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ABSTRACT

Cloud computing has emerged as a result of continuous development in the field of information technology. It is expected that most of the enterprises will adopt this new computing model in the near future. There are three main deployment models in cloud computing, namely, public, private, and hybrid cloud. To implement the cloud service, enterprises have to choose one of these deployment models. The purpose of this paper is to suggest a decision model for cloud computing deployment. To that end, this paper uses the analytic hierarchy process (AHP) and benefit-cost-opportunity-risk (BCOR) analysis to select the best cloud computing deployment model with a holistic view based on the benefit, cost, opportunity, and risk factors. The results of this study will be useful for managers who have the intention to adopt cloud computing for their organization.

Keywords

Cloud Computing, Analytic Hierarchy Process (AHP), Benefit-Cost-Opportunity-Risk (BCOR)

INTRODUCTION

Recently some enterprises are adopting cloud computing as an alternative to the client-server model because of many reasons. Irrespective of the type of services or application, all enterprises have to choose one of the following three deployment models in order to implement a cloud computing solution. These models are public, private, and hybrid cloud. Depending upon the specific requirements, context, and the capability of enterprises, they can adopt different cloud computing deployment models. Thus, the important issue is how to choose the best deployment model considering various factors based on the business strategy. Since cloud computing is a new concept and most enterprises don't have enough knowledge about it, this might be a difficult issue to handle. The purpose of this paper is to present a practical decision model considering the various aspects of cloud computing. The decision model can provide a better understanding of the challenges, chances, and obstacles of cloud computing deployment, especially for the three deployment models of cloud computing. To that end, this paper uses the analytic hierarchy process (AHP) and benefit-cost-opportunity-risk (BCOR) analysis to select the best cloud computing deployment model from the holistic view based on benefit, cost, opportunity, and risk factors. The results of this study will be useful for managers who have the intention to adopt cloud computing for their organization.

LITERATURE REVIEW

AHP and BCOR Analysis

The Analytic Hierarchy Process (AHP) is a general theory of measurement (Saaty, 2001a) which depends on values and judgments of individuals and groups. It has been widely applied to multi-criteria decision making, planning and resource allocation, conflict resolution, and prediction problems in many fields.

The core of the AHP is to construct a hierarchy of the problems and to use pairwise comparison between alternatives. AHP provides decision makers with a way to transform subjective judgments into objective measures. AHP has been applied to many decision making scenarios based on the benefit-cost-opportunity-risk (BCOR) analysis. In BCOR analysis, the first step is to construct benefit, cost, opportunity, and risk hierarchies separately. And then, by taking the BCOR ratio for each alternative, the alternative with the highest ratio would be the optimal choice. Practitioners can apply different forms of BCOR analysis according to the business strategy, for example simple BC (benefit-cost), BCO (more positive), BCR (more negative) or BCOR (more holistic) (Sarkis et al., 2011).

There are several papers using BCOR analysis for solving practical problems or suggesting new applications. Kengpol and O'Brien (2001) integrated the BC model, the decision-making effectiveness model and a common criteria model for selecting Time Compression Technologies (TCT) to help the firm achieve rapid product development such as rapid prototyping. Tummala et al. (1999) also used BC for an evaluation of the success factors in implementing ISO 14001 based EMS and deciding whether to implement it or not. Besides, the trend to combine BCOR with other methodologies is becoming a common practice (Wijnmalen, 2007). For instance, Erdogmus et al. (2005) used AHP together with BCOR and multi-actors for evaluating high-tech alternatives. Also researchers created AHP framework including BCOR with approximately 50 different factors for finding the best policy in offshore outsourcing from the policy maker's perspective (Tjader et al., 2010).

Cloud Computing

Cloud computing is not a new information technology. Instead, it is a model for providing IT services to meet a certain set of requirements. In simple terms, it is a new way to organize and operate the resources in the Internet environment by adopting several existing technologies (Weiss, 2007) such as virtualization, service-oriented architecture (SOA), autonomic computing (Sterritt, 2005) and gird computing (Baker et al., 2002). The unique contribution of cloud computing that differentiates it from the other innovations in IT is helping to deliver IT applications and services to the user anytime, anywhere, any computer. This is the reason why it is commonly referred to by some scholars as a public utility such as water or electrical power. According to NIST (Mell and Grance, 2009), cloud computing contains five essential characteristics, three service models and four deployment models (Figure 1). This working definition seems to have captured the commonly agreed aspects of cloud computing (Khajeh-Hosseini et al., 2010).

