Quantification of Quality Expressions for Cloud Migration Decision Support

By: Ashenafi Alemu

A Thesis Submitted to the

Department of Computing

School of Electrical Engineering and Computing

Presented in Partial Fulfillment for the Degree of Masters of Science in Software Engineering

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May 2018

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DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented as a partial degree requirement for a degree in any other university, and that all sources of materials used for the thesis have been dully acknowledged.

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This thesis has been submitted for examination with my approval as thesis advisor.

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Signature:____

Date of Submition:___________________

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We, the undersigned, members of the Board of Examiners of the final open defense by ___________________________________have read and evaluated his/her thesis entitled "____" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of ……………………………………

Supervisor/Advisor	Signature	Date
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External Examiner	Signature	Date

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Before all else, I would like to praise **Almighty God** and **his Mother St. Merry** for everything happened, happening and will happen in my life. And, generously speaking, it would be unimaginable to bring-forth such a study on the scene without their involvement, faith, and mystical help.

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Table of Content

List of Equations

List of Tables

List of Figures

List of Abbrivations and Acronyms

AHP	Analaytical Hierachical Process
ANSI	American National Standards Institute
ANP	Analytical Network Process
ASTU	Adama Science and Technology University
Avg	Avergage
AWS	Amazon Web Service
CPU	Central Processing Unit
DM	Decision maker
ds	Dataset
DSRM	Design Sience Research Methodology
GB	Giga Byte
Gen	Generation
GHz	Gega Hertz
IaaS	Infrastructure as a Service
IBM	International Business Machine
ICT	Information and Communication Technology
IEC	International Electronical Commision
ISO	International Organization for Standard
IT	Information Technology
KPI	Key Performance Index
Mgt	Management
Max	Maximum
$(MC^2)^2$	Multi-Criteria comparison method for cloud computing
MCDM	Multi-Criteria Decision Model
Min	Minimum
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure

MTTR	Mean Time To Repair
MYSQL	Structural Query language
NIST	National Institute of Standard and Technology
OS	Operating System
QoS	Quality of Service
PaaS	Platform as a Service
RAM	Random Access Memory
SaaS	Software as a Service
SLA	Service Level Agremeent
SMI	Service Measurement Index

Abstract

Cloud computing is an internet-based technology, that turned in premise practice of traditional computing technology to a different approach called off-promises utilization of computing infrastructure such as storage, computer and bandwidth, in pay as you go bases. This emerging technology is being adopted by varies companies. The main reason for its fast and growing acceptance is its characteristics of being omnipresent, on demand access to a shared pool of services that can be configured, provisioned and de-provisioned with a minimum configuration effort, are a few to mention. On the other hand, cloud computing spending is growing faster than expected and a large queue of cloud computing industries are being providing the service. However, beside its vast acceptance; the technology experiences limitation and drawback from both sides': customers and providers. For instance, interoperability, and lack of common service level agreement (SLA) management incurred difficulty in the provider selection process. On top of this, the functionality, which the large number of providers is providing, is the same, so that it is a means for an ambiguity to select the best provider of customers' choice. To mitigate this problem, researches have been conducted and urged that it is better to choose the best cloud provider a head than a late excuse. Although some of them addressed hybrid i.e. both the personal and objective as well as a complete judgmental approach, none of them concentrate on a complete objective assessment of provider's service, where quantification of QoS is a base. From this perspective, the underline work concentrates on quantification of cloud's QoS that are meant used for cloud migration decision support. Thus, in this study, we have selected and proposed eighteen QoS mathematical models. The eighteen criteria are selected based on twenty-five recent research papers demand while the demand threshold is set to four. Having the established mathematical model for QoS, a case study was used, with a prototype system developed for this purpose, to assimilate the importance of the proposed model and justify its discrimination power the mathematical models. In addition to the case study, the proposed method is validated against DSRM validation method, Moody and Shakes quality framework and the four principles of Osterl et al. According to the evaluation result the proposed mathematical model can discriminate cloud providers based on the QoS they possess as well as it is justified that the proposed model is complete, integral, flexible, understandable, correct, simple and abstract.

Keywords: Quantification of QoS, Decision Support System, Cloud Migration, Design Science Research Methodology (DSRM).

CHAPTER ONE

1. Introduction

1.1 Background of the Study

The introduction of cloud computing becomes a turning point, towards the current business process and the development of new paradigm. Besides, this uninventable change turned up through promising business benefits it offers as well as the technological advancement it brings by focusing on the way we design computing systems, develop applications, and leverage existing services for building software [1]. And mainly, this is because of, cloud's capability to be ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction [2], which paves the way to be adopted by organizations gigantically.

Apart from a large number of demand from consumers side, hundreds of technology companies, such as Google, Microsoft, Yahoo!, Salesforce.com, international business machine (IBM), Amazon, and others, are provisioning this promising technology [3]. However, an organization, looking to utilize services from such a large number of service providers, faces potential pros and cons. For instance, providers grant equal functionalities for their respective customers, e.g. customer might consume cloud service to host Web applications, so as it can earn a benefit such as elasticity, pay-per-use, and abundance of resources [4] of cloud features.

On the other hand, business models and their respective service offerings are defined differently by the providers. Mainly, as a result of lack of global definition for the term quality, different alternatives definitions have been given under different circumstances. Regardless of the time period or context in which quality is examined, the concept has had multiple and often muddled definitions and has been used to describe a wide variety of phenomena [5]. Apparently, cloud service providers specify their quality metrics in different type and format. For instance, the way AWS and Google Cloud address their customer service review and rating is quite different.

Furthermore, quality cannot be elaborated and determined by a single concept, but rather by multidimensional concepts. Likewise, customers viewpoint and the level of abstraction of a service quality, as well as its conventional and popularity with our daily language, foreclose its professional use. Particularly, this is where the confusion lies and boom for the user to select between alternatives based on quality that a cloud service poses.

Moreover, the adoption of cloud computing and its implementation merely depends on a variety of technical and non-technical factors [6]. Often, users are not technically competent to estimate and understand their requirements [7]. Whereas, the decision of using the cloud [8]and migrating from one service model to another service model must take the diversity of relevant criteria into account.

Then again, the set of criteria and their respective weight nevertheless varies from organization to organizations, and from case to case. In making the decision about whether to move an existing service to the cloud, one must additionally examine the expected average and peak resource utilization, especially when an application experience highly variable spikes in resource demand; the practical limits on real-world utilization of purchased equipment; and various operational costs that vary depending on the type of cloud environment being considered [9].

Challenges, due to distinct characteristics of cloud computing [7], are also the main factors of the complication in the ranking process of cloud providers. For instance, different cloud service models are provisioned by providers in the form of software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS), while all the service models have different quality of services (QoS) and performance [10].

At the same time, lack of standard service level agreement (SLA) makes, user's requirement representation and evaluation of the quality of service, difficult. A limiting element in this and other such inquiries has been the absence of an objective, consistent and repeatable definition of what constitutes a quality in cloud computing environment. Therefore, in general, choosing the right cloud provider and service model becomes a much harder task to do and not a straightforward exercise [11].

But then, many cloud selection tools and techniques have been evolving as a result of a research work. All researchers tend to meet two objectives; helping to present a market platform for cloud providers with uninterrupted services and to provide alternative cloud providers for cloud users thereby enabling them to discriminate cloud providers on the spot. Likewise, varies techniques have been introduced for the discrimination process, for instance, multi-criteria decision making

(MCDM), multi-criteria optimization technique [12] and, multi-criteria comparison method for cloud computing $(MC^2)^2$ [8] are a few to mention.

On top of this, we proposed QoS mathematical model with the aim of investigating and defining QoS expressions that are used to rank cloud providers based on QoS they possess. And also, discuss cloud selection techniques and test the discrimination power of the proposed model with analystical hieratchical proecess (AHP) multi-criteria decision-making model. Thus, as compared to previous works, the underline work dares to bring the coverage of the most important QoSs up to date with their respective metrics.

1.2 Motivation

In the specification of quality attributes, often I wish to answer how much "Good is good enough?" question, like others' discipline scholars does. For instance, during house construction, engineers precisely measure and state the quality of the house, in terms of strength, the number of class size, etc. Likewise, making critical QoS attributes measurable in the cloud community is an inevitable task for a better communication between cloud providers and their customers.

Otherwise, providers will have no clear targets to work towards, and there will be no precise criteria for judgment of required services delivered or not. On the other hand, the quantified QoSs' used to evaluate results and improve communication about complex requirements in the unambiguous and consistent way. The primary motivation is not to check whether a system is reliable or secure, but how much reliable or secure it is. Quantified expressions and QoS extension to SLA excel at expressing these ideas through its use of more than one level of achievement, which is believed to be accurate and precise to rank and communicate thoroughly.

1.3 Statement of the Problem

In the process of evaluating, ranking and selecting the best cloud provider among a large number of cloud providers, QoSs specified in the SLA play the major role [13]. However, outside of the structure of English, which is subjected to ambiguous, incomplete, and inconsistent means of expression, few methods for specifying QoS and SLA have been established.

It is a well-known paradigm that you can manage what you can measure. If one wants to achieve something in practice, then quantification and later measurement are essential first steps for making sure he/she get it. If one does not make critical performance attributes measurable, and then it is likely to be less motivating for cloud providers to find ways to deliver necessary performance levels.

As far as our knowledge, cloud computing is subjected to lack of interoperability [14], where different cloud vendors unable to provide a platform on which a single or, set of related services offered commonly. This is due to lack of standardized effort that made it difficult to move deployed services from one vendor to another [1]. Because of this, it is difficult and expensive to reconsider another vendor once the decision is made and implemented. Thus, there has to be a way that makes the selection process unambiguous, effortless, and complete, as it is far better to be safe than sorry, in this case. In order to mitigate the aforementioned problem, we raised the following research questions.

Q1. What QoS asspects should be considered in order to evaluate cloud service, and thereby rank cloud providers?

Q2. How does the hierarchical nature of the cloud QoS characteristics defined?

Q3. What are the QoS mathematical model for the purpose of the decision support?

Q4. How can we us QoS metrics in order to compare and rank cloud providers with respect to their respective QoS they possess?

1.4 Objectives

1.4.1 General Objective

The main objective of the research work is to provide a mathematical model of QoS expressions and develop a cloud provider selection prototype that will help customers to select the best cloud provider.

1.4.2 Specific Objectives

The proposed work will meet the following objectives.

- Surveying and defining important QoSs that are necessary to evaluate cloud service and rank cloud providers.
- Specifying the hierarchical nature of the QoSs
- Providing mathematical models of the QoSs.

- Ranking cloud providers based on user-provided weigh using AHP MCDM.
- Demonstrating cloud service evaluation and providers ranking with a prototype.

1.5 Methodologies

In this study, it has been identified that Design Science Research Methodology (DSRM) is used and followed. This is because, it gives a rich space starting from searching a problem which in turns identified as gaps of previous research works, and thereby, structured as the research question of the study. Moreover, it gives a natural procedure, on which solution space modeled and rectified with the developed prototype, and then, evaluation of the model will follow. In general, the steps in the methodology are described as follows.

Problem identification and motivation: On this stage, the problem is identified and justified.

Definition of the objective of a solution: Through literature review, surveying important articles, books, and other sources are inevitable steps in order to extract the QoSs, define the objective of the study for the solution.

Design and development: It is a step, in which, the solution is discussed for the specified problem. Thus, at this point in the study, mathematical representations or models of QoS expressions is generated in order to validate, use, and make sure that the evaluation of cloud service and ranking process of providers precise and accurate.

Demonstration: It is where mathematical QoS model, demonstrated with a real-world example. The test code developed using Java with NetBeans editor while the repository at the backend lifted using MYSQL.

Evaluation: Results from the experiment analyzed and used to support decision making for cloud consumer. Most importantly, the proposed work validated against mathematical quality metrics and DSRM evaluation framework and from there a conclusion is drawn to justify the impact, completeness, and importance of the proposed work.

1.6 Scope and Limitations

1.6.1 Scope

Because of a head tight schedule, the research work is limited to the quantification of the most important QoSs that are believed to be used for cloud service evaluation and thereby providers ranking. However, it is not limited to specific service models as well as deployment models.

1.6.2 Limitations

Because of the introduction of cloud service in Ethiopia is in its gestation stage, which in turn resulted in lack of domestic cloud providers and cloud users, the raw data for the proposed work is going to be extracted wtih sytematic literature review. Thus, the impact of these secondary data and drawback of the systematic literature review methods may influence the outcome of the research. Literally, Because of this, the application of the research work is viewed as a snapshot comparison among alternative cloud providers, which is mainly based on previous works.

