



## Adaptive Risk Assessment Framework for Selection of Public Cloud Service Providers using Fuzzy-Analytic Hierarchy Process Approach

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### Abstract

#### Keywords:

Cloud Computing,  
Risk Assessment,  
Risk Factors,  
Analytic Hierarchy Process,  
Fuzzy Logic.

*The benefits of cloud computing technology is not in doubt, so also, the expression of fear by the prospective users of adopting the technology is visible, particularly on the challenges faced in the process of selecting the best cloud providers that meet their organizations' requirements. The selection decision becomes more complicated in case of multiple service providers, multiple conflicting criteria and imprecise parameters. This paper proposes a hybrid risk assessment framework for the public cloud consumers based on cloud information security and service availability by taking into consideration the complexity and dynamism of the technology using the combined Analytic Hierarchy Process (AHP) and Fuzzy Logic approach to help the public cloud consumers to assess the associated risk of selecting particular cloud service provider(s).*

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### INTRODUCTION

In the recent years, the advent of cloud computing technology have enabled the delivery of computing services in a pervasive way that allow the subscription for such services to be based on usage rather than fixed price. Today, the technology is fast assisting individuals, businesses and organizations in increasing their capability, productivity and efficiency. It has eliminated the border restriction of obtaining special computing resources and expertise that are not available locally to the organizations and individuals. Organizations and individuals can now access specialized computing resources without the need to invest in the establishment of new infrastructure.

The cloud computing infrastructures are enclosed in large data centres that are mostly managed by a third party, who then provides the computing services to the users on a demand bases. In each case, both the providers and the consumers derive different benefits from the services. To the "Cloud Providers", it is the consolidation of computing resources resulting to the

centralized management of resources and economies of scale, while the "Cloud Consumers" gain from the rapid access to computing resources that lead to overall cost reduction and lowers the barrier of entry to many processing-intensive activities (Zhang et al., 2010; Lutz and Keith, 2012).

However, inspite of the immeasurable benefits the technology promises, it has also raised major challenges as regards the information privacy, security, service availability and reliability. The most worrisome part is that, the number of cloud services providers is growing very fast, making the comparison and selection process very difficult for prospective consumers, particularly in the developing countries (Te-Shun, 2013; Keiko et al., 2013; Michael, 2015). The process of selecting a cloud provider by the consumers has been challenging for several reasons, including the diversity of cloud services, security resources available, multiple conflicting selection criteria and imprecise general parameters for the consumers to assist them in the selection process.

The fact that “all clouds are not created equal” is a major concern to the public cloud consumers in making a better decision when planning to adopt public cloud computing and, more difficult when comparing the different cloud computing offerings of different competitive public cloud providers with the motive of selecting the best provider that meets their requirements (Taiye, 2012). It is not therefore unexpected that organizations strive to assess the level of risks associated with their choices at every point in time in order to be guided in their decision making. The selection process involves the evaluation of the public cloud services risk using the requirements’ multiple criteria; the evaluation of the alternatives selection’s associated risks can be regarded as a multiple criteria decision making problem.

The International Organization for Standardization ISO defines risk as the effect of uncertainty on objectives (ISO 31000, 2009). It is expressed as a combination of the consequences of an event and the associated probability of occurrence with the potential to influence the achievement of an organization’s objectives (Berg, 2010). The need to provide the cloud consumers with reliable risk assessment framework to measure the risks level of choosing particular public cloud provider(s) in term of its information security and services availability is a major challenge facing the public cloud services consumers.

The existing works have devised various methods of evaluating associated risks of selecting particular provider(s) from the available alternatives, such as QUIRC by Prasad and Ben (2010); Chandran and Angepat (2010); SecAgreement by Matthew and Rose (2012); Feng et al. (2012); Mouna et al. (2015); Microsoft by Greg and Pierre (2016). However, none of the existing works has explored hybrid methods, such as Fuzzy-AHP in the assessment of public cloud services providers’ associated risk. This work is proposing a Fuzzy-AHP framework for the assessment of public cloud services providers’ risk for the purpose of selecting the best among the available alternatives that meet the prospective consumers’ requirements.