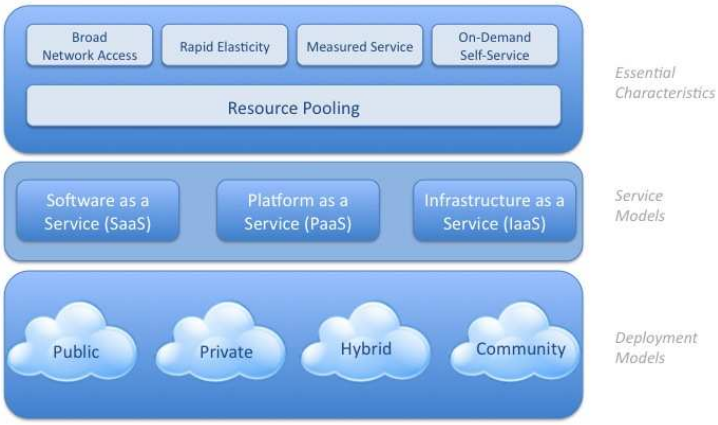

Figure 1. Visual Model of Cloud Computing from NIST

Currently, the research on cloud computing with respect to its definition, features, underlying technologies, benefits, risks, and challenges are continuously being refined to give a comprehensive and unified picture for cloud computing in the future.

RESEARCH MODEL

There are a number of methodologies for decision making support, but AHP emerges as the most popular and prominent methodology due to its effectiveness and ease of use. Among many different approaches, AHP, BCOR methods have been selected to be used as the research methodology. As cloud computing is still in its developing process, BCOR is a good choice to consider. This technique can allow us to judge in a careful and comprehensive way, by taking into account the cloud computing potentials and instability. Moreover, it seems there is no existing study addressing the same problem and applying the same methodology in cloud computing research area. Therefore, it is the necessity and the helpfulness that act as the motivation to perform this research. The hierarchy from each dimension: benefit, cost, opportunity and risk can be seen in Figures 2, 3, 4 and 5 respectively.

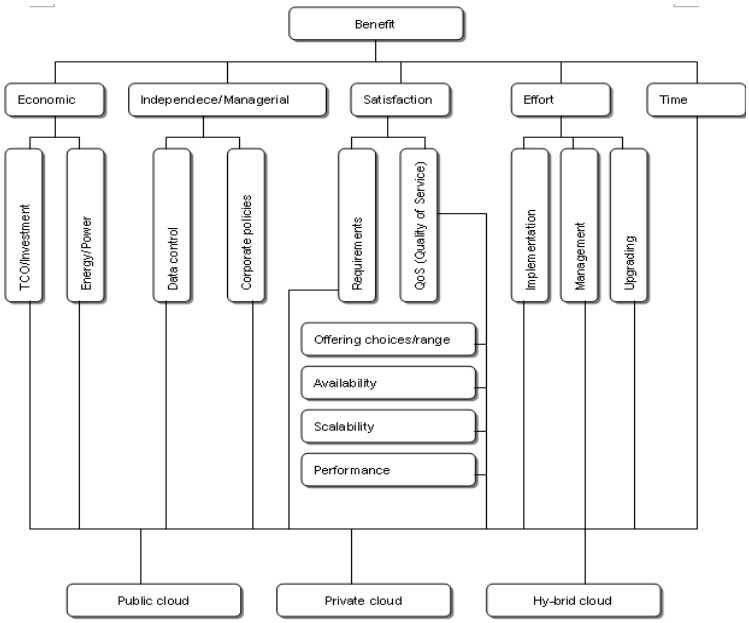

Figure 2. Benefit Hierarchy for Selecting the Optimal Cloud Deployment Model

Benefit Hierarchy

The hierarchy for the benefit aspect contains four levels, from general criteria to specific criteria, respectively, and the lowest level is the alternatives. The benefit model considers which advantages, or utility that the adopter can benefit from by implementing one of three alternatives. The first (highest) level includes five fundamental benefit criteria. From these criteria, they break into more particular sub-criteria in the second level for the ease of evaluation for the practitioners. Next, certain sub-criteria that need to be defined more clearly are structured into smaller concerns in the third level. The criteria and the sub-criteria are briefly discussed below.

