1.6058
e_j									0.976112	0.97562	0.60498	0.896213
1-e_j									0.023888	0.02438	0.39502	0.103787
w_j									0.043665	0.04456	0.722058	0.189712

Table 15: Entropy-TOPSIS Method Results

Index	Normalized decision matrix Using equation (4)											
W_j	0.043665	0.04456	0.722058	0.189712	Weighted normalized decision matrix Using equation (5)							
criteria	C1	C2	C3	C4	C1	C2)	C3	C4	Sij^+	Si^-	Pi	Rank
1	0.312348	0.235702	0.1139606	0.10857903	0.0136387	0.0105028	0.0822862	0.0205987	0.41179106	0.1290436	0.2386	5
2	0.312348	0.471405	0.227921	0.1628957	0.0136387	0.0210058	0.1645722	0.0309033	0.3295886913	0.14484559	0.3053	4
3	0.468522	0.471405	0.227921	0.7887867	0.020458	0.0210058	0.1645722	0.1496423	0.35360349	0.0832334079	0.190537	6
4	0.312348	0.235702	0.455843	0.298742	0.0136387	0.0105028	0.3291451	0.0566749	0.16935724	0.263784484	0.609	2
5	0.312348	0.471405	0.455843	0.331332	0.0136387	0.0210058	0.3291451	0.0628576	0.170457986	0.26190294	0.3576	3
6	0.6246954	0.471405	0.683764	0.374785	0.0272773	0.0210058	0.4937173	0.0711012	0.050503	0.4641686655	0.90187	1
Vj^+					0.0272773	0.0210058	0.4937173	0.0205987				
Vj^-					0.0136387	0.0105028	0.0822862	0.1496423				

5.1.6. Experimental results:

CRITIC-TOPSIS ranked the alternatives as A6, A5, A2, A4, A1, and A3. Entropy-TOPSIS ranked alternatives as A6, A4, A5, A2, A1, and A3. When comparing the two hybrids, we found they agreed that the alternative A6 was the best and the alternative A3 was the worst. And they differed in the ranking of alternatives A4, A2, A1 as shown in figures 4, 5. To ensure the accuracy of one of the two results, we conducted a set of experiments consisting of applying other four methods of MCDM to the same research problem and comparing the results with each hybrid approach as shown in figures 6, 7, and 8. The results found that despite the different weights in each method, the results for the weighted product model, Classical TOPSIS were completely identical to CRITIC-TOPSIS, and the weighted sum product method differed only in that A1 was the worst instead of A3 and the similarity in PROMETHEE in that the A6 is The best followed by A5, then A2, and differed in evaluating the other three alternatives. When comparing the results with Entropy-TOPSIS approach, it was found that it rarely resembles one of them, given that the weighted sum product method was only similar in that the alternative A6 was the best and differed in

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

evaluating of the rest of the alternatives. The weighted product model was similar in the ranking of three alternatives and differed in three. Similar Entropy-TOPSIS was mentioned with classic TOPSIS in that A6 was the best, and A3 was the worst. PROMETHEE -‖ agreed that the A6 was the best and disagreed with him on the rest. In the end, the similarity of experimental results to CRITIC-TOPSIS confirmed the accuracy of its results.

Table 16: comparison of results

ALT S/M	CRIT IC-TOP SIS	CRIT IC-	ENT ROP Y-	ENT ROP	WSP weig hts	WSP	WP M weig	Wpm	Class ical TOP	Class	PRO MET HEE-	PRO MET
A1	0.475856	5	0.2386	5	0.507263	6	0.4354007	5	0.495958	5	0.030136515	6
A2	0.556477778	3	0.3053	4	0.6567	3	0.603028	3	0.549892	3	0.06467895	3
A3	0.30301556	6	0.190537	6	0.520825	5	0.0	6	0.26778	6	0.05176515	4
A4	0.5388398	4	0.609	2	0.57199	4	0.557591	4	0.548822	4	0.040523615	5
A5	0.607817406	2	0.3576	3	0.6866625	2	0.663091	2	0.580574	2	0.07867575	2
A6	0.762786008	1	0.90187	1	.881215	1	0.851159	1	0.83451	1	0.48461175	1