## LITERATURE REVIEW

The general acceptance that there are peculiar risks in the public cloud technology environment and that the traditional risk assessment models are incapable of evaluating these risks have resulted in the design and development of some specific cloud-context risks assessment frameworks and models. The cloud computing as a new technology officially came to existence around 2006, the issue of designing risks assessment frameworks and models for cloud environment therefore started around 2009 with the design and publication of Cloud Computing

Information Assurance Framework by the European Union Agency for Network and Information Security Assurance (ENISA) (Daniele and Giles, 2009). The following literatures of the existing frameworks and models were reviewed according to the risk factors and the methodologies used.

Daniele and Giles (2009) designed a framework for the information security assessment for public clouds based on international standard of ISO/IEC 27005:2008 risk level estimation approach. The framework uses generic qualitative approach of Decision Tree Analysis with four risk factors; however, the generic qualitative approach adopted makes it very difficult for the consumers (users) to comparatively evaluate the associated risks of adopting a particular public cloud provider as the overall risk estimation is left to the opinion of the expert with the likelihood of being biased and subjective, more so, the framework only taken into consideration the security of the information within the cloud environments as the basis of assessing the associated risk of a provider.

Chandran and Angepat (2010) developed a public cloud risk assessment framework based on Trust Matrix Approach for security risk analysis to ensure that formal risk assessments are aligned with the enterprise-wide framework to facilitate transparency, and increase trust level between the cloud customers and the cloud providers. The framework used two risk criteria of “Data Cost” and “Providers’ History”. In “data cost” consumers can assign a cost to data based on the data’s criticality whereas “Provider’s history” includes the record of the past services provided by the provider to consumers. The framework also focuses on the information security within the cloud environments as a basis for assessing the provider’s selection risk.

Peiyu and Dong (2011) produced a cloud information security risk assessment model for public cloud services consumers using Analytic Hierarchy Process (AHP) approach with security as the only risk factor which is subdivided into eight criteria of cloud security principles and their corresponding correlation coefficients. Further to this, Feng *et al.* (2012) presented a risk management framework for public cloud consumers on the basis of the providers’ previous services to assist the public cloud consumers in ascertaining the risk associated with selecting particular service provider(s) among the available alternatives. The framework adopted five criteria processes of consumer requirement self-assessment, cloud service providers’ desktop assessment, risk assessment, third party agencies review and continuous monitoring based on Decision Tree Analysis Approach.

In Microsoft, a cloud risk decision framework was designed based on ISO 31000 standard (ISO 31000, 2009) to assist the public cloud consumers to take appropriate risk decision before moving to the public cloud by using the framework as a template in assessing the risks associated with particular cloud providers among available alternatives (Greg and Pierre, 2016). The framework adopted four risk factors of operational risk, market and finance risk, strategies risks and compliance risks using Risk Matrix Approach.

It was observed from the reviewed literatures that the available frameworks and models for the assessment of public cloud providers risk for the purpose of selecting the best among the available alternatives have been based on the classical probability models of multi criteria decision making methods of AHP, Decision Tree and Trust Matrix that integrates experts opinions and qualitative rating into a simple elementary hierarchy system through the decomposition of complicated problems from higher hierarchies to lower ones.

The two major elements in the selection process are: the selection of specific criteria that applied to the service domain for decision making purposes and the choice of the method for ranking the available alternatives. However, this paper focuses on the second part of choosing a method to rank the available alternatives based on the alternatives' associated risks. Ordoobadi (2009) observes that the common characteristic of ranking the available alternatives in services selection processes is based on two factors: the providers' performance on decision-making criteria and the relative interpolation weight of these criteria. It is discovered that both factors may be subjective based on the decision-makers' perspectives and the importance of the criteria to their organizations goals, especially for qualitative criteria.