1.7 Beneficiaries and Application of Results

The main beneficiaries of the proposed work are cloud providers, cloud users, and fellow researchers. Cloud providers provided with a market platform for their respective services in which they address their services easily as per users requirement. Whereas, cloud customers are provided with an interface that entirely simplifies their decision support in selecting the best cloud provider from the given alternatives. Likewise, the communication of cloud providers and their respective customers becomes smooth as a result of precisely defined QoS. That means, quantifying quality expression helps to make precise communication and reach consensus using numbers from both sides.

Correspondingly, customers can select the best cloud provider transparently. They are not expected to deal with the working principles and mapping of quality attributes complexity. Whereas, the time takes to discriminate cloud providers as well service model decreases exponentially.

The other beneficiaries are fellow researchers because they get a chance to replicate and extend the proposed work as well as it could be a base for other related work. On the other hand, the author gets a chance and exposed to research concept, methodology, and a way of finding a new solution scientifically.

By summarizing the above claims, the research work result can be applicable in cloud computing decision making as well as service selection, defining and enforcing service agreement, service verification, and as a milestone for a fellow researcher as well.

1.8 Organization of the Thesis

The thesis work is organized into seven chapters. The first chapter introduced the background of the thesis, motivation, statement of the problem, research questions, objectives, methodology, scope of the thesis, limitation as well as application of the result.

Chapter two of this thesis discussed literature review and related work part of the research work. In this section, overview of cloud computing, its characteristics, cloud service and deployment models are discussed. Apparently, the term quality and its popular as well as professional views have been discussed from its generic and cloud QoS perspective. AHP, which is a well known MCDM approach, introduced, just before related works, that have the same idea, are reviewed.

Chapter three has compiled the research methodology which is merely followed in the thesis work. It discussed DSRM where problem identification, the thesis objective development, the data collection method along with inclusion and exclusion criteria, QoS quantification model, implementation, evaluation as well as communication methods are discussed.

Chapter four is about development of cloud QoS quantification method. In this section, quantified categories along with their QoS that are said to be important for cloud migration decision support are selected, and then those selected QoS mathematical model is illustrated followed by the recipe of ranking procedure.

Chapter five narrated the realization of the proposed method with a real-world case study. It is where the collected key performance index (KPI) and the proposed models are exemplified with three cloud provides i.e. AWS, Microsoft Azure, and Google Cloud and one potential customer ASTU. The example is also, automated so as to enable the target customers work with the proposed model and rank providers based on its preference. Chapter six presents evaluation and discussion of the proposed model based on the developed prototype and demonstrated case study. Chapter seven, the last chapter of the thesis, talk about research conclusion, and discover future works that would be taken as further research focus from this research topic perspective.

CHAPTER TWO

2. Literature Review and Related Work

2.1 Overview of Cloud Computing

Computing is being transformed into a model consisting of services that are commoditized and delivered as a fifth utility service such as water, electricity, gas, and telephony [1]. In such a model, users access services based on their requirements, regardless of where the services are hosted. The technology is basically delivered based on the concept of dynamic provisioning, which is applied not only to services but also to compute capability, storage, networking, and information technology (IT) infrastructure in general [2].

Forty-nine years back, Leonard Kleinrock pictured the future and said that as computer networks grow up and become sophisticated, we will probably see the spread of 'computer utilities' which, like present electric and telephone utilities, will service each home and offices across the country [1]. This type of insight has emerged into reality in twenty-first centuries in which computing service is being readily available on demand just like other utilities currently available. At the same time, customers need to pay providers only when they access the underlined service.

To sum up, such a capable emerging technology is referred as cloud computing. However, controversy erupts in defining the term cloud computing. It is defined differently by different business and researchers and sometimes it is impossible to get consensus. However, current, most acceptable and used definition is National Institute of Standard and Technology (NIST) definition of cloud computing. NIST defines cloud computing as a model for rendering ubiquitous, convenient, off-premise network access to a shared pool of configurable computing resources in the fashion of rapidly provisioned and released with minimal interaction from the consumer side.

It is worthwhile to bring here, customers view of the term cloud computing as reported in [1], customers view cloud technology and respond in a such a way that I don't care where my servers are, who manages them, where my documents are stored, or where my applications are hosted. I just want them always available and access them from any device connected to the Internet. And I am willing to pay for this for as long as I need it.

2.2 Characteristics of cloud computing

NIST has lifted the nature of cloud service with five essential characteristics that are considered as important and unique features of cloud computing as compared to the old IT technology that possesses asset-based physical resources management, from that of cloud computing approaches, which in turn possess service based virtual resources. The following lists describe the five characteristics briefly.

i. On-demand self-service: - refers to the characteristic that encapsulates the ability of cloud providers' autonomous service delivery without interaction of human for their respective consumers when the need arises.
ii. Broad network access: - refers to the capabilities which are serviced over a network and accessed through standard mechanism to reach heterogeneous thick and thin client platforms.
iii. Resource pooling: - refers to the capability that increases an efficient utilization of computing resources cloud providers pool, their computing resources to serve multiple cloud service consumers by using multitenancy models that frequently rely on the use of virtualization technologies. Through the use of multitenancy technology, the resources can be dynamically assigned and reassigned, with respect to cloud service consumer demand.
iv. Rapid elasticity: - pertains to the concept resources that can be elastically provisioned and released automatically to scale outward and inward to match with the current demand. This allows customers to change their levels of service at will without being subject to any of the limitations of physical or virtual resources.
v. Measured service: - means cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service. Resource usage can be monitored, controlled, audited, and reported, providing transparency for both the provider and consumer of the utilized service.

2.3 Cloud computing service Models

Meanwhile, it is necessary to discuss the driving forces behind the growth of cloud computing. Cloud computing commonly clubbed as a three service delivery models namely; software as a service, platform as a service and infrastructure as a service model, which is arranged from provider's side for customer consumption, as depicted in Fig 2.1. Quality attributes emerge by studying the characteristics and features of those service models.

Software as a Service (SaaS): - At this layer service provider out to manage service delivery in the form of an application running on a cloud infrastructure. The underlined service provided for varies client devices through thin client interface or interface program. The main advantage of such a service is that service configuration and related overheads are transparent, except some limited user-specific application configuration settings. A third-party vendor takes place the configuration and management of the application as well as another cloud resource.

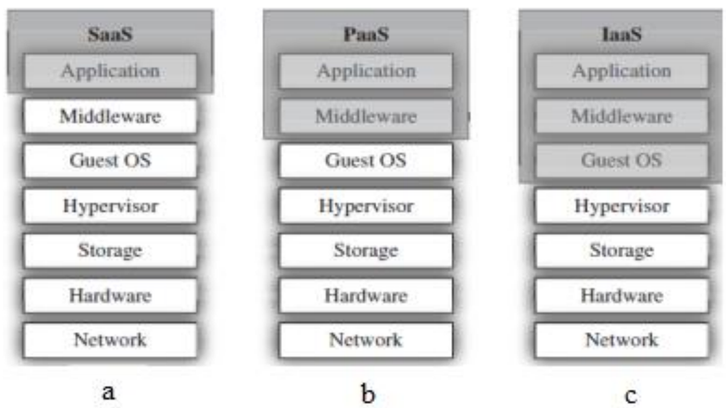

Figure 2.1 Cloud service model: software (a), platform (b), and infrastructure (c) as a service

Platform as a Service: - At this layer, consumers provided a platform in which they can develop, test, configure, and deploy consumer application while cloud providers manage and control the underlying cloud infrastructures like network, servers, operating systems, or storage.

Infrastructure as a Service: - At this layer cloud third-party vendors provide virtual computing resources (simulated hardware components) including but not limited to central processing unit (CPU), virtual machine, network accessible storage, servers, and networking. As compared to SaaS and Pass, in IaaS users are prompted to deploy and run arbitrary software, which can include operating systems and applications. The resources usually consumed in the form of pay for the resource consumed. In this layer, cloud providers are responsible for the hardware performance and maintenance to ensure the server run correctly.

2.4 Cloud computing deployment models

In cloud computing environment, there are four commonly used cloud deployment models, namely private, public, and hybrid clouds, community cloud. Customers do not popularly adopt private deployment model. The deployment model is described below and depicted in Fig 2.2.

Private cloud: it is built and managed within a single organization. Organizations use software that enables cloud functionality, such as VMWare, vCloud Director, or OpenStack.

Public cloud: it is a set of computing resources provided by third-party organizations. The most popular public clouds include Amazon Web Services, Google AppEngine, and Microsoft Azure.

Hybrid cloud: it is a mix of computing resources provided by both private and public clouds. A community cloud shares computing resources across several organizations and can be managed by either organizational IT resources or third-party providers.

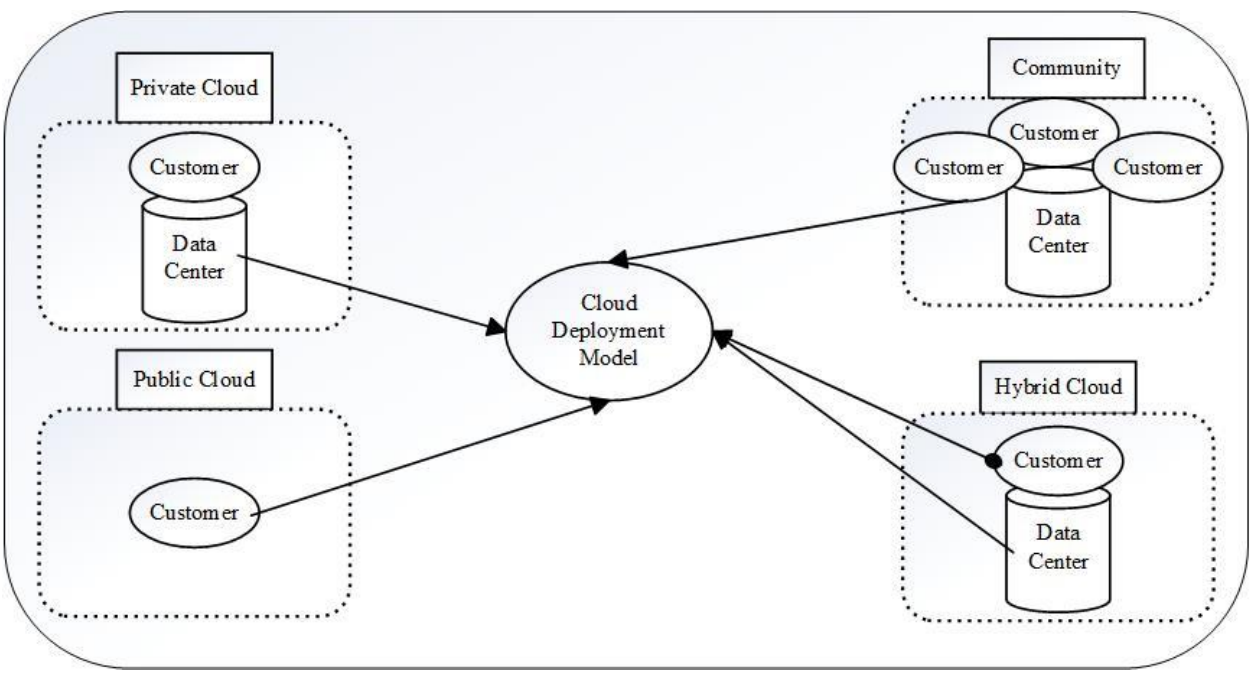

Figure 2.2 Cloud deployment model

Generally, as aforementioned, according to NIST definition of cloud computing model, the fifth essential characteristic is defined as "measured services". To this end, in defining the measurable services in terms of quality of service (QoS) with their respective KPI and metrics, it is necessary to identify the properties of measurable services with their respective standards of measurement and metrics. The following topic discusses cloud computing service measurement index and available QoS definition from grassroots.

2.5 Orthogonal Views of Quality

The term quality by its nature has varied definitions, and still, it is a means for a dispute between varies scholars as well as those who meant to use it. In the next subsections, the term quality reviewed with two views, viz, popular views and professional views.

2.5.1 Quality: Popular Views

The term "quality" derived from the Latin (qualitas) and means attribute, characteristic, property, condition [15]. It can be perceived, defined and interpreted in deferent ways by different scholars, and disciplines [16]. However, it could be exemplified in terms of excellent quality, good quality, or bad quality while still does not precisely determine the intended concept objectively [5]. This is because, it depends on peoples' perception of the value of product or service under consideration and their expectation of performance, durability, reliability, etc. of the product or service.

Often, the term quality also used as a distinguished attribute or, characteristics of someone or something in the market where expensive products classified as quality products. In general, its popular view is intangible; it can be discussed, felt, and judged, but cannot be weighed and measured [17]. That is why it was believed that quality is a term that cannot be controlled managed, nor can it be quantified from this perspective.