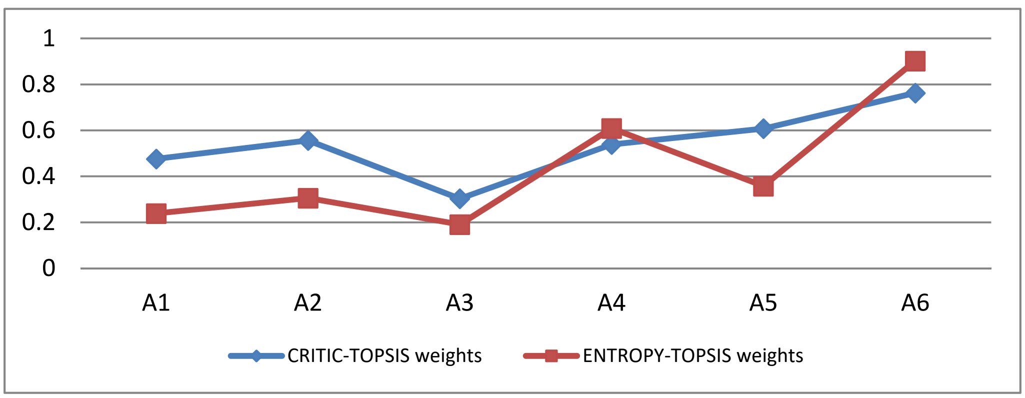

Figure 4: Comparison of Alternatives Weights of Two Hybrids

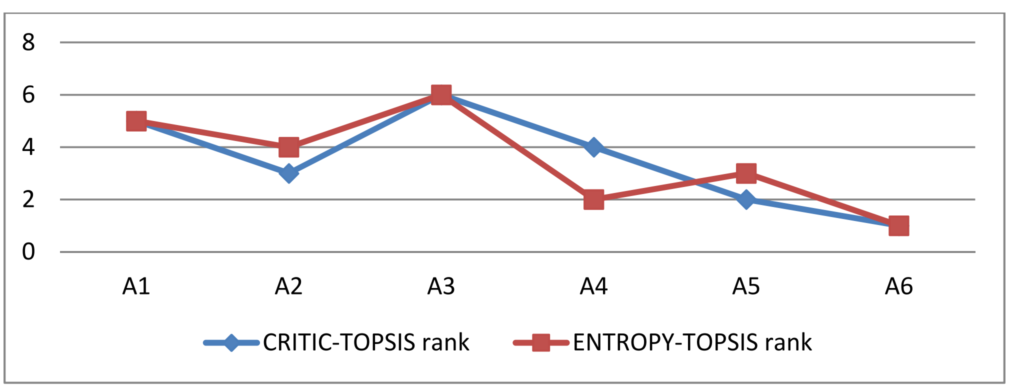

Figure 5: Comparison of Alternatives Ranking of Two Hybrids

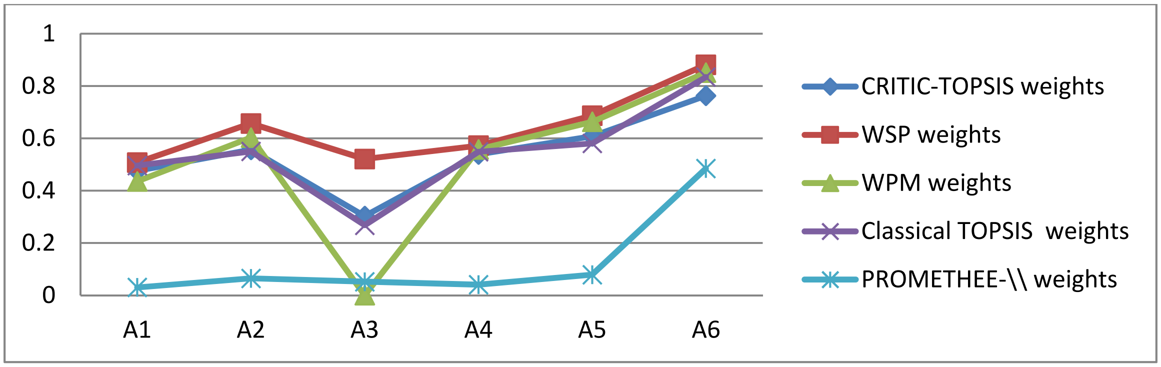

Figure 6: Comparison between CRITIC-TOPSIS Weights of Alternatives and weights by other Four MCDM Methods