The AHP, like other classical decision making methods assume that the decision maker would be able to provide exact assessments when comparing criteria and the available alternatives. However, due to uncertainty, incompleteness and subjectivity of the information, it is difficult to provide exact judgements as qualitative experts' opinions expressed through verbal judgements may mean different level of risk for different persons. Moreover, these classical decision making methods, have been criticised for simplifying the decision process by forcing the decision maker to express their view on crisp numeric scale (Zheng et al., 2012; Piltan et al., 2012). Interestingly, fuzzy explicitly resolves these uncertainty, subjectivity and vagueness of experts' opinions by considering the underlying cause-and-effect relationships within the problem complexity in aiding the conversion of the verbal scales into

numeric values that offer a consistency analysis. A risk assessment and decision-making platform built on a fuzzy logic system can provide consistency when analyzing risks with limited data and knowledge. It allows people to focus on the foundation of risk assessment, which involves the cause-and-effect relationship between key factors as well as the exposure for each individual risk. Rather than a direct input for the likelihood and potential severity of a risk event, it encourages human reasoning from the facts and knowledge to the conclusion in a consistent and well-documented way.

This work is therefore proposing a combination of the classical multi-criteria decision making method of AHP with the Fuzzy's ability and flexibility of handling imprecise and nonlinear functions of arbitrary complexity (Chai et al., 2013).

### **FUZZY-ANALYTIC HIERARCHY PROCESS**

Fuzzy-AHP method represents the fusion of a standard AHP method into the fuzzy domain by using fuzzy numbers for evaluation (Petkovic, 2012; He et al., 2012). The method was introduced by Laarhoven and Pedrycz (Laarhoven and Pedrycz, 1983). AHP as a multi-criteria decision making method takes the pair-wise comparisons of different alternatives with respect to various criteria and provides a decision support tool for multi criteria decision problems. In the AHP model, the objective is in the first level, the criteria and sub-criteria are in the second and third levels while the alternatives are found in the fourth level (Kilincici and Onal, 2011).

In Fuzzy-AHP, the pair wise comparisons of the criteria and the alternatives are performed through the linguistic variables, which are represented by triangular numbers otherwise known as fuzzy scale (Kilincici and Onal, 2011). Laarhoven and Pedrycz (1983) performed the first fuzzy AHP applications in which the triangular membership functions for the pair wise comparisons were defined. Afterwards, Buckley (1985) went further by determining the fuzzy priorities of comparison ratios having triangular membership functions. A new technique of using triangular numbers in the pair-wise comparisons was introduced in 1996 by Chang (Chang, 1996). The method has systematically solves major selection problems by using the concepts of fuzzy set theory and hierarchical structure analysis, thereby inheriting the strengths of both Fuzzy and AHP methods (Alessio, 2014).

There are many applications of Fuzzy-AHP in various fields including; personnel selection (Güngör, 2009), weapon selection (Dağdeviren & Yüksel, 2009), energy alternatives selection (Kahraman & Kaya, 2010), job selection (Kilic & Cevikcan, 2011), washing machine selection (Killincci and Onal, 2011)

and performance evaluation systems (Kilic & Cevikcan, 2012).

Going by the literature review of the existing cloud providers' selection processes based on the evaluation of the public cloud service providers' risks, and considering the multi criteria structure of the problem coupled with the performance of the Fuzzy-AHP method in other applications area, such as, in the selection of products and services, it is the opinion of this researcher that Fuzzy-AHP is a more suitable method of assessing the public cloud providers' associated risks for the purpose of selecting the best alternative. Although, there are various techniques embedded in Fuzzy-AHP, however, this study adapts the Buckley's methods (Buckley, 1985) in determining the relative risk weights for both the criteria and the alternatives following the under listed steps:

**1<sup>st</sup> Step:** Decision Maker compares the criteria or alternatives via linguistic terms shown in Table 1.

**Table 1: Linguistic terms and the corresponding triangular fuzzy numbers**

Saaty Scale	Definition	Fuzzy Triangular Scale
1	Equally Risky (Eq. R.)	(1, 1, 1)
3	Weakly Risky (W. R.)	(2, 3, 4)
5	Fairly Risky (F. R.)	(4, 5, 6)
7	Strongly Risky (S. R.)	(6, 7, 8)
9	Absolutely Risky (A. R.)	(9, 9, 9)
2	The intermittent values between two adjacent scales	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

In accordance with the triangular fuzzy numbers in linguistic terms, if the "Criterion 1 (C<sub>1</sub>) is considered Strongly Risky than Criterion 2 (C<sub>2</sub>)", then the fuzzy triangular scale is taken as (6, 7, 8). On the contrary, in the pair wise contribution matrix of the criteria, comparing C<sub>2</sub> to C<sub>1</sub> will take the fuzzy triangular scale of (1/8, 1/7, 1/6).