2.5.2 Quality: Professional Views

In contrast to the popular view of quality, professional's standpoint is different, they perceive quality as a trait that can, and should, be operationally defined, measured, monitored, managed, and improved [17]. Within this context, ISO 8402-1986 standard defines quality as "the totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs." While ISO [ANSI/ISO/ASQ Q9000-2005] defines quality as "the degree to which a set of inherent characteristics fulfills requirements." Similarly, [18]defines it as "fitness for use." These three definitions are related and consistent.

The third definition takes customers' needs and expectations into account, which involve whether the services fit their uses. It means that products must possess multiple elements of fitness for use [17] i.e. the service is expected to be reliable, usable, secure, etc. All of these elements are quality attributes and they can be classified into categories known as quality characteristics. The same is true for cloud services in which characterization of the service delivered by different providers takes a variety of relevant criteria into account.

2.6 Quality Model of Cloud Services

The key element in cloud provider's and customer's relationship is believed to be the quality of the service being delivered. On this ground, consumers are considered to be the ultimate assets for providers as well as the reasonable showcase of the quality of the service being delivered. This is because, consumers do not tend to compare, rank, and use the service being delivered by varies providers, and instead they consume the assurance that their expectations for the service will be met. Thus, cloud provider has not really got anything else to sell but quality [1].

Essentially, ISO/IEC 25010 articulate the merit of categorizing a product quality into characteristics and sub-characteristics as an advisable and a good practice [19]. Likewise, Cloud Service Measurement initiative consortium developed [20] service measurement index (SMI) hierarchical framework which is meant to provide a standardized method for measuring and comparing a business service.

The framework divided into three layers. The first layer divided the measurement space into seven categories while the second layer further refined the seven categories into four or more attributes each. The third layer in SMI accommodates a set of KPIs for each attribute. As a lower layer in the hierarchy, KPIs describe a concrete quality data to be collected for each metric. SMI took the lead and filled in the first two layers of the hierarchy framework as discoursed below.

2.6.1 Characteristics and sub-characteristics of cloud service quality model

As explained, QoS uses for objective discrimination of cloud providers based on consumer's interest by calculating the KPI of QoS attributes. Unfortunately, the required QoS characteristics have been labeled, defined, and explained in a different manner across varies findings and businesses.

To tackle this problem, in this research work, Service Measurement Index Framework Version 2.1 has been selected for the reason that, it manages, categories as well as depicts the hierarchical structure of QoSs clearly [SMI]. Moreover, it gives a holistic view of QoS needed by consumers for selecting a cloud service provider based on Accountability, Agility, Assurance of service, cost, performance, security and privacies, and usability as illustrated in Fig. 2.3. However, SMI does not complete the framework as they did not specify KPI which is considered to be a foundation for quantification. But most importantly, since well-defined and understood terms use for efficient communication and bring clarity of cloud computing QoSs the following lists define necessary QoSs based on SMI framework.

Figure 2.3 Higher level of SMI

Accountability: in this category, the accommodated attributes merely related with cloud provider organization independent of the service being provided. Accountability can be expressed in terms of the following main attributes of the service provider organization.

- ***Provider business stability:*** it is the degree to which the service providers stick with the service being delivered and concerned customers within the contracted terms.
- ***Provider Support:*** it is the extent to which service providers react to guide users in answering questions about the service, and working around, or correcting any problems that may arise.
- ***Providers certification:*** service providers commitment in maintaining current certification for standards to their clients' requirements.
- ***Sustainability:*** it deals with on the impact of the service provider in its environment in terms of economy, society, and environment.

- ***Governance:*** entails the process used by the cloud service provider to manage client expectations, issues and service performance.

Agility: it is an important attribute that makes the consumer much more competitive [A]. Agility measured as a rate of change metric, showing how quickly new capabilities are integrated into cloud infrastructure as needed by the business. Within this umbrella organizations want to ensure the system:

- ***Adaptability:*** it deals with the change in cloud service provider in accordance with the client request.
- ***Elasticity:*** it is the degree to which cloud service handle workload alteration by provisioning and de-provisioning resources automatically to meet client demand as closely as possible in time.
- ***Extensibility:*** it is the capability of cloud service to handle new requirements to the existing system.
- ***Flexibility:*** it is the capability of cloud service to add ore remove prespecified features.
- ***Portability:*** it deals with the movability of the cloud system from one cloud provider to the other with minim modification.
- ***Scalability:*** it is the ability of the system to scale in and scale out the available resources in order to meet client's requirement and agreed on SLA.

Assurance: this category comprises quality attributes that are used to specify the likelihood of service availability as stipulated.

- ***Availability:*** it is the percentage of time a customer can access the service during a particular time interval.
- ***Maintainability:*** it is the ability of cloud service provider to keep the service up to date with relevant modification.
- ***Recoverability:*** it is the degree to which the service able to resume the expected function quickly just after an unplanned disruption.
- ***Reliability:*** it reflects a measure of how the service maintains its operation without failure under a given condition during a given time period.

- ***Resiliency/ fault tolerance:*** it is the ability of the service in maintaining the expected service properly while experiencing failure in one or more of its components.
- ***Service stability:*** it is the degree to which the service is resistant to change, deterioration, or displacement.
- ***Serviceability***: the easy of performing maintenance and correcting problems with the service.

Financial attributes: this category has to be dealt with a great attention in order to rank and select the best cloud provider. This is because attributes like cost are considered to be the most vital information that needs to be communicated thoroughly as they are one of cloud's technology advantage and a reason for migration. In addition to cost, the billing process, financial agility, and financial structure are categorized under financial attributes.

- ***Cost:*** it is classified and measured into two sub-attributes called transition cost and acquisition cost i.e. it is client's cost to consume a service over time.
- ***Billing process:*** the level of integration that is available between the client and cloud service provider's billing systems and the predictability of periodic bills.
- ***Financial agility:*** the flexibility and elasticity of the financial aspects of the cloud service provider's services

Performance: performance covers the features and functions of the provided services. The followings are attributes of this category;

- ***Accuracy:*** the degree to which the service adheres to its requirement.
- ***Functionality:*** dealt with the promised features provided by the service
- ***Suitability:*** it reflects how closely the capability of the proposed service matches the user requirements.
- ***Interoperability:*** it measures the ability of the service possess to easily interact with the other services within both the same service provider or another service provider.
- ***Service response time:*** it measures the time between sending a request and getting a response.

Security and Privacy: this category includes categories that indicate the effectiveness of a cloud service provider's control on access to services, service data, and the physical facilities from which services are provided.

- ***Access control and privilege management:*** policies and processes in use by the cloud service provider to ensure that only the personnel granted appropriate privileges can make use of or modify data/work products.
- ***Data geographic/political:*** the client's constraints on service location based on geographic or political risk.
- ***Data integrity:*** keeping the data that is created, used, and stored in its correct form so that clients may be confident that it is accurate and valid.
- ***Data privacy and data loss:*** client restrictions on use and sharing of client's data are enforced by the cloud service provider. Any failures of these protections are promptly detected and reported to the client.
- ***Physical and environmental security:*** policies and processes in use by the cloud service provider to protect the provider facilities from unauthorized physical access, damage, or interference.
- ***Proactive threat and vulnerability management:*** Mechanisms in place to ensure that the service is protected against know recurring threats as well as new evolving vulnerabilities.
- ***Retention/disposition:*** the cloud service provider's data retention and disposition processes meet the clients' requirements.
- ***Security management:*** the capabilities of cloud service providers to ensure application, data, and infrastructure security based on the security requirements of the client.

Usability: under this category varies attributes reflect the easy of using cloud service, using the following attributes:

- ***Accessibility:*** the degree to which the underlined service support disabilities
- ***Installability:*** it measures the time and effort required to get a service ready for delivery.
- ***Learnability:*** measures the effort required of users to learn to use the service
- ***Operability:*** the ability of the service to be easily operated by users.
- ***Transparency:*** it defines the extent in which the change in the feature or component of the service affects usability.

- ***Understandability:*** the easy with which users can understand the capabilities and operation of the service.

2.7 Quality Measurement

History of measurement starts from the time human being started comparing things relatively. The use of measurement evolved and developed in the physical sciences using standardized metrology process [11]. Even disciplines, like medicine and social sciences able to measure attributes that were previously thought unmeasurable [21]. For example, attributes such as intelligence and, air quality are attributes that humankind able to measure and use it as a basis for important decisions that affect their everyday life.

However, some measurements are not refined as they are expected to be. In improving and refining attributes of this kind, the most developed measurement model, a physical model is used [21]. Generally speaking, developing, evolving and maintaining measurement in cloud computing is an inevitable process for the development of the discipline.

2.7.1 Metrology of cloud computing

Prior to cloud service selection, evaluation of cloud should be performed. The evaluation can be performed in two different approaches; using subjective [22] [23] or objective approaches [22] The latter takes place from ordinary QoS parameter and predesigned benchmark testing [24].

Before advocating objective (quantitative) approach in order to understand how quantification increases the power of cloud providers discrimination, it is much better recognizing the limitations of subjective quality assessment. Subjective assessments have the risk of inaccuracy i.e. it is subjected to bias and does not reflect the real situation. Most importantly, there may be malicious consumers who give unreasonable subjective assessments with the intention to device others and benefit themselves in some cases [24]. As a result of this, not only cloud environment, the world is shifting into quantification assessment approach.

Galileo Galilei once used to say “what is not measurable makes measurable” [25]. It is that view of quantification that makes quality characteristics more visible and therefore more understandable and controllable as opposed to the objective assessment. Thus, it is worthwhile to create ways of measuring cloud, while maintaining and improving already developed mathematical models.

Currently, researchers have been working hard towards quantification of QoS such as security [26] [27] [28], scalability, elasticity, efficiency [29] as far as cloud is concerned. But, some scholars claim that some important QoS attributes are far from quantification, like usability [30] [31]. Here it is important to note that, attributes like time, temperature, and speed were once unmeasurable by primitive people of that time. Thanks to the science of measurement, now time, temperature and speed easily measured by almost everyone [21].

Likewise, it is a good practice to use measurement to advance our understanding of them. This is because of the act that, proposing such measures will open a debate that leads to greater understanding, even if it is not clear how measurement performed with such attribute.

Thus, the importance of measurement in cloud computing is twofold i.e. it helps in both measuring the QoSs of cloud services as well as in acquiring a common understanding of those QoSs. In getting such understanding and possessing measurement in a cloud environment, metric provides a standard for describing the measurement and measurement results [11].

A metric is a way to define knowledge about the characteristics of cloud through both its definition and the values resulting from the observation of the property. On the other hand, it could give information which is necessary for to reproduce and assert observations and measurement results [11]. Specifically, the role of a metric plays in decision making, selecting cloud services, defining and enforcing service agreements, monitoring, and accounting and auditing cloud service is enormous [11].

2.8 Multi-Criteria Decision Support

After quantification of QoSs, cloud providers comparison and ranking follows. Since, cloud performance analysis composed of multiple QoSs, multi-criteria decision-making(MCDM) approach fit for the problem under this context [24]. The approach takes a set of decision criteria that means QoSs and a set of alternatives in this case cloud providers then produce a result in the form of the best alternative [MCDM].

Although multi-criteria decision making has widely diverse methods, many of them have some common aspects such as [MCDM]:

Alternatives: it represents different choices of actions available to the decision maker (DM). These choices are in the form of cloud providers, which are supposed to be screened, prioritized and ranked.

Multiple attributes: reflects QoSs that represents different dimensions from which the alternatives can be viewed.

Conflicting among criteria: QoSs that may conflict each other.

Incommensurable units: it references the unit of QoSs. Because, different QoSs involve in the decision making, their unit of measure might vary accordingly.

Decision weights: it represents the QoSs weight of importance as per consumers requirement.

Decision metrics: MCDM problem expressed in terms of matrix format. Decision matrix A is an (mXn) matrix in which element aij indicates the performance of alternative A_i when evaluated in terms of decision criteria C_j (for i=1, 2…, m and j=1, 2..., n).

In utilizing any of MCDM decision techniques, the following steps of analysis of alternatives involve:

1. Determining the relevant criteria and alternatives.
2. Attaching numerical measurement to the relative importance of the criteria and to the impacts of the alternatives on these criteria.
3. Process the numerical values to determine a ranking of each alternative.

As common sense, it is better to assume that the criteria represent some kinds of profit, for instance, the higher the value the better it is.

2.8.1 Analytical Hierarchical Process (AHP)

AHP is a well-known mechanism which is used to solve a MCDM problem. It decomposes MCDM problem into a system of hierarchies. It gives a flexible mechanism and can be adopted to many number of attributes and sub attributes, which is the reason to be followed here, too. The final step in the AHP deals with the structure of m X n matrix, where m is the number of alternatives and n is the number of criteria.