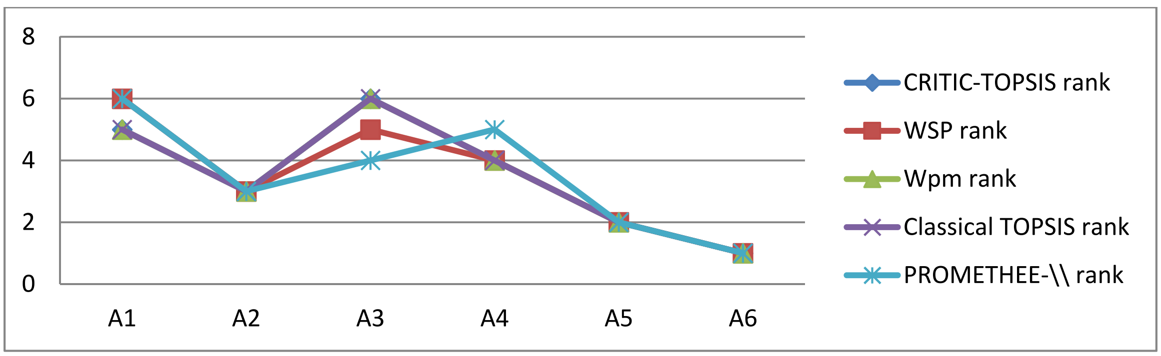

Figure 7: Comparison between CRITIC-TOPSIS Ranking of Alternatives and Ranking by other Four MCDM Methods

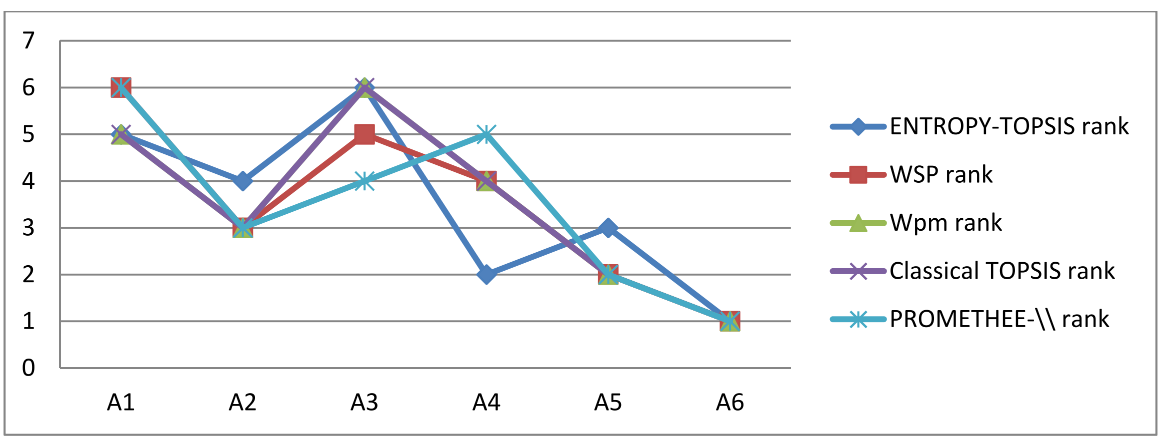

Figure 8: Comparison between Entropy-TOPSIS Ranking of Alternatives and Ranking by other Four