The equation 1 shows the pair wise distribution matrix, where D<sub>ij</sub> indicates the preference of i<sup>th</sup> criterion over j<sup>th</sup> criterion via fuzzy triangular numbers. For example, D<sub>12</sub> represents the preference of first criterion over second criterion, which is represented in triangular number as (6, 7, 8).

$$\bar{A} = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & \dots & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{bmatrix} \dots\dots\dots 1$$

**2<sup>nd</sup> Step:** The geometric mean of fuzzy comparison values of each criterion in triangular values is obtained using the equation 2 (Buckley, 1985).

$$r_i = \left( \prod_{j=1}^n d_{ij} \right)^{1/n}, \quad i=1, 2, \dots, n \dots\dots\dots 2$$

**3<sup>rd</sup> Step:** The fuzzy weight of each criterion are obtained with equation 3, by finding the vector summation of each r<sub>i</sub> and the (-1) power of summation vector. Then, arrange the fuzzy triangular number in an increasing order.

$$w_i = r_i \otimes (r_1 \oplus r_2 \oplus \dots \oplus r_n)^{-1} = (lw_i, mw_i, uw_i) \dots\dots\dots 3$$

**4<sup>th</sup> Step:** The fuzzy weight of criterion in fuzzy triangular numbers (w<sub>i</sub>) are de-fuzzified through the equation 4 by centre of area method (Chou and Chang, 2008).

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \dots\dots\dots 4$$

**5<sup>th</sup> Step:** Finally, the de-fuzzified weight of criterion (M<sub>i</sub>) is normalized (N<sub>i</sub>) using the equation 5.

$$N_i = \frac{M_i}{\sum_{i=1}^n M_i} \dots\dots\dots 5$$

These stated steps are performed to find the normalized weights of both the criteria and the available alternatives. By multiplying each alternative weight with related criteria, the risk values for each alternative is obtained. These values are then available for the decision makers to guide their decisions. The alternative with the highest risk value is considered as the alternative with the highest risk while the alternative with the lowest risk value represents the alternative with the lowest risk. Therefore, the risk values of the alternatives represent the alternatives' risk ranking.

**APPLICATION OF FUZZY-AHP IN PCS PROVIDERS SELECTION**

The Fuzzy-AHP technique is applied in an insurance company that provides general insurance, life insurance, health insurance, pension and assets management services in Nigeria to assist the organization in the selection process of its new public cloud service provider for "Business Continuity Management". In the selection process, the organization shortlisted four major public cloud providers (names withheld) otherwise refers to in this

paper as alternatives and based the risk factors on five criteria of Asset Cost, Service History, Service Location, Adopted Technology and the People (Users) with sub-criteria as described by the

organization. The weights of both the criteria and the alternatives were determined to arrive at the risk values of the alternatives.