The matrix is constructed by using the relative importance of the alternatives in terms of each criterion as it is given on equation 2.1 [32].

$$A^{*}AHP - score = max \sum_{j=1}^{n} a_{ij}w_j$$

Equation 2.1 AHP of MCDM approach

Where, $A^{*}AHP - score$ is the AHP score of the best alternative, n is the number of decision criteria, a_{ij} is the actual value of the i^{th} alternative in terms of j^{th} criteria and $w_j$is the weight of importance of the j^{th} criteria.

As compared to Weighted Sum Method (WSM), AHP uses relative values instead of actual ones, which makes it applicable for single or multi-dimensional decision-making problem like in cloud migration decision making.

However, as a result of ranking inconsistency in AHP Belton and Gear improved AHP and come up with Revised Analytical Hierarchical Process (Revised AHP). Revised AHP divided each alternative value A_1, A_2…, A_m by the maximum value of the relative values, instead of having the relative values of alternatives sum up to one.

2.8.2 Cloud Migration Decision Support Process

The overall process of decision making, which is used to evaluate and rank from the available cloud service provider alternatives, passes through varies activities as illustrated in Fig 2.4. The process starts by letting the customer feed the QoSs of his or her choice with their respective weights into the system.

Then after, the system fetches the selected parameter’s KPIs of all the available alternatives, as labeled as number 3 on Fig 2.4, and passes them to quantification module, which is labeled with number 5 of Fig 2.4.

Right after the quantification, the ranking module, which is labeled as number 4 in Fig 2.4, takes the weight and quantified values of QoS’s as an input for AHP, which in turn uses to compute multiple criteria and rank alternatives based on the computed values. Finally, the result displayed for the user in its chronological order starting from highly qualified to less qualified providers.

Generally, the core element of this particular research work lies on label 5 of Fig 2.4. The label takes KPI’s of a particular cloud service provider and quantifies QoS which is, in turn, uses as an input for the AHP process in parallel with their respective weights.

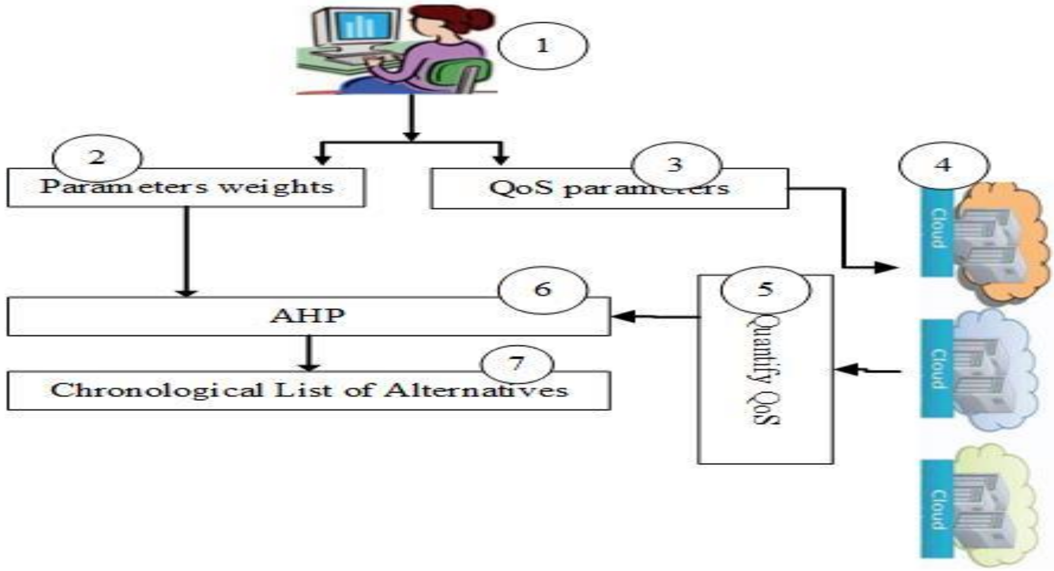

Figure 2.4 Overview of Cloud Migration Decision Support

2.9 Related Works

Objectively assessing quality attributes and, therefore, ranking cloud providers based on the assessment are being thematic main research area across varies researchers in the academy and organizations. However, in quantifying quality characteristics a little is done [33]. As a result of this, as per the author knowledge, no single work is done for quantifying quality attributes and developing quantification method for cloud quality attributes, exclusively. However, some researchers are devoting an extensive attention in parallel with cloud decision support techniques, cloud service evaluation and providers ranking.

Likewise, [29] Developed a model to systematically drive metrics for scalability, elasticity, and efficiency properties of cloud computing using a goal question metrics (GQM) in a systematic top-down fashion. First, they defined the goal for specification analysis. Second, they formulate questions that will help to achieve the goal. Finally, metrics identified, from which, six new metrics have been derived from the given properties in response to answering the questions. For scalability; scalability range and scalability speed derived. Likewise, for elasticity; mean time to quality repair and number of service level objectives variation metrics derived. Whereas, for efficiency; resource provisioning efficiency and marginal cost metrics discovered. The derived metrics and the proposed model demonstrated with online bookshop scenario. Although authors played the first-class role in systematically deriving and quantifying cloud metrics, they are limited to scalability, elasticity, and efficiency of cloud property. The research, lack aggregated measurement method of the individual metrics, which is the surface that needs to be built upon.

Most importantly, [13] work is a pioneer in providing a methodical explanation in relation to metrics for estimating cloud products and services. The aim of this work is to come up with a method that determines QoS metrics which is intended to be used by cloud providers to maintain their customer requirement. It proposed varies metrics under four categories, namely performance metrics, economic metrics, security metrics and general metrics. Under performance metric, communication, computation, memory and time are considered. Concerning economic metrics, the proposed characteristics are cost elasticity. Security metrics, in turn, represented in terms of data security and authentication. Whereas, the general metrics accommodates, availability, scalability, reliability, efficiency reusability, composability, adaptability, usability, modifiability, and sustainability. Even if, varies quality metrics that are a supply for quantification have been identified with this research work, authors did not quantify the proposed metrics. (it gave an evidence on the difficulty of QoS lists). in addition, the research work failed to automate and evaluate of derived metrics.

On the other hand, [31]contributed cloud measurement framework, which is responsible for evaluating, and comparing cloud characteristics as well as ranking cloud service providers with the proposed framework called SMICloud. The framework realized SMI framework. Accordingly, they outlined seven attribute categories, namely, accountability, agility, cost, performance, assurance, security, and usability. The framework is composed of components such as SLA Management, SMI Calculator, and Ranking system. For a ranking of cloud providers, AHP MCDM method is used. However, the framework merely designed for IaaS service, which intern did not consider other services like PaaS and SaaS. on the other hand, the proposed work did not consider all SMI metrics while it collects inputs from provider side which is subjective to bias.

Similarly, Mehwish N and Mayram Nazar [34] proposed a framework to evaluate the quality of SAAS Freemium model using analytical network process (ANP) based on the quality of metrics they possess. They considered varies quality attributes, like, usability (appropriateness, recognizability, learnability, operability, user error, protection), security (integrity, confidentiality, traceability), reliability (availability, completeness, correctness, continuity, stability, consistency), tangibility (visibility, professionalism, user interface, aesthetic), responsiveness (timelines, interaction, elasticity) and empathy (self-service, measurability, courtesy and initiative). To realize the evaluation and selection of SaaS, the following consecutive steps incurred; defining the problem domain, pairwise comparison Matrix, supermatrix formulation, weighted supermatrix formulation, limit matrix formulation and finally, selection of SaaS. the downside of this finding is that the evaluation and selection framework is limited to SaaS services, while PaaS and IaaS remained the main factors for decision making. Whereas, the proposed work is expected to be verified, and evaluated by practical implementation and case study.

Some researchers took initiative in developing a quality model for cloud service. For instance, [30] developed a quality model with six quality metrics, like, usability, availability, reliability (mean time between failures (MTBF), mean time to failure (MTTF)), responsiveness, security and elasticity from cloud service perspective. Except for usability, all the quality metrics assessed using objective assessment approach. The result empirically evaluated on three cloud storage service providers namely Amazon S3, Microsoft Windows Azure Blob and Aliyun Open Storage service. The result of quality metrics validated with correlation, consistency, and discriminative power. The major drawback of this work goes to the limited number of quality metrics considered. And it leaves a room where other quality metrics such as scalability, security, etc. are lifted and studied.

Quantification has been also raised and studied extensively in cloud provider selection method. Neda T, Dicle Y.O, Kemal K and Faran A [35], used a Fuzzy extension of AHP and proposed MCDM based cloud providers selection model. The alternate selection criteria obtained directly from experts who are aware of requirements, technological basis, and the required budget. Fuzzy scales used to predict quality metrics weight. Basically, authors tend to evaluate IaaS quality in particular. The selection process involves multiple ordered steps, such as criteria selection, weight the criteria, determination of cloud service provider alternatives and an overall score of the providers. The model implemented and verified using five cloud service providers, like, Amazon, Windows, Google, Rackspace, and IBM. Quality metrics used to carry out the study are acquisition and transaction cost, availability, storage capacity, CPU, performance, and security. Although the authors have gone far in solving MCDM problem involved in selecting the best cloud vendor, they are limited to a small number of criteria as well as the selected criteria are not quantified.

To sum up, the summary of the related works and the ground, which needs to be built upon, are illustrated in Table 2.1 below.

Table 2.1 Related work summary

Ref No	**Open issues**	**Problem solved**	**Not yet covered**	**Will be addressed by this thesis**
[29]	Previously proposed metrics a) Lack of systematic derivation b) Need knowledge of implementation detail	Identified metrics for scalability, elasticity, and efficiency using goal question metrics	a) Limited to a very small number of attributes b) Lack aggregated measurement method c) Lack metrics selection criteria	a) Prioritize and select the most important quality attributes that need to be quantified b) Quantify other additional quality attributes c) Adopt an aggregate measurement method for the quantified attributes namely AHP
[13]	a) Lack of methodical explanation related to metrics for estimating cloud product and services	Proposed a large number of QoS metrics list for service vendors compared to [26].	a) The proposed metrics are not quantified. b) Failed to automate and evaluate the proposed metrics	a) Quantify the most important once from identified quality metrics b) Demonstrate the quantified metrics and thereby employ them for providers ranking

[31]	a) Lack of an automated framework that enhances the selection of cloud vendors based on customer needs b) trouble to decide which vendor fulfills customer's requirement	Proposed a framework called SMICloud which is responsible to evaluate, compare and rank cloud vendors and quantified all IaaS service metrics except for usability category	a) the research work is limited to IaaS service metrics b) usability category is not quantified even if its evaluation and discrimination power is asserted	a) quantify quality metrics that are believed to be important in evaluating and discriminating cloud vendors from usability category. b) Give due attention to all cloud services.
[34]	a) Difficulties in selecting a service that actually meets customer's requirement	Proposed a framework to assess the quality of SaaS freemium using ANP	a) Limited to SaaS freemium services b) Not automated	a) Give due attention to all cloud services. b) Quantify as well as demonstrate the use of quantified quality metrics for cloud migration decision support
[30]	a) Lack of common sense on how to define and measure cloud quality	Proposed a quality model for cloud services called CLOUDQUAL and demonstrate the	a) A very limited number of cloud quality metrics are considered	a) More cloud quality service metrics that are important to evaluate and rank the most important, such as scalability,

		model with three real-world cloud storage Evaluate the quality model using standard criteria		security, etc. are discovered and quantified as well as evaluated.
[35]	a) Confusion and complexity in the decision-making process of cloud vendors selection.	Proposed Fuzzy AHP(FAHP) as a solution to for cloud service selection problem, they have demonstrated the result with five cloud service providers	a) As of the above research works they have considered a very limited selection criterion and b) They did not quantify the select criteria	a) Much more quantified version of cloud selection criterions are considered and demonstrated

On top of aforementioned research works, this research work extends the power of quality metrics by giving due attention on quantification of quality characteristics and its uses for cloud service providers discrimination. Thus, the research discovers important cloud quality expression, propose a mathematical representation of those expression that are not quantified, and select as well as adopt already quantified quality expressions in the previous works, and thereby, form a quantified cloud service quality metric catalogs for cloud migration decision support.