MCDM Methods

5.2. Sensitivity Analysis:

Sensitivity analysis was performed on our proposed approach to verify its potency and robustness. Many experiments of interchanges between criteria have been conducted as different scenarios. For any changes in the criteria weights, if the ranking order changes, then the result is known to be sensitive; otherwise, it is robust [11]. Six experiments to do sensitivity analysis. For each experiment, we named for example (C1 ____ C2) means that the weights of C1 and C2 are reciprocal. Figure (9) shows that the ranking of alternatives in each scenario, quite similar to proposed approach ranking of alternatives. This validates its robustness and rarely is sensitive.

Table 17: Experiments of Sensitivity Analysis

ALTS	A1	A2	A3	A4	A5	A6
C1 ↔ C2	0.33937	0.493691	0.260956	0.524129	0.408657	0.76694
C1 ↔ C3	0.497469	0.572881	0.316561	0.514859	0.583448	0.750635
C1 ↔ C4	0.4410456	0.52634	0.322085	0.514565	0.588601	0.755286
C2 ↔ C3	0.441074	0.504485	0.2613929	0.563409	0.69374	0.7848826
C2 ↔ C4	0.376156	0.407173	0.33567	0.43016	0.48067	0.6641889
C3 ↔ C4	0.50963	0.58607	0.29495	0.54705	0.61232	0.74419

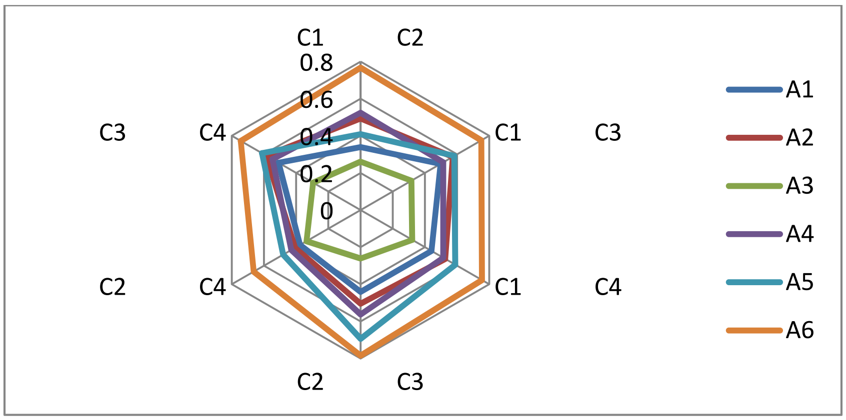

Figure9: Results of Sensitivity Analysis

6. CONCLUSION

Finally, this novel hybrid approach in context of cloud services selection based problem, can be used to assist enterprises and decision makers to rank cloud services based on a number of criteria. Our proposal helps solve the challenges of inconsistency and uncertainty by integrating CRITIC the objective weighting technique to assign weights to criteria rather than conflict decision makers, the Dedicated RAM criterion has the highest weight (0.314196), Dedicated CPU cores has the least weight (0.20441), then use TOPSIS method to rank alternatives. The hybrid approach identified that the QUAD SMART server was the best (0.762786008) and Cloud4You'server was the worst (0.30301556). We applied sensitivity analysis to proposal and compared the proposal results with another hybrid MCDM approach (Entropy-TOPSIS) method then results of two hybrids compared with results of other four MCDM methods(Classical TOPSIS, PROMETHEE-||, weighted sum product, weighted sum model) which validated proposal potency and robustness. And make sure that it can be adoptable in such problems.

7. LIMITATION:

The hybrid approach in this paper has not been applied to other examples of such problems.

8. Future work:

We are looking forward to doing a lot of experiments using the proposal and other different MCDM methods on the other problems and in different fields.

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