- **Economic**. This criterion is one of the basic and most important benefit of cloud computing. It refers to the efficiency in economic aspect when implementing the specific deployment model. It has two sub-criteria.
  a. **TCO (Total cost of ownership)/Investment**. This sub-criterion represents the costs for setting up and maintaining a cloud (Li et al., 2009). It consists of hardware, software, IT resources to manage the application and any internal charges from the firm's IT department for hosting the application or appliance.
  b. **Energy/Power**. Energy management and costs for providing adequate power and cooling systems is important to consider when deciding to adopt cloud computing for the system. Hamilton's research (2009), pointed out that the cost of powering and cooling accounts for 53% of the total operational expenditure. There will be a big difference in energy benefit between three deployment forms of cloud computing.
- **Independence/Managerial**. The second main criterion refers to the independence or freedom of the organization from managerial perspective after adopting cloud computing. It contains self-reliance in the two aspects below.
  a. **Data control**. This deals with the management privilege of the users on their own data
  b. **Corporate policies**. Each organization has its own rules for operating and managing IT, and doing business within the organizational scope. This sub-criterion refers to the managerial benefit in case the leaders can enforce their agency regulations.
- **Satisfaction**. This third general criterion focuses on the beneficial side of feeling when the enterprise needs are met and satisfied. It is characterized by two concrete sub-criteria.
  a. **Requirements**. Depending on the distinctive situation of each enterprise, they will have different requirements. This sub-criterion evaluates the degree of company satisfaction based on how much their requirements are met by every deployment model.

b. **QoS (Quality of Service)** (Braunwarth and Heinrich, 2008). It has several specific measurements.

i. **Offering range/choice**. In a cloud computing environment, the service offered by service providers can be defined, adjusted according to the needs of the user. Beside the service items, there are also time, quality and performance requirements provided with the service. Generally, these agreements are referred to as Service Level Agreements (SLA) (Kandukuri et al., 2009)."

ii. **Availability** (Armbrust et al., 2010; Martens et al., 2011). This measurement refers to the extent to which the new systems deployed using the three models are always in a ready state to serve and perform their functions. Besides confidentiality and integrity, availability is evaluated on the three most common IT security objectives (Bishop 2002).

iii. **Scalability**. Cloud computing is scalable without depending on geographical locations and hardware performance. This is sometimes called surge computing (Armbrust et al., 2009). All organizations change their needs with time, so the ability to scale up or down to fit the applied model is critical.

iv. **Performance**. This is a concern of general measurement and it refers to the common performance of the whole system. There are a lot of standards to judge the performance of one system, for example the productivity, the speed of data transfer, the storage capacity, the response time, etc.

- **Effort**. The fourth main criterion refers to the benefit gained based on the effort. This criterion is concerned about personnel aspect rather than the monetary side. It is divided into detailed types efforts as follows:

a. **Implementation**. The effort spent to fully implement the solution, e.g. building the system structure, negotiating.

b. **Management**. It represents the attempt to manage, control and master the built system.

c. **Upgrading**. In addition to maintaining the system, it needs to be upgraded to keep up and achieve more tasks . This would require more effort from the organization and is dependent on deployment models.

- **Time**. The last main criteria shows the benefits achieved from saving time for applying one specific cloud model. This could include deployment time, delivery time, or provisioning cycle time, etc. In our high-paced society, the less time we spend, the more advantages we get.

Cost Hierarchy

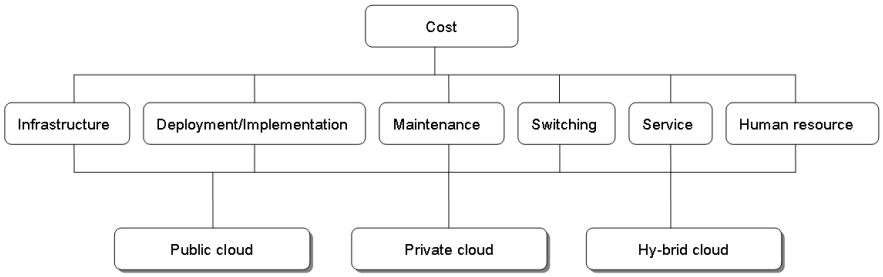

Figure 3. Cost Hierarchy for Selecting the Optimal Cloud Deployment Model

The hierarchy for cost is simpler than the benefit hierarchy. It just has one level that corresponds to the criteria and the lower level which corresponds to the alternatives. There are six different types of costs incurred, as shown below.