CHAPTER THREE

3. Research Methodology

3.1 Overview

Establishing and answering this research questions, and thereby attaining the research objectives requires a sound methodology, which is a process and roadmap that ranges from problem formulation to evaluation. Likewise, to accomplish the above claim, we select Design Science Research Methodology (DSRM) approach. This is because, the underlined work is a mathematical model that uses an expected output as an ultimate evaluation of research result and it also provide space for acceptance criterion, that we take as a reason to consider DSRM fit and realize the proposed work. In addition to this, as the QoS model revolves around built and evaluate in order to understand better, the effect of all QoS as it has been used in [36] reason for adoption. More importantly, it is a well-developed methodology where its popularity for use, in information system study, is extended from late 1990's [37]. The main reason for its popularity and particularly the reason for adoption in this study is its ability in providing educate solution space to build a system according to the defined model taking into account restrictions and limitations [36]. Moreover, DSRM propose the creation and evaluation of IT artifacts that may include constructs, models, methods, and instantiations [38], and therefore, it is reasonable to use DSRM as the proposed artifact is a model, which is intended to provide guidance on how evaluation and ranking of cloud providers performed objectively. The methodology consists of six iterative steps as shown in Fig 3.1.

As stated in the previous chapter, especially in the first chapter, the entry point for this study was the problem. The processes adopted for this problem centered study are described below.

3.2 Problem identification and motivation

It is the process of defining a specific research problem and justifying the value of a solution, problem identification and justification has been carried out in the proposal stage as well as in the first three main topics of chapter one. In this study, lack of proper and unambiguous cloud service evaluation, as well as, lack of objective cloud service providers ranking and selection model is considered to be the main problem and motivation that bring about this study to the scene.

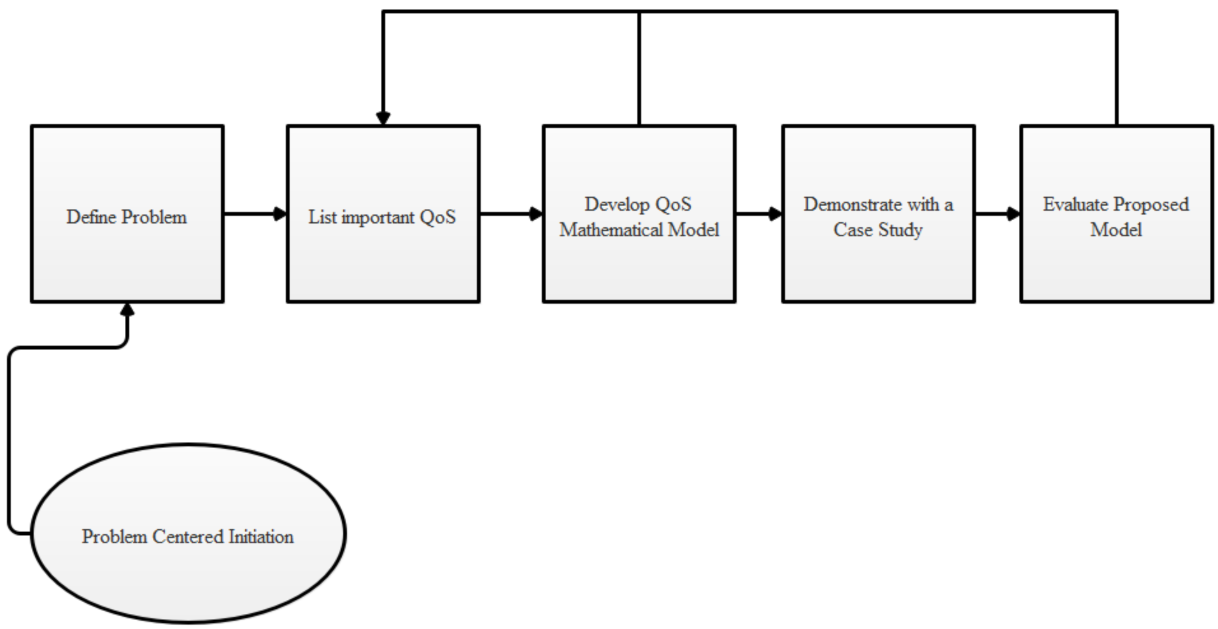

Figure 3.1 DSRM Process: adapted [36]

3.3 Definition of the objective of a solution

The rationale to undertake this research work and resources required for this study as well as definitions of the objective for a solution have been inferred from the systematic literature review, and providers' website. The objective of the study is given on the first chapter under general and specific objective topics. The resource required to infer the state of knowledge as well as the existing solution with its respective drawback is given in the second chapter of this work. Steps followed to review literature are given below.

3.3.1 Data collection

In this study, cloud quality of services identified from the literature review. The mined expressions are quantified and made available to evaluate and rank cloud providers. In the following steps, the step of identifying, quantifying, implementing and analyzing the QoSs, are explained.

3.3.1.1 Definition of research questions for cloud QoS source extraction

In order to consume overview of research area, and at the same time identify the quantity of research and result available within it, we asked the following questions and thereby set goal from which research papers were identified for QoS identifications.

i. Which journals databases include papers on cloud computing QoS and migration decision support?
ii. What are the most investigated cloud QoS for cloud migration decision support topics?
iii. What types of QoS are addressed for cloud migration decision support?

3.3.1.2 Conduct literature search

To extract relevant reference, reference databases were explored with customized search string followed by manual filtering of the result and using predefined inclusion and exclusion criteria. To search relevant papers on cloud QoS and migration decision support, we use five reference databases, all of which indexed cloud-computing papers.

1. IEE Xplore
2. SienceDirect
3. Spring
4. Elsevier
5. Google scholar

With the specified reference databases, we search for a paper between 1st of Jan 2008 and 1st of Feb 2017. We choose 2008 as a starting date because previous work [33] has surveyed that QoS and cloud migration decision support are brought a comprehensive overview of existing work on cloud migration decision support and QoS. We set the end date 1st Feb 2017 because the search started in March 2017.

Table 3.1 Search string similar items on the same row

Search string items
Cloud service characteristic/s, cloud computing characteristic/s
OR cloud service evaluation, cloud computing evaluation
OR cloud computing quality of service, cloud quality of service
OR cloud computing service attribute/s, cloud service attribute/s
OR quality of service for cloud migration decision support
OR cloud computing service measurement index
OR Quantification of quality expression
OR mathematical model of quality expression

Having in mind research questions, we developed a key word for a search string and we refined the search string with a synonym and contextual equivalent words as many authors paraphrased keywords with equivalent keywords. For example, cloud quality characteristics can be rephrased as cloud quality attributes, and because of this, we identified both cloud quality attributes and characteristics as a search-string. Furthermore, we considered plural and singular forms such as such as characteristic and characteristics. Finally, all search strings in the search string in Table 3.1 are connected with OR statements, to make sure that all relevant papers are identified.

3.3.1.3 Screening of papers and search process

Papers are filtered using inclusion and exclusion criteria. Whenever paper meet all inclusion criteria, it was kept for further considerations and when the paper meet exclusion criteria, it was removed from the study. When I was not sure about the inclusion and exclusion of the paper advisor was involved in the decision process instead of approval.

A. *Inclusion criteria:* research work within focus area of QoS in cloud computing. The research work must address the service quality of SaaS, PaaS and/or IaaS. The described service quality must be from the perspective or cloud provider and/or consumer.

B. *Exclusion criteria:* articles written in the non-English language, topics of similar words with cloud but not computing concept (for instance metrology concept), papers published before 1st of Jan 2008 and after 1st of Feb 2017 and sources in the form of a tutorial, book review and presented slide as recommended by [39] are excluded.

As illustrated in Fig 3.2 we adopted a search process on five-reference database and we got different number of papers for each venue. We used JabRef to manage references and thereby remove duplicates. From a total of 48754 references obtained with an automatic searching 27400 of them were removed as a result of duplication.

Second, title based selection performed and checked against inclusion and exclusion criteria thereby maintain studies that were related to this work and include those articles into next phase. Whenever difficulty arises in identifying the relevancy of a particular study based on its title, it was just passed for the next phase, too. The step differed 143 papers for next phase.

Then, we filtered research papers by reading abstraction and introduction section of each paper. In addition, if it becomes confused to judge from abstract and introduction we read conclusion section. If it is still difficult to deduce the relevance of the paper, we kept for the next step. In this step, we obtained 90 research papers for further study.

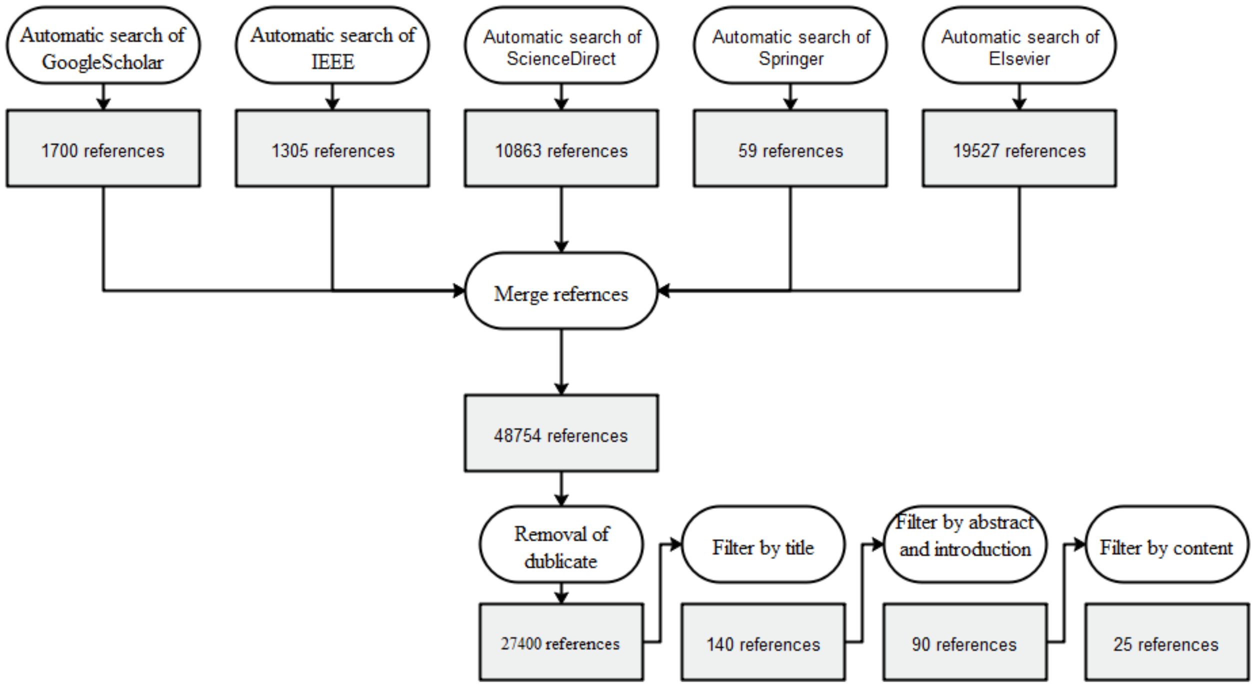

Figure 3.2 Search Process

Finally, the full content of each paper was examined and made a final decision about each paper. When I became confused to include or exclude a particular paper, I discuss with my advisor in order to make the final decision instead of the approval. This step resulted in 25 references.

3.3.1.4 Data extraction and Mapping

While keeping the research questions and source identification questions in mind, we have distilled the following results regarding the extracted references and the content of the researches. Regarding the content of the research work in particular with the research question raised in section 4.2.1 of chapter 4.

Whereas, to answer the first question, which was not answered in chapter 4, Table 3.2 shows the top most popular venues for paper on QoS, cloud computing and cloud migration decision support. We noticed that those venues include around 84% of 25 all selected papers.

Table 3.2 Number of papers published in top most popular publication venues

Venues	Numbers of papers	%
Google scholar	3	12%
IEE	18	72%
Thomson Reuters SCI	0	0%

3.4 Design and development

In this study, the artifact is a mathematical model where research contribution is embedded. To create the model, its desire functionality is determined from related work i.e. it extends the knowledge base or applies existing knowledge in new ways. Thus, the contribution of this phase and the research work is a quantified QoSs which is extended to be used for cloud quality evaluation, and therefore, enables cloud consumers to select the best cloud provider from the given alternatives.

In such a process, first, cloud quality categories, attributes, and KPIs that are believed to be used for evaluation and discrimination of alternatives are selected. Second, a mathematical model is defined for each selected alternative. Third, general mathematical representation of selected cloud quality characteristics is specified. The general mathematical model is determined with respect to MCDM. Finally, a cloud migration decision support architecture is specified by accommodating the research contribution i.e. mathematical model. The proposed model is discussed in chapter four.

3.5 Demonstration

The developed model implements and then demonstrates the instance of the solution with a case study. As such, the demonstration mainly concerned with the use of the proposed method for selecting cloud service providers from the given alternatives. The case study and demo described in chapter five.

3.6 Evaluation

Right after the demo, the conformance of the solution to the problem was observed and measured. The demo was evaluated against quality metrics, namely, correlation, consistency, and discrimination power. At the end of this activity, a decision can be made to roll back to the previous activity or disseminate the result for relevant audience. The result is illustrated in chapter 6. After the result discussed a conclusion was made in chapter 7.