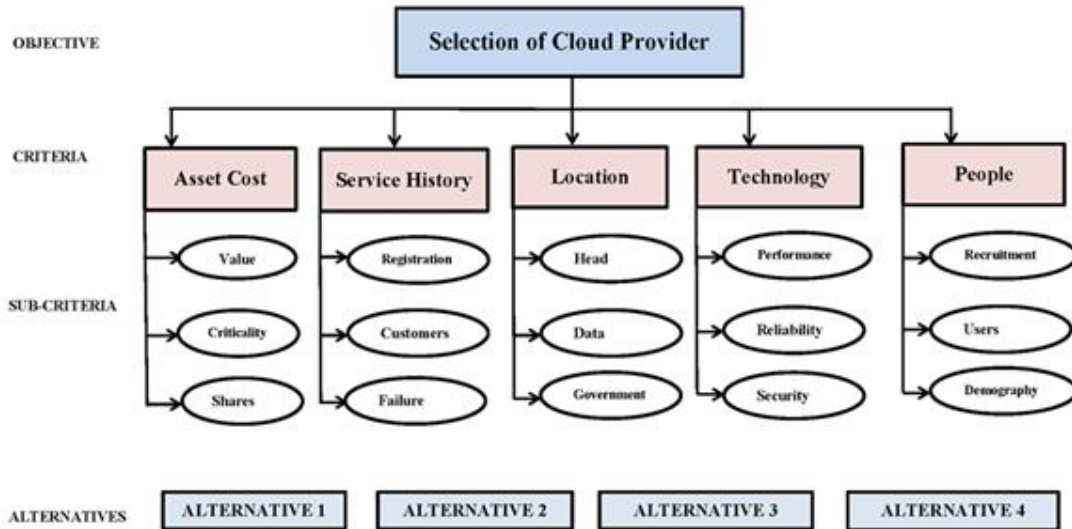


Figure 1: The Hierarchy of the Criteria and the Alternatives

**Determination of the Weights of Criteria**

In determining the criteria and evaluate the alternatives for the selection process, the decision makers preferences were presented based on the

established criteria in linguistic term (definition) which is further transfer to triangular fuzzy number format, the averaged pair wise comparison of the criteria is as represented in table 2.

**Table 2: Comparison Matrice for Criteria**

CRITERIA	Asset Cost	Service History	Location	Technology	People
Asset Cost	(1, 1, 1)	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)	(9, 9, 9)
Service History	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/6, 1/5, 1/4)	(2, 3, 4)	(4, 5, 6)
Location	(1/8, 1/7, 1/6)	(4, 5, 6)	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)
Technology	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/6, 1/5, 1/4)
People	(1/9, 1/9, 1/9)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(4, 5, 6)	(1, 1, 1)

At this stage, the geometric mean of fuzzy comparison values of each criterion in triangular values is calculated. Taking “Asset Cost” criterion as an example, the geometric mean of fuzzy comparison values of “Asset Cost” criterion ( $r_i$ ) is calculated as follow:

$$r_i = \left( \prod_{j=1}^n d_{ij} \right)^{1/n}$$

$$r_i = [(1*2*6*4*9)^{1/5}; (1*3*7*5*9)^{1/5}; (1*4*8*6*9)^{1/5}]$$

$$r_i = [3.37; 3.94; 4.44]$$

The same approach is used to obtain the geometric mean of fuzzy comparison values of the other four criteria.

Therefore, the geometric means of fuzzy comparison values of all the five criteria, including the total values and the reverse (power of -1) values are obtained. More so, the geometric means of fuzzy comparison values is conventionally in ascending order, the order of the values is rearranged as shown in table 3.

**Table 3: Geometric Means of Fuzzy Comparison Values**

CRITERIA	$r_i$		
Asset Cost	3.37	3.94	4.44
Service History	0.80	1.00	1.25
Location	1.52	1.78	2.05
Technology	0.26	0.30	0.38
People	0.41	0.47	0.53
Total	6.36	7.49	8.65
Reverse (Power of -1)	0.16	0.13	0.12
Order Arrangement	0.12	0.13	0.16

In the 3<sup>rd</sup> step, the fuzzy weight of the “Asset Cost” criterion is obtained using the equation 3.

$$w_i = r_i \otimes (r_1 \oplus r_2 \oplus \dots \oplus r_n)^{-1} = (lw_i, mw_i, uw_i)$$

$W_i = [(3.37*0.12); (3.94*0.13); (4.44*0.16)]$   
 $W_i=[0.404; 0.512; 0.710]$

The same approach is used to obtain the fuzzy weight values of the other four criteria. Hence the relative fuzzy weights of each criterion are given in table 4.

**Table 4: Relative Fuzzy Weights of the Criteria**

CRITERIA	$w_i$		
Asset Cost	0.404	0.512	0.710
Service History	0.096	0.130	0.200
Location	0.182	0.231	0.328
Technology	0.031	0.039	0.061
People	0.049	0.061	0.085

In the 4th step, the relative non-fuzzy weight of each criterion ( $M_i$ ) is calculated using the centre of area method by taking the average of fuzzy numbers for each criterion (equation 4), while the relative non-fuzzy weight of each criterion is normalized ( $N_i$ ) in the 5<sup>th</sup> step using the equation 5. Taking the “Asset Cost” criterion as an example:

Relative Non-Fuzzy Weight (Asset Cost)

$$M_i = \frac{lw_i + mw_i + uw_i}{3}$$

$$M_i = \frac{0.404 + 0.512 + 0.710}{3} = 0.542$$

**Table 6: Comparison Matrice of Alternatives with Respect to “Asset Cost” Criterion**

ALTERNATIVES	A1	A2	A3	A4
A1	(1, 1, 1)	(1/8, 1/7, 1/6)	(9, 9, 9)	(4, 5, 6)
A2	(6, 7, 8)	(1, 1, 1)	(2, 3, 4)	(1/6, 1/5, 1/4)
A3	(1/9, 1/9, 1/9)	(1/4, 1/3, 1/2)	(1, 1, 1)	(6, 7, 8)
A4	(1/6, 1/5, 1/4)	(4, 5, 6)	(1/8, 1/7, 1/6)	(1, 1, 1)

The geometric mean of fuzzy comparison values of each alternative in respect to “Asset Cost” criterion in triangular values is calculated using equation 2, taking the alternative A1 as an example as follow:

$$r_i = \left( \prod_{j=1}^n d_{ij} \right)^{1/n}$$

Normalized Relative Non-Fuzzy Weight (Asset Cost)

$$N_i = \frac{M_i}{\sum_{i=1}^n M_i} = \frac{0.542}{0.404 + 0.096 + 0.182 + 0.031 + 0.049} = 0.711$$

The relative non-fuzzy weight ( $M_i$ ) and normalized relative weights ( $N_i$ ) of each criterion is represented in the table 5.

**Table 5: Averaged and Normalized Relative Weights of Criteria**

CRITERIA	$M_i$	$N_i$
Asset Cost	0.542	0.711
Service History	0.142	0.186
Location	0.247	0.324
Technology	0.044	0.057
People	0.065	0.085

**Determination of the Weights of Alternatives with Respect to Criteria**

Having obtained the normalized non-fuzzy relative weights for criteria, the same methodology is applied to find the corresponding values for the alternatives, that is, the normalized non-fuzzy relative weights of the alternatives. The alternatives are pair wise with respect to each particular criterion. This means that, the following procedure is to be repeated for all the five criteria, however, because of space, only the analysis for the “Asset Cost” criterion will be presented herein, although, the results for the alternatives with respect to all the five criteria are represented. The pair wise comparison of alternatives with respect to “Asset Cost” criterion is presented in table 6.

$$r_i = [(1*0.125*9*4)^{1/4}; (1*0.143*9*5)^{1/4}; (1*0.167*9*6)^{1/4}] = [1.46; 1.59; 1.73]$$

The same approach is used to obtain the geometric mean of fuzzy comparison values of the other alternatives and the results are as represented in table 7.

**Table 7: Geometric Means of Alternatives with Respect to “Asset Cost” Criterion**

ALTERNATIVES	$r_i$		
A1	1.46	1.59	1.73
A2	1.20	1.43	1.68
A3	0.64	0.71	0.82
A4	0.54	0.62	0.71
Total	3.84	4.35	4.94
Reverse (Power of -1)	0.26	0.23	0.21
Order Arrangement	0.21	0.23	0.26

The fuzzy weights of alternatives in respect to “Asset Cost” Criterion in triangular values are calculated using equation 3 and taking alternative A1 as an example:

$$w_i = r_i \otimes (r_1 \oplus r_2 \oplus \dots \oplus r_n)^{-1}$$

$$= (lw_i, mw_i, uw_i)$$

$$W_i = [(1.46*0.21); (1.59*0.23); (1.73*0.26)]$$

$$W_i = [0.307; 0.366; 0.450]$$

**Table 8: Fuzzy Weights of Alternatives with Respect to “Asset Cost” Criterion**

ALTERNATIVES	$w_i$		
A1	0.307	0.366	0.450
A2	0.252	0.329	0.437
A3	0.134	0.163	0.213
A4	0.113	0.143	0.185

**Table 10: Normalized non-fuzzy relative weights of each alternative for each criterion**

ALTERNATIVES	Asset Cost	Service History	Location	Technology	People
A1	0.363	0.148	0.325	0.127	0.246
A2	0.329	0.231	0.518	0.082	0.185
A3	0.165	0.096	0.294	0.053	0.201
A4	0.143	0.052	0.377	0.119	0.103

By using table 5 and table 10, the individual weight values of each alternative for each criterion, and the subsequent risk value for each alternative are presented in table 11.