① **Infrastructure**. This is the cost to facilitate IT infrastructure and equipment to implement cloud computing, for example servers, storage devices, wire system, etc.

② **Deployment/Implementation**. It refers to the expense for fulfilling cloud computing deployment task. Based on the distinct features of the selected cloud model, the enterprises can spend different amounts of money.

③ **Maintenance** (Martens and Teuteberg, 2011). After completing cloud adoption, the important task is to maintain it and ensure system stability. Maintenance cost includes energy cost for supplying electricity, renewing the hardware, data transfer costs, auditing (Armbrust et al., 2010; Martens et al. 2011), etc.

④ **Switching**. If there is a situation like changing the vendor or shifting the cloud model that the organization should think about, this would lead to switching costs such as integration costs (Martens et al., 2011) and some problems that will be pointed out in the risk hierarchy.

⑤ **Service**. Except for the above costs, occasionally the organization uses the other services for cloud system such as training or learning new knowledge of cloud computing, consulting cost, etc. There could be some unexpected services occurring during adoption and usage.

⑥ **Human resource**. The last cost is to invest in human resource of the company to be responsible and to manage the above mentioned tasks. This cost also changes for every cloud computing model.

Opportunity Hierarchy

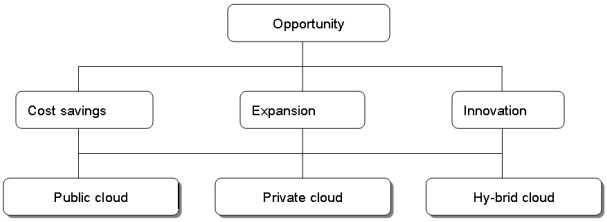

Figure 4. Opportunity Hierarchy for Selecting the Optimal Cloud Deployment Model

The opportunity model contains three primary options.

1) **Cost savings**. It refers to the opportunity for saving costs in the future while continuously using that cloud computing model. This is the kind of model that could have high implementation costs, but is profitable for long time usage while the other is just the opposite. Several savings can be listed such as lower operating cost, extending expenditures, renew or fix IT infrastructure expenses.

2) **Expansion**. This is the ability that the system can facilitate easy reallocation of resources (e.g., networks, servers, storage, applications, services), as needed (Petkovic, 2010). When the business requirements of a company change, the system which is quickly adaptive and responsive will bring advantages for the owner, especially the competitive competence.

3) **Innovation**. Cloud computing is promising to provide valuable benefits for the adopter in the future. Operating organization's business within the cloud computing environment may help the organization not only to keep pace with the rapid changes but also create and obtain the innovative opportunities.

Risk Hierarchy

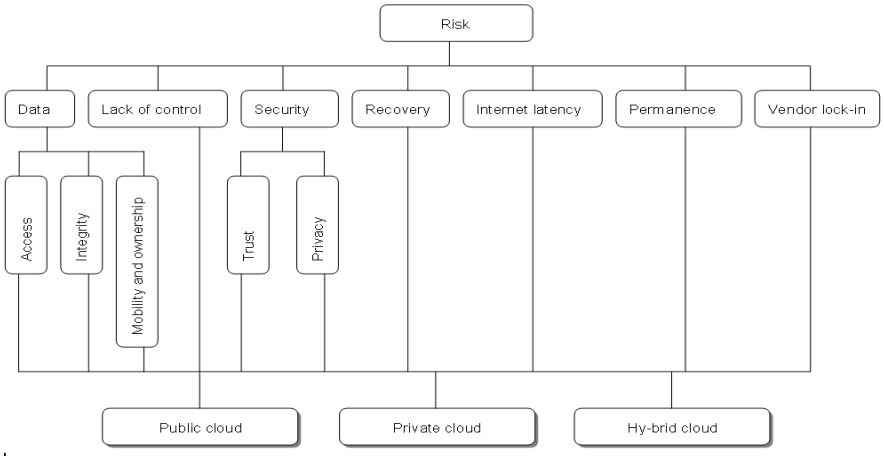

Figure 5. Risk Hierarchy for Selecting the Optimal Cloud Deployment Model

The risk hierarchy is a little bit complicated compared to the cost and opportunity hierarchy because "cloud computing services are exposed to a high degree of risks that result from technical issues" (Martens and Teuteberg, 2011). It has three levels; the principal criteria, sub-criteria and the alternatives, respectively. It is concerned about the following issues.