CHAPTER FOUR

4. Proposed Cloud QoS Quantification Model

4.1 Overview of the Model

Having all quality of service attributes described in SMI, that have been demanded for cloud service providers evaluation and selection, more than fifty quality attributes are proposed. Although they are determined to be useful for ranking and selecting cloud service providers, by far, it requires an extended time with a multiple discipline background and upfront resources to quantify and test them entirely. Above all, all SMI quality attributes are not required and used by cloud service consumers. Whereas, some attributes are service (i.e. IaaS, PaaS, and SaaS) dependent while others are not. Some other quality attributes, for instance, efficiency [13] [39] [40], reusability [13] [39] and safety are also used to evaluate and rank cloud service providers.

As a result of this, it is a wise step to determine and select the most useful set of criteria and quantify them accordingly. Then, those selected QoSs are used as an evaluation and ranking criteria in quantitative form as shown in Fig 4.1, as opposed to the previous works that use both quantitative and qualitative forms [31]as shown in Fig 4.1. The description of each module remains the same except the qualitative module eliminated so as the specified qualitative attributes are quantified.

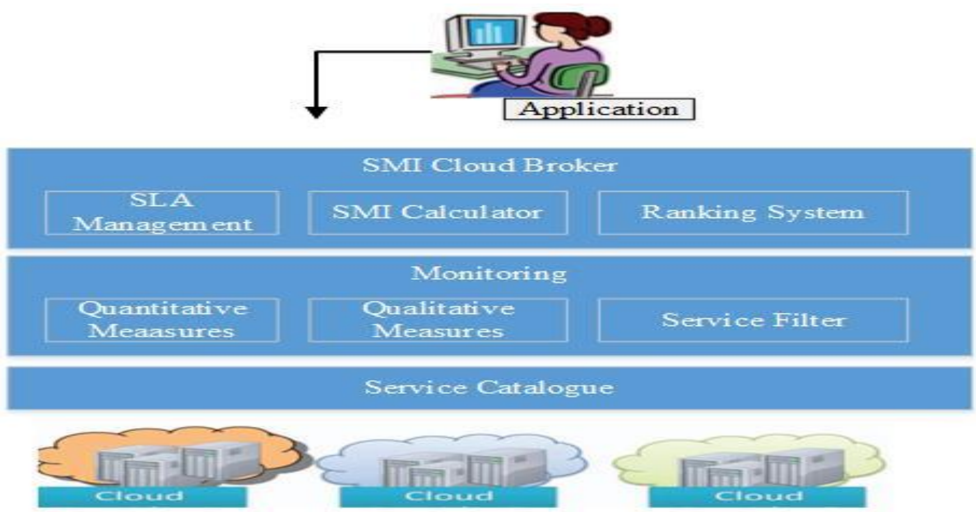

Figure 4.1 Previous SMI cloud framework

Thus, this chapter discusses three main sections, first selecting an appropriate set of attributes is performed. Second, the attributes that are said to be quantified and non-quantified are identified. Finally, the proposed mathematical model turns up and, thereby, discussed in parallel with the use of the model as an input for cloud service provider evaluation and selection process.

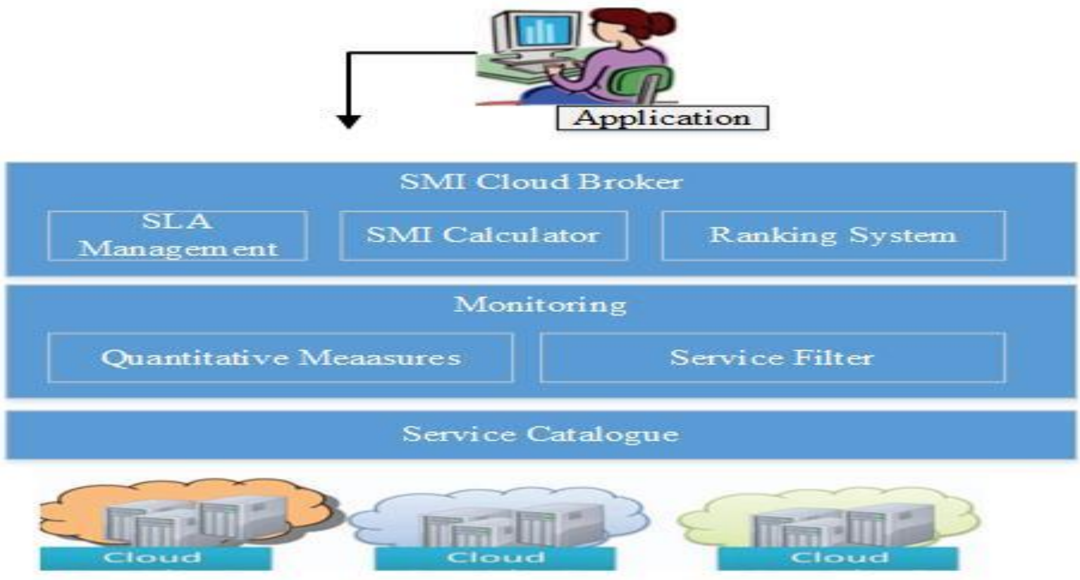

Figure 4.2 Adopted SMI cloud framework

4.2 Cloud service providers selection criteria

4.2.1 Cloud service providers selection criteria procedure

As aforementioned, although, it is much better to quantify all quality of service attributes proposed by SMI, as well as, exclusively favored by varies scholars, it is out of reach in terms of time and available resources to quantify all. In addition to this, the need of multi-discipline scholars, such as industrial engineering, mathematics, and statistics, apparent to computing background, are constraints to quantify the expressions completely. However, to mitigate this problem, the most important quality attributes for cloud service selection are selected and quantified. In this section, the quality attribute selection process is described briefly.

In selecting attributes with respect to their significance in discrimination capability, a survey of literature is performed. To this end, 25 research works, particularly related to cloud service selection paradigm, are reviewed. The review is carried out in two steps. The first step identifies the most demanded category or characteristics, whereas, the second step coined out the most important quality of service attributes or sub-characteristics out of selected characteristics.

Likewise, in order to select the most important QoS category and metric, absolute majority and simple majority rules are considered. Consequently, the latter rule is used to pick out the most important category as all the twenty-five papers are considered as voters with no abstention. Conversely, in the former case, the most important QoS are identified, out of twenty-five literatures identified as voters, abstention of being demanded of a category that encompasses a particular QoS in effect counts as a negative vote.

Understandably, in this kind of voting system which requires a majority of votes i.e. half plus or two third of the given literatures demand of particular criteria is considered as a threshold in order to select the most important QoS as well as the category. However, in order to consider a large number of categories and QoSs, one-third plus of reviewed research work and one-third plus of SMI category is taken as a selection threshold, respectively.

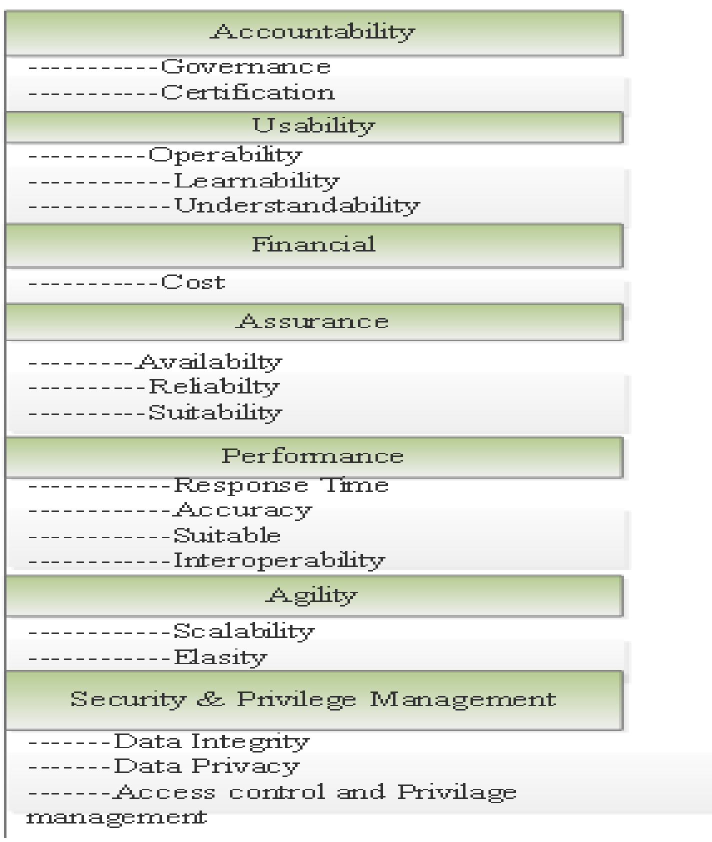

Figure 4.3 Selected cloud service quality parameters

On top of this, out of the 7 categories in SMI, assurance took the lead being favored by 19 papers. Whereas, performance demanded by 17 research works followed by security and privacy, agility, financial, accountability and usability, being preferred by 10, 13, 10, 11, and 9 papers, respectively. As selection criteria for this step, the categories should be demanded by one third plus research works i.e. they must be referred by more than 8 research works. Consequently, all SMI quality attribute categories meet the specified threshold, and, therefore, they have been selected for further inquiry of their sub-characteristics.

In the second phase of this section, the relative importance of SMI attributes and those that are not proposed by SMI are discovered based on their distribution over selected twenty-five research works. That means the proposed selection criterion is said to be important attribute depending on the research works demand of that particular attribute. Thus, an attribute which is said to be important should be consumed by at least one-third plus of SMI category selection threshold, i.e. the attribute will be selected as important selection criteria, if and only if, it is demanded by at least 4 research works. The result is shown in Fig 4.3.

In addition to SMI attributes, other quality characteristics are also considered and examined based on their distribution over the selected research works. However, none of them meet the specified threshold. Whereas, out of 53 attributes in SMI 18 meet the specified threshold. Table 4.1 to 4.7 illustrate the distribution of SMI quality attributes over selected 25 research works

4.2.2 Mapping previous research QoS demand to SMI category and attributes

From those 18 criteria two are from accountability category, namely, governance and provider certification, being demanded by 4 papers work each as shown in Table 4.1.

Table 4.1Mapping Accountability attributes to literature

SMI Attributes	[40]	[41]	[31]	[42]	[9]	[43]	[44]	[45]	[46]	[47]
Auditability		X			x					
Contracting Experience		X								
Governance		X					x	x		x
Ownership		X						x		
Provider Business Stability		X								
Provider Certifications	x	X			x					x
Provider Contact/SLA Verification		X		x					x	
Compliance		X							x	
Easy of doing Business		X								
Provider Ethicality		X								
Provider Personnel Requirements		X				x				x
Provider Supply Chain		X								
Provider Support		X								
Sustainability	x	X	x							

As shown in table 4.2 of usability category; operability, understandability, and learnability are selected, as they are referred by 4, 4, and 5 research works, respectively.

Table 4.2 Mapping usability attributes to literature

SMI Attributes	[39]	[48]	[13]	[30]	[41]	[49]	[50]	[31]	[42]
Accessibility					x				x
Client Personnel Requirement			x		x				
Install ability					x		x	x	
Operability		x			x	x		x	
Transparency				x	x			x	
Understandability	x	x			x			x	
Learnability	x				x	x	x	x	

In a financial category as shown below, cost is the only attribute that meets the threshold being demanded by 10 research works.

Table 4.3 Mapping financial attributes to literature

SMI Attributes	[51]	[40]	[52]	[13]	[35]	[41]	[50]	[31]	[53]	[47]
Cost	x	x	X	x	x	x	x	x	x	x
Financial Agility			X			x				
Billing process			X							
Financial structure			X							

Concerning assurance category, availability, reliability, and service stability are the one that meets the specified threshold being demanded by 15, 13 and, 4 research works, respectively.

Table 4.4 Mapping assurance attributes to literature

SMI Attributes	[54]	[39]	[51]	[40]	[52]	[13]	[30]	[35]	[41]	[49]	[50]	[31]	[42]	[43]	[9]	[53]	[44]	[45]	[46]
Availability	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x		
Maintainability									x										x
Recoverability									x							x			
Reliability		x		x		x			x	x	x	x	x	x		x	x	x	x
Resiliency									x										
Service stability			x						x	x		x							
Serviceability									x										

Similarly, service response time, accuracy, suitability, and interoperability met the specified threshold from performance category being demanded by 13, 4, 4, 5 papers, respectively.

Table 4.5 Mapping performance attributes to literature

SMI Attributes	[55]	[56]	[54]	[51]	[40]	[52]	[13]	[30]	[41]	[50]	[31]	[43]	[9]	[53]	[44]	[46]	[47]
Service response time	X	x	x	x	x	x		x	x	x	x	x	x	x			
Accuracy				x					x		x						x
Functionality									x								
Suitability				x			x		x		x						
Interoperability				x					x		x				x	x	

Similarly, elasticity and scalability from agility category are considered, being demanded by 7, and 9 research works, respectively.