**Risk Value for A1**

$$RV = [(N_{i(criteria)1} * N_{i(alternative)1}) + (N_{i(criteria)2} * N_{i(alternative)2}) + (N_{i(criteria)n} * N_{i(alternative)n})]$$

$$RV = (0.711*0.363) + (0.186*0.148) + (0.324*0.325) + (0.057*0.127) + (0.085*0.246)$$

$$RV = 0.258 + 0.028 + 0.105 + 0.007 + 0.021$$

$$RV = 0.419$$

The non-fuzzy weight ( $M_i$ ) and normalized non-fuzzy weight ( $N_i$ ) values are obtained by using centre of area

method of equation 4 and 5 respectively using alternative A1 as an example in respect to “Asset Cost”. The same approach is repeated for the other alternatives and the results are represented in table 9 Relative Non-Fuzzy Weight (Asset Cost)

$$M_i = \frac{lw_i + mw_i + uw_i}{3}$$

$$M_i = \frac{0.307 + 0.366 + 0.450}{3} = 0.374$$

Normalized Relative Non-Fuzzy Weight (Asset Cost)

$$N_i = \frac{M_i}{\sum_{i=1}^n M_i}$$

$$N_i = \frac{0.374}{0.374 + 0.339 + 0.170 + 0.147} = 0.363$$

**Table 9: Averaged and Normalized Relative Weights of Alternatives**

ALTERNATIVES	$M_i$	$N_i$
A1	0.374	0.363
A2	0.339	0.329
A3	0.170	0.165
A4	0.147	0.143

Following the same steps for the alternatives in respect to other criteria of “Service History”, “Location”, “Technology” and “People”, the normalized non-fuzzy weights of each alternative for each criterion are represented in table 10.

The risk values of the alternatives is estimated by multiplying each alternative weight with related criteria weights and the values summation is derived, taking the alternative A1 as an example. The same

approach is adopted for all the other alternatives.

**Table 11: Aggregated results for each alternative according to each criterion**

CRITERIA	Weights	Risk Values of Alternatives with Respect to Related Criterion			
		A1	A2	A3	A4
Asset Cost	0.711	0.363	0.329	0.165	0.143
Service History	0.186	0.148	0.231	0.096	0.052
Location	0.324	0.325	0.518	0.294	0.377
Technology	0.057	0.127	0.082	0.053	0.119
People	0.085	0.246	0.185	0.201	0.103
<b>Total</b>		<b>0.419</b>	<b>0.508</b>	<b>0.250</b>	<b>0.248</b>

From the result in table 11, the alternative 2 has the largest total risk value of 0.508 while the alternative 4 has the lowest total risk value of 0.248. The implication from the results is that it is highly risky for the specified consumer to engage the alternative 2 and least risky for the specified consumer to engage the alternative 4. Therefore, the alternative 4 is suggested as the best service provider among the four (4) alternatives with respect to the five (5) criteria and the fuzzy preferences of decision makers.

**CONCLUSION**

The daily rise in the adoption of cloud computing services by individuals and organizations couple with the increase in the number of the cloud computing services providers has brought up the pursuit for a reliable approach of assessing the risks of adopting the technology and in particular in selecting a particular service provider among multiple alternatives based on various criteria. Since these criteria conflict each other with different preferences from the prospective services consumers, the alternative providers should be effectively assessed in terms of the risks associated with each of them.

In achieving a better assessment of the alternatives' risks, this study proposes the Analytical Hierarchy Process (AHP) technique that is embedded with fuzzy approach, as the decision makers' preferences depend on both tangible and intangible criteria, such vague linguistic variables can effectively be represented by Fuzzy Set Theory.

Therefore, the hybrid approach is designed to provide a more accurate and reliable risks assessment of the public cloud services providers to select the best provider among the alternatives. The approach is applied for the aforementioned public cloud service consumer with respect to five (5) criteria namely; Asset Cost, Service History, Location, Technology and People.

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