1) **Data**. Data is always paramount in majority of IT applications, not just in cloud computing. Nevertheless, this concern becomes more and more crucial in cloud computing, by the diversity of implementation form and service provided. The risk related to data could be classified into these issues.

   a. **Access** (Guo et al., 2010; Jun and Sha-sha, 2011). Organizations should be careful in protecting their data access rights. Especially in case of a public cloud, the adopter often has to worry about the illegal and unauthorized data access by the provider or third party, such as hackers. "Storing the company's data on the service provider's equipment raises the possibility that important business information may be improperly disclosed to others (Hawthorn, 2009)."

   b. **Integrity** (Guo et al., 2010). This is concerned with the occurrence of sudden troubles or unexpected incidents such as broken hardware, power supply damage that leads to the potential loss of data integrity. Therefore, it requires the well-prepared solutions together with the reasonable recovery function to deal with these problems. It is considered one of the three most common IT security objectives (Bishop 2002; Martens and Teuteberg, 2011).

   c. **Mobility and ownership** (Jun and Sha-sha, 2011). The user should know clearly about the data sharing or data integration policy of vendors between clouds, as well as the data migration rule to ensure the continuous working on the new service and the data ownership. Will the data be removed or still kept after ending the service? Moreover, the complexity of the cloud can make the solution more difficult to execute, thereby leading to more risks..

2) **Lack of control**. It refers to the concern about the incomplete control of sensitive data and personal information, especially in large organizations and public cloud adoption. "What are the political implications for organizations that lose control over some aspects of their services?" (Khajeh-Hosseini et al., 2010). Furthermore, in case of using cloud computing from many providers, how will the responsibility be handled (Kaufman, 2009)?

3) **Security** (Guo et al., 2010; Petkovic, 2010; Gupta et al., 2008). The security threats will be far higher than the traditional model. It represents the need for safety and security for a cloud system. The system could be in danger by the hacker's attacks or the poor security capability of that system. It includes two concerns, as given below:

   a. **Trust**. This refers to the degree the organization believes in the service provider and that the cloud model will face the safety and security issues. For cloud computing to spread, users must have a high level of trust in the methods by which service providers protect their data.

   b. **Privacy** (John, 2010; Petkovic, 2010; Martens and Teuteberg, 2011). It refers to the extent to which the user could be private on the deployment models of cloud computing, in particular the government agencies or businesses requiring high level of confidentiality in data access and transfer such as financial transactions and online payment. Make sure a cloud service includes data encryption, effective data anonymization, and mobile location privacy." (Guo et al., 2010)

4) **Recovery**. It is concerned about the recovery capability to roll back the previous state in case of error, exception, destruction or incident. Besides the data, the system must ensure the correctness of functions and the consistency in daily operations. Because cloud computing is complex, it isn't easy to recover once a problem occurs.

5) **Internet latency**. "It is primarily about the Internet and network performance" (Petkovic, 2010). Particularly, the network bandwidth and the data transfer rate are limited to those of Internet Service Provider (ISP). It may lead to the data latency and other problems which will influence the operational activity of system, for example data transfer bottlenecks (Armbrust et al., 2010).

6) **Permanence**. For the public cloud model, the concern is how long the system survives. Is it long term or short term? And is there a sustainable survival? Moreover, there is a concern about the uncertainty particularly in rental software contracts (Singh et al., 2004) and general agreements, SLA missing or lacking important terms with respect to unpredictability, etc.

7) **Vendor lock-in**. The dependency and the tie of provider regulations is user attention worthy.

Alternatives

From the aspect of deployment, specializing in the viewpoint of publicity of usage of cloud computing, there are three types of cloud (Petkovic, 2010).

1) **Public cloud**. Cloud vendors offer their services through the Internet, for example Salesforce.com, Google App Engine, Microsoft Azure, and Amazon EC2 (Petkovic, 2010). The customer has no visibility and control over where the infrastructure is hosted. And the computing infrastructure is shared between any organizations using that service. The service based on this type of cloud computing can deliver the best economies of scale, in contrast, it can limit the configuration, SLA specificity and security due to the shared infrastructure.