Table 4.6 Mapping agility attributes to literature

SMI Attributes	[39]	[40]	[13]	[30]	[41]	[49]	[50]	[31]	[42]	[9]	[53]	[44]	[45]
Scalability	X	x	x		X				x	x	x	x	x
Adaptability			x		X			x					
Extensibility													
Flexibility													
Portability												x	
Elasticity		x	x	x	X	x	x	x					

As far as security and privacy concerned; three quality attributes are selected, to wit, access control and privacy management, data privacy and data loss, and data integrity being cited by 7, 4, and 4 research works, respectively.

Table 4.7 Mapping security and privacy to literature

SMI Attributes	[13]	[30]	[41]	[49]	[50]	[9]	[53]	[44]	[46]	[47]
Access Control and Privacy Management	x	X	x		x		x	x	x	
Data Geographic/Political			x				x			
Data Privacy and Data Loss			x			x			x	x
Data Integrity			x	x				x	x	
Physical and Environmental Security			x							
Proactive threat and vulnerability					x					
Retention/Disposition			x							
Security Management			x							

4.3 Quality of service mathematical model

In this section, description of a mathematical model for the selected quality attributes is introduced and discussed. The model is explained weather by customizing an existing model or defining a new model for some attributes. In this context, customization takes place from the given twenty-five papers, in which the best and reasonable mathematical model are selected and explained while the rest are ignored.

The process of customizing and discovering a new model needs a theoretical and operational defined concept from where quality metrics incurred. However, the process by itself is not a straightforward. For instance, being operationalizing a definition and deriving measurement indicators, it is a must to consider the scale of measurement, such as nominal, ordinal, interval and ratio scales. On the other hand, application of basic measurement and data analysis techniques must be taken with a careful consideration.

In this case, ratio scale is taken into account, so as, it gives an opportunity to apply all mathematical operations like addition, subtraction, division, and multiplication, which is not naturally applicable for the rest. Whereas, percentage is taken as one of measurement approach with high tendency i.e. as the number increases, the quality of a particular attribute is said to be getting high in its quality. From these perspectives, the attributes mathematical model is explicated along with their category below.

4.3.1 Accountability

4.3.1.1 Governance

Governance specifies and measures a process, which is utilized by cloud service provider to manage client expectation, issues, and service performance, in general. Thus, it is quite important to take an indicator of good and bad governance into account with the issue cloud providers exclusively solved as they are detected or reported within the promised duration in time. Therefore, governance is given by Equation 4.1;

$$Governance\ = \left(\frac{\text{N}\underline{\text{o}}\ of\ solved\ issues}{\text{N}\underline{\text{o}}\ of\ detected\ or\ reported\ issues}\right) * 100\%$$

Equation 4.1 Governance mathematical model

Where N$\underline{o}$ $of\ solved\ issues$ represents the number of solved complains related to the service delivered to the customer concerning performance degradation, or some other issues within a month as it has been promised, whereas, N$\underline{o}$ $of\ detect\ or\ reported\ issues$ denotes all reported issues or exclusively detected by service providers. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a provider that has a very limited capability with ignorant policy, while 100% represents a provider which is capable of confronting client issues and maintaining their expectation to the finest level.

Not that, N$\underline{o}$ $of\ detected\ or\ reported\ issues$ should be non -zero.

4.3.1.2 Provider certifications

Provider certification asserts and measures the percentage of cloud provider's currently maintained certification for standards, such as ISO 27001 as customer call for it. It is mainly expressed through currently available certifications in response to requested certification and it is given by Equation 4.2;

$$Provider\ certifications = \left(\frac{\mathrm{N\underline{o}}\ of\ available\ certificate}{\mathrm{N\underline{o}}\ of\ requested\ certificate} \right) * 100\%$$

Equation 4.2 Provider certification

Where N$\underline{o}$ $of\ available\ certificate$ represents the number of available certificates the provider will be able to grant in response to the requested ones. Whereas, N$\underline{o}$ $of\ requested\ certificate$ denotes the number of requested certificates from customers side. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a provider which is not granted the required certification at all, while 100% represents a provider which that is furnished with all required certification that a customer expects.

Not that, N$\underline{o}$ $of\ requested\ certificate$ should be non -zero. Usability

4.3.1.3 Operability

Operability measures the tendency of the system to be easily operated by a user. It is mainly computed by the time taken to accomplish a given use case. Therefore, the operability of a system is measured by Equation 4.3.

$$Operability = \left(f_{i=1}^{n} \frac{\text{min response time}}{\text{Operation time}_i}\right) * 100$$

Equation 4.3 Operability mathematical mode

Where $\min response$ time represents the minimum response time of ith transaction. Whereas, Operation time_i denotes a time taken to accomplish *ith* use case, and f is a function that measures the central tendency of a set of data. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service that has low understandability, while 100% represents highly understandable service.

Not that, Operation time_i should be non -zero.

4.3.1.4 Understandability

Understandability measures the degree of customer's understanding of the capability and operation of the system. This is mainly verified through the number of services understood, and thereby, used out of provided ones. From this perspective, understandability is given by Equation 4.4.

$$Understandability = \left(f_{i=1}^{n} \frac{\text{N}\underline{\text{o}} \text{ of services used}_\text{i}}{\text{N}\underline{\text{o}}\ of\ services\ offered_i}\right) * 100$$

Equation 4.4 Understandability mathematical model

Where, N<u>o</u> of service used represents the total number of services used by the customer and N<u>o</u> of service offered represents the number of services offered by the provider, and f is a function that measures the central tendency of a set of data. On the other hand, no. of services offered should be greater than zero. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service that has low understandability, while 100% represents highly understandable service.

Not that, $\text{N}\underline{\text{o}}\ of\ services\ offered_i$ should be non -zero.

4.3.1.5 Learnability

Learnability measures the effort required of users to learn to use the system. The ability of the user to learn and start operating on the system is revealed by the number of users started using the service. Therefore, learnability is given by Equation 4.5;

$$Learnability = \left(f_{i=1}^{n} \frac{\text{N}\underline{\text{o}}\ of\ users\ using\ the\ service_i}{\text{total N}\underline{\text{o}}\ of\ \text{users}_i} \right) * 100\%$$

Equation 4.5 Learnability mathematical model

Where N$\underline{\text{o}}$ $of\ users\ using\ the\ service_i$ represents the number of users utilizing *ith* service to its full potential. Whereas, total N$\underline{\text{o}}$ of users denotes the total number of users registered to use the *ith* service and n represents the number of services being provided by a provider. Similarly, f represents a function that measures the central tendency of a set of data, such as the mean and medial. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service which is difficult to learn, while 100% represents a service which is easily learned.

Not that, total N$\underline{\text{o}}$ of users_i should be non -zero.

4.3.2 Financial

4.3.2.1 Cost

Cost measures the amount of money that should be devoted in terms of ongoing and acquisition cost for the leased service. Since comparing the cost of varies resources across service providers entails difficulties for the measurement. For instance, providers offer different amount of services such as computing, storage, and networking units, whereas, sometimes the same providers can provide a different price for the same service of different performance. In addition to this, there are factory that can affect price such as, penalty based pricing, reservation based pricing and hybrid pricing. However, such difficulties are mitigated by intruding volume base metrics as stated in [31]. Whereas, in this case discount factory cost is introduced by considering the unit price of the leased service of type storage, network, computation, platform, and application, etc. Here, a free price or non-payment service is marked $0. Having the above information on-demand cost and discount factors, given by Equation 4.7 and 4.8, a minimum cost is given by general Equation 4.6;

$$\text{cost} = \frac{1}{(\text{ondemand cost} - \text{discount factor cost})}$$

where, on-demand cost and pricing factors cost are given by Equation 4.7 and 4.8, respectively.

Equation 4.6 Cost Mathematical Model

$$\text{on demand unit cost} = \left(\frac{p}{\prod_i^n service_{\mathrm{i}}}\right)$$

Equation 4.7 On demand unit-cost calculation

$$\text{discount factors cost} = (on\ demant\ cost * f_{i=1}^{n} factor_{\mathrm{i}}\%)$$

Equation 4.8 Discount factor cost calculation

Where, p represent the sum of unit prices of required services i.e. for one unit of computing, network, and/or RAM, which is allocated service provider. Whereas, j represents weights for each service, where the sum of the weight should be one. n represents the number of services a customer wants to lease. A multiplication inverse of cost is taken in order to reverse its tendency and, as a result the tendency of this quality attribute is high and ranges from 0 to 1 i.e. 0 represents a service which is cheap, while 1 represents non-affordable service as far as cost is concerned by assuming the list price to $1.

Not that, $\text{ondemand cost} - \text{discount factor cost}$ should be non -zero.

4.3.3 Assurance

4.3.3.1 Availability

Availability refers to the percentage of the service accessibility by its users during a particular time interval. It is mainly concerned with a total time the service is said to be available or not for the requested time interval. Therefore, it is given by Equation 4.7;

$$Availability = \left(\frac{MTTF}{MTTF + MTTR}\right) * 100$$

Equation 4.9 Availability mathematical model

Where, MTTF represents mean time to failure in which the service said to be accessible without failure, whereas MTTR denotes mean time to repair, which is a total time for which service was not available. The tendency is high and ranges from 0% to 100% i.e. 0% represents low available service while 100% represents highly available service.

Not that, $MTTF + MTTR$ should be non -zero.

4.3.3.2 Reliability

Reliability measures the percentage of a service operation without failure during a given time and condition. The measurement considers the mean time between failure experienced during service time and meantime failure promised by the service provider. Therefore, it is given by Equation 4.8.

$$Reliability = \left(\frac{P_{MTBF}}{\mathrm{MTBF}}\right) * 100\%$$

Equation 4.10 Reliability mathematical model

MTBF is given by Equation 4.9,

$$MTBF = \frac{\text{total service time}_{\mathrm{i}}}{\text{number of failure}_{\mathrm{i}}}, where\ number\ of\ failure \neq 0$$

Equation 4.11 MTBF calculation

Where, MTBF represents mean time between failure that occurs during the total service time of a particular service provider that exceeds the promised mean time between failure, whereas P_{MTBF} represents the promised mean time to failure. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a provider that experiences low reliability, while 100% represents highly reliable service.

Not that, MTBF and number of $\text{failure}_{\mathrm{i}}$ should be non -zero.

4.3.3.3 Service Stability

Service stability measures the percentage in which the system remains unchanged, non-displacement and non-impairment. It is mainly concerned with the ability of the system being resistant to failure and bear on its normal functionality as specified in SLA. Service stability is given by Equation 4.10.

$$Stability = \left(\frac{Avg\ resource\ performance_i}{P_{SLA}\ resource\ performace_i}\right) * 100\%$$

Equation 4.12 Service stability mathematical model

Where $Avg\ resource\ performance$ is given by Equation 4.11.

$$Avg\ resource\ performance = f_{j=1}^{n} \frac{\text{resource performance}_j}{\text{n}}$$

Equation 4.13 Average resource performance calculation

Where $\text{resource performance}_i$ represents the unsatisfied observed performance of computation, network, storage, or etc. unit of the user j who leased a cloud service. Whereas, $P_{SLA}\ resource\ performace$ represents the promised performance in the SLA and n is the total number of users. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service that has low stability, while 100% represents highly stable service.

Not that, $Avg\ resource\ performance_i\ and\ n$ should be non -zero.

4.3.4 Performance

4.3.4.1 Response time

Response time measures the time between where the service is requested and the service is available. and it is mainly given by the ability of cloud service to perform a request during a time interval. Therefore, it is measured by Equation 4.12.

$$Response\ time = \left(\frac{t_{\max}}{f_{i=1}^{n}(t_i)} \right) * 100\%$$

Equation 4.14 Response time mathematical model

Where, t_i denotes the time between the submission and the completion of the *ith* request that exceed the acceptable response time t_{max}, and n is the number of requests issued in an operational period and f is a function that measures the central tendency of a set of data, such as the mean and medial. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service which is not responsible at all, while 100% represents minimum response time.

Not that, $f_{i=1}^{n}(t_i)$ should be non -zero.

4.3.4.2 Accuracy

Accuracy measures the degree to which a service stick with its requirement. It is mainly concerned with replied correct responses made out of varies requests. Which is given by Equation 4.3.

$$Accuracy = \left(f_{i=1}^{n} \frac{\text{number of correct responses}_i}{\text{total number of requests}_i}\right) * 100\%$$

Equation 4.15 Accuracy mathematical model

Where $\text{number of correct responses}_i$ represents the number of error free replies hit for the *ith* user, whereas the $\text{otal number of requests}_i$ denotes a total number of requests submitted by the *ith* user. And, n represents the total number of users and f is a function that measures the central tendency of a set of data, such as the mean and medial. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service which is not accurate, while 100% represents highly accurate service.