2) **Private cloud**. The cloud infrastructure is owned or leased by a single organization and is operated solely for that organization (Petkovic, 2010). Thus, the service built on this cloud is inside (resides within) the firewall system of the organization and works on the private network. Private clouds are of two types: On-premise private cloud and externally hosted private cloud (or off premise). Externally hosted private cloud is also exclusively used by one organization, but is hosted by a third party specializing in cloud infrastructure while on-premise private cloud is the opposite.

3) **Hybrid cloud**. A hybrid cloud includes the services from both the private and public space with multiple options for provider. This kind of cloud is more complicated than the others and requires the customer to have to keep track the system and also ensure that all aspects of the business can communicate with each other. But it offers more flexibility than both public and private cloud, specifically the tighter control and security while still facilitating service expansion and contraction.

Figure 6 illustrates the three types of deployment model in detail, along with the main features of each cloud and the services that each deployment model can deliver. Figure 7 depicts the whole picture of cloud computing, including the three deployment models and the interaction between them in the macro context.

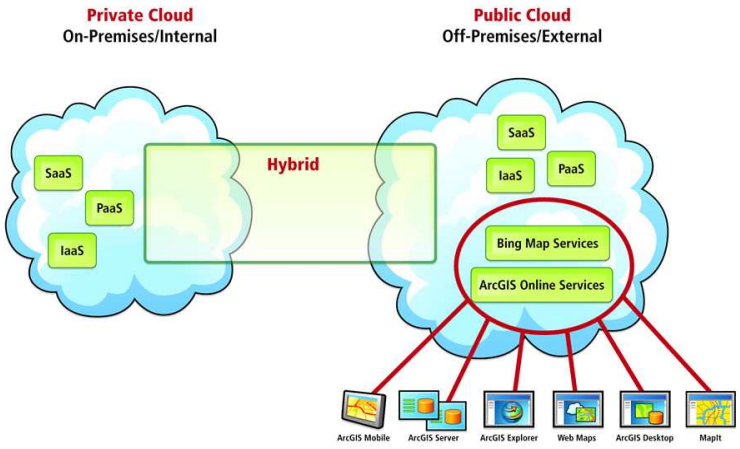

Figure 6. Three Deployment Models of Cloud Computing

NUMERICAL EXAMPLE

A sample case is shown below to illustrate the use of BCOR and how to apply our models to solve the problem intuitively. XYZ is a medium size company working on public relations. Because of the large demand on managing customer information and leveraging it most productively, the company wants to adopt customer relationship management (CRM) system. Between the traditional model client-server and new emerging paradigm - cloud computing, XYZ tends to choose cloud computing due to its promising vista, thus the company can be able to broaden its CRM system with new functions like social CRM, and catch new trends in business environment, e.g. social commerce, online user's community in the future. Given the crucial role of CRM system, the company carefully considers which approach of cloud computing service it should implement to ensure the performance and the stable development of system in long term. Hence, organization XYZ applies the BCOR framework to support the decision-making of opting for 3 models of cloud computing.

The company uses ExpertChoice software (or Super Decision software is also a good replacement). The procedure detail is modeled as follows.

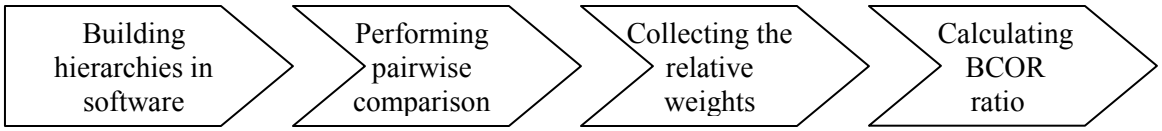

Figure 7. BCOR Analysis Steps

Because the whole process is almost executed by the software, except some important parts that need the intervention of human for building and evaluating the hierarchy, the company may not have any obstacles to perform it.

- Realizing the available hierarchies: benefit, cost, opportunity, risk associated with the software.
- Making the comparison for all the hierarchies and alternatives.
- Getting the relative weight of each alternative in every hierarchy through the automatic synthesizing function of software. Table 1 shows the priority of criteria and the relative weights of 3 alternatives according to the criteria in each model.
- Deriving the BCOR ratio of each alternative then selecting the best alternative.

Benefit	Priorities	Public cloud	Private cloud	Hybrid cloud
OC/Investment	0.088	0.731	0.188	0.081
Energy/Power	0.022	0.667	0.111	0.222
Data Control	0.137	0.072	0.649	0.279
Corporate Policies	0.046	0.085	0.644	0.271
Requirements	0.092	0.072	0.649	0.279
Offering Choices/Range	0.044	0.691	0.149	0.160
Availability	0.047	0.122	0.558	0.320
Scalability	0.022	0.625	0.136	0.238
Performance	0.164	0.100	0.466	0.433
Implementation	0.016	0.731	0.188	0.081
Management	0.059	0.731	0.081	0.188
Upgrading	0.053	0.683	0.117	0.200
Time	0.208	0.769	0.147	0.084
Final weight		0.377	0.375	0.248

Cost	Priorities	Public cloud	Private cloud	Hybrid cloud
Infrastructure	0.051	0.067	0.661	0.272
Implementation	0.185	0.061	0..353	0.586
Maintenance	0.279	0.105	0.637	0.258
Switching	0.257	0.558	0.122	0.320
Service	0.094	0.333	0.333	0.333
Human Resource	0.134	0.085	0.644	0.271
Final weight		0.246	0.407	0.346

Opportunity	Priorities	Public cloud	Private cloud	Hybrid cloud
Cost Savings	0.088	0.600	0.200	0.200
Expansion	0.243	0.140	0.528	0.333
Innovation	0.669	0.097	0.570	0.333
Final weight		0.150	0.528	0.322

Risk	Priorities	Public cloud	Private cloud	Hybrid cloud
Access	0.189	0.691	0.091	0.218
Integrity	0.031	0.683	0.117	0.200
Mobility and Ownership	0.077	0.731	0.081	0.188

Lack of Control	0.077	0.683	0.117	0.200
Trust	0.058	0.691	0.091	0.218
Privacy	0.232	0.691	0.091	0.218
Recovery	0.112	0.250	0.095	0.655
Internet Latency	0.039	0.691	0.091	0.218
Permanence	0.131	0.691	0.091	0.218
Vendor Lock-in	0.055	0.243	0.088	0.669
Final weight		0.616	0.094	0.290

Table 1. Relative Weights of the Three Alternatives with Respect to the Criteria

The company can consider among three different ratios and choose which one is the best match to their aim, then, calculating the corresponding ratio for each alternative. Table 2 is the final weights of 3 alternatives for each hierarchy and the ratios. The formulations of these ratios are given below.

- B/C = Benefit/Cost
- B/(C*R) = Benefit/ (Cost * Risk)
- (B*O)/(C*R) = (Benefit * Opportunity) / (Cost * Risk)

Alternative	Benefit	Cost	Opportunity	Risk	Standard B/C	Pessimistic B/(C*R)	Realistic (B*O)/(C*R)
Public cloud	0.377	0.246	0.150	0.616	**1.533**	**2.488**	**0.373**
Private cloud	0.375	0.407	0.528	0.094	**0.921**	**9.802**	**5.175**
Hybrid cloud	0.248	0.346	0.322	0.290	**0.717**	**2.472**	**0.796**

Table 2. Summary of the Final Weights and the Ratio Calculation

For every ratio, the alternative that has the highest value is the recommended solution. In case of Table 2, if company XYZ uses BCOR ratio, the optimal choice will be the private cloud.

CONCLUSION

By combining BCOR technique of the AHP and cloud computing, the paper suggests a selection framework to support the decision makers on the issue of type of deployment models to be applied for adopting cloud computing. This framework has four hierarchies representing four primary aspects including benefit, cost, opportunity, and risk together with various criteria. The approach to develop these selection models is from the practical view point rather than the theoretical perspective. It provides a useful, significant and comprehensive tool for managers, and CIOs to solve problems similar to this one. Furthermore, it also makes a contribution to the research field of cloud computing which doesn't have many practical and in depth studies for these issues. In addition, the results of this research also enhances the growing and evolution period of cloud computing. The given challenges, obstacles and chances could be effectively considered for better improvement and utilizing cloud computing from the vendor and user perspective.

Through the right and overall assessment of cloud computing based on well-equipped knowledge, clearly understanding the needs and the situation of the organization, users can maximize the benefits while minimizing the disadvantages, and prevent the risks. By choosing the best deployment model for the organization to use, the value of cloud computing can be improved and usher in the next bright era of IT.

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