Not that, $\text{total number of requests}_i$ should be non -zero.

4.3.4.3 Suitability

Suitability measures the percentage of how closely the capability of service providers match the feature needed by the client. The measurement considers the essential features that a service consumer would like to acquire in response to available features. Therefore, the measurement is given by Equation 4.14;

$$Suitability = \left(f_{i=1}^{n} \frac{\text{N}\underline{\text{o}}\ \text{ of essential services provided}_i}{\text{total N}\underline{\text{o}}\ \text{ of essential services requested by user}_i}\right) * 100\%$$

Equation 4.16 Suitability mathematical model

Where $\text{N}\underline{\text{o}}\ \text{ of essential services provided}$ represent the number of necessary features being delivered for *ith* customers. Whereas, $\text{total N}\underline{\text{o}}\text{ of essential services requested by user}_i$ denotes the number of features required by the *ith* customer and n represents the number of customers and f is a function that measures the central tendency of a set of data, such as the mean and medial. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service which is not suitable at all, while 100% represents highly suitable service.

Not that, $\text{total N}\underline{\text{o}}\ \text{ of essential services requested by user}_i$ should be non -zero.

4.3.4.4 *Interoperability*

Interoperability measures the ability of the service interaction with other services. The interaction can be requested to the same cloud service provider or other cloud providers. It mainly concerned with a service's capability to support a given platform. Therefore, it is given by Equation 4.15;

$$Interoperability = \left(\frac{\text{N}\underline{\text{o}}\ \text{of platforms offered by the provider}}{\text{total N}\underline{\text{o}}\ \text{of platforms required by user}}\right) * 100\%$$

Equation 4.17 Interoperability mathematical model

Where $\text{N}\underline{\text{o}}\ \text{of platforms offered by the provider}$ represents the number of platforms being offered for *ith* customer and $\text{total N}\underline{\text{o}}\ \text{of essential services requested by user}_i$ denotes the total number of platforms requested by *ith* customer. Whereas, f is a function that measures the central tendency of a set of data, such as the mean and medial and n represents the number of customers. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service which does not support all requested platform, while 100% represents a service that supports all the requested platform.

Not that, $\text{total N}\underline{\text{o}}\ \text{of platforms required by user}$ should be non -zero.

4.3.5 Agility

4.3.5.1 *Elasticity*

Elasticity measures the ability of the system to adapt to workload change by provisioning and de-provisioning resources in an automated manner and rapid enough period of time to meet customer demand. It is mainly featured by pay per use or pay as we go characteristic of cloud computing. for instance, elasticity might include dynamically deploying a new virtual machine or shutting down inactive virtual machines. In this context, the parameter of measuring elasticity merely depends on the number of resources allocated and requested, whenever requested by a customer, as closely as possible. That means the duration of time it takes to deprovision and provision a resource is the main factor. Therefore, it is given by Equation 4.16;

$$Elasticity = \left(1 - f_{i=1}^{n}\ \frac{\text{defect time of resource}_{\text{i}}}{\text{total time}}\right) * 100\%$$

Equation 4.18 Elasticity mathematical model

Where, $\text{defet time of resource}_{\text{i}}$ represents a time that took beyond the promised grace time to provision or deprovision *ith* resource. On the other hand, total time denotes a total time to provision and deprovision the resource, i.e. the sum of grace time and defect time. Whereas, f is a function that measures the central tendency of a set of data, such as the mean and medial and n represents the number of resource provisioned or deprovisioned. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service with low elasticity while 100% represents a service which is highly elastic.

Not that, total time should be non -zero.

4.3.5.2 Scalability

Scalability is one of the most important quality aspects in cloud computing, in such a way that, the concept of cloud computing revolves around scaling up and down automatically as the need arises. Likewise, scalability defined as the capability of increasing the computing capacity of service provider's computer system and system ability to process more users request, operations or transactions in a given interval [1]. From this definition, it is quite important to look at requested resources, and available resource closely. Therefore, scalability is given by Equation 4.17;

$$Scalability = \left(f_{i=1}^{n} \frac{\text{available resources}_i}{requested\ resourecs_i} \right) * 100\%$$

Equation 4.19 Scalability mathematical model

Where, available resources and requested resources represent granted resource by cloud service provider in response to a requested resource from cloud service consumer at the *ith* request, respectively. whereas, *n* denotes the number of requests forwarded by the service consumer, and f is a function that measures the central tendency of a set of data. The tendency is high and ranges from 0% to 100% i.e. 0 represents low scalability while 100 represents highly scalable service.

Not that, $requested\ resourecs_i$ should be non -zero.

4.3.6 Security and privacy

4.3.6.1 Data privacy and data loss

Data privacy and data loss measures defects on client restrictions on use and sharing of client data that are enforced by the client service provider. This defect mainly discovered and reported as soon as information kept on the cloud is observed and disturbed by others. Therefore, the measurement is given by Equation 4.18;

$$Data\ privacy\ and\ data\ loss = \left(1 - f_{i=1}^{n} \frac{\text{N}\underline{\text{o}}\ of\ third\ party\ access_i}{total\ \text{N}\underline{\text{o}}\ of\ access_i} \right) * 100\%$$

Equation 4.20 Data privacy and data loss

Where N$\underline{\text{o}}$ $of\ third\ party\ access_i$ represents the number of successful third-party accesses on ith user data and $total$ N$\underline{\text{o}}$ $of\ access_i$ denotes the total number of attempts undertook on the ith user data. Whereas, f represents a function that measures the central tendency of a set of data, such as the mean and medial. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a service that lack a security mechanism to preserve a breach on data privacy and disturbance, while 100% represents a service with high security mechanism to defend the third-party access attempt.

Not that, $total$ N$\underline{\text{o}}$ $of\ access_i$ should be non -zero.

4.3.6.2 Data Integrity

Data integrity measures the degree in which the data, which is created, used and stored is in its correct form, so as it is still accurate, and valid. This attribute is concerned with the data accuracy and consistency before and after modification, and therefore, given by Equation 4.19;

$$Data\ Integrity = \frac{\left(f_{i=1}^{n} \frac{validity_{dsi} + accuracy_{dsi} + consistency_{dsi}}{\text{N}\underline{\text{o}}\ of\ record\ in\ the\ dataset_i} \right)}{3} * 100\%$$

Equation 4.21 Data integrity mathematical model

Where, N$\underline{\text{o}}$ $of\ record\ in\ the\ data\ set_i\ represents$ is the current valid and invalid, accurate and inaccurate, as well as consistent and inconsistent data of ith dataset (ds). Whereas $validity_{dsi}$ represents a dataset that confronts to the data syntax of its definition. Similarly, $accuracy_{dsi}$, and $consistency_{dsi}$ represents the count of accurate object and number of distinct record, respectively. And n represents the number of dataset under consideration. Whereas, f represents a function that measures the central tendency of a set of data, such as the mean and medial. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents less accurate and consistent service, while 100% represents a service with high accuracy and consistency.

Not that N$\underline{o}$ $of\ record\ in\ the\ dataset_i$ should be non -zero.

4.3.6.3 Access control and privilege management

Access control and privilege management measure the capability of policies that are in place to safeguard the use and modification of data or work products by unauthorized personnel. Cloud providers policies and technical capability in detecting and making the right measures before unauthorized user gets into the system can be measured through password reset volume request per month. Thus, access control and privilege management is given by Equation 4.19;

$$Access\ control\ = \left(f_{i=1}^{n} \frac{1}{\text{N}\underline{\text{o}}\ of\ password\ reset\ request_i} \right) * 100\%$$

Equation 4.22 Access control and privilege management mathematical model

Where N$\underline{o}$ $of\ password\ reset\ request$ represents a number of password reset request forwarded for password reset help desk from ith customer per month and it assumes that one password reset request per month is an acceptable request. Whereas, f represents a function that measures the central tendency of a set of data, such as the mean and medial and n is the number of customers under consideration. The tendency of this quality attribute is high and ranges from 0% to 100% i.e. 0% represents a provider that has a very limited capability with ignorant policy towards access control and privacy, while 100% represents a provider with reliable access control and privilege management policy.

Not that, N$\underline{o}$ $of\ password\ reset\ request_i$ should be non -zero.

4.4 Cloud service provider selection mechanism

In the above two sections, selection criteria and quantification of the selected criteria are specified. Right after evaluating and computing QoS attributes values, the candidate cloud services are evaluated and ranked to support end users' preference. Thus, in this section, AHP discussed with respect to the use of quantified quality of service models. AHP follows the following procedures to rank alternative using selection criteria and criteria weight.

1. Decompose the problem in to its constituent elements i.e. as it is given in the second section of chapter two, seven class of cloud service quality categories has been decomposed into multiple sub-characteristics called attributes, and in turn, the decomposition continues to

the indivisible key performance indexes that are used in the mathematical model of this chapter.

2. Define a set of criteria that the alternatives need to be evaluated with, in this case, the first section of this chapter has narrated the process of selecting the most important cloud service evaluation and cloud provider selection criteria.
3. Define a set of alternatives from where the outfitted cloud provider is selected from. Simply, it is a set of cloud providers that are competing to provide services on demand.
4. Accurately estimate the pertinent data. In MCDM, most of the time, it is a must to tackle with a qualitative data which is difficult to represent by aesthetic value, for instance, representing usability of a service provided by a service provider in terms of aesthetic value. Although, those quality attributes (selection criteria) are vital in decision making but difficult to use if not impossible to quantify it correctly. In the second section of this chapter, a mathematical model has been presented and briefly discussed to solve this problem.
5. Construct a set of pairwise comparison matrices. To perform the comparison, a scale of 0 to 1 is used. The scale represents the importance of one attribute over other attributes with respect to their parent attributes. Those assigned scales are known as the local weight of each attribute. The sum of the local weight is one. Apparent to this, global weight of the upper class should be obtained and assigned to all categories. The sum of the global weight is one.
6. To compute the service ranking, for each service candidate, the calculated attributes values multiplied with the obtained wait from the previous step. Then the results summed up using weighted sum method.

Strictly Sticking with the above procedures, it is simple and straightforward to rank providers based on the given criteria. In addition to this, to accommodate a consumer that demands a few selection criteria for the selection process and to deal with the hierarchical nature of the problem, decoration design pattern has been selected in order to implement the ranking system in such a way that open for extension and close for modification, whenever a new criteria and other modifications introduced to the system.

CHAPTER FIVE

5. A case study: Experimentation on AWS, Microsoft Azure, Google

5.1 Overview

As the main objective of the research work was developing a mathematical model for cloud vendors QoS and thereby inherit them in cloud migration decision support, a simple case study was conducted to realize and clarify the importance of the proposed model from a real-world perspective.

Accordingly, in this section, the mathematical models were exposed with three popular, competitive and representative cloud providers, to wit Amazon Web Service (AWS), Microsoft Azure and Google Cloud, to rank and thereby depict the decision-making capability of the research work. The main reason for the selection of the three vendors was their status as a three-top leading adopted cloud vendor of 2018, 2017, and 2016 [57] [58] [59]as well as their position of being the leading industry innovator in the IT industry.

Although it was an inevitable task to evaluate all functionally equivalent providers, it is time-consuming, difficult and sometimes impossible to evaluate all the available alternatives. Thus, the decision maker is given the aforementioned providers as an alternative, viz, AWS, Microsoft Azure and Google Cloud, and they are prompted to select category and QoS, with their respective weight.

Amazon Web Service characterized as the current leading cloud service provider [59] with a dynamic growing business unit within Amazon.com. It is providing more than one hundred fifty services under twenty-four categories regardless of where the user located. Whereas, Microsoft Azure has a catchword that gives more than one hundred services in anywhere anytime bases with an end to end tools. It has an exponentially growing market in the current cloud market. On the other hand, Google Cloud has more than one-hundred services with thirteen categories that are accessed on bases of get-work from anywhere on any device.

On the other end, the case study implemented on ASTU, as cloud watcher customer. ASTU is believed to be one of the potential customers who is looking to adopt cloud service as a solution for many of its service as soon as the technology introduced in the country, for know, atleast they are eager to introduce computing and storage services from a better cloud provider. ASTU meets the research problem as there are no complete quantified QoS collections to this degree, in order to select a better cloud vendor from the given alternatives, unambiguously. Thereof, ASTU started the process of identifying the better vendor based on QoS they possess.

5.2 Dataset description

There are different kinds of services that are provided by the same and different cloud providers. The quality of those providers extracted from KPI which is possessed by their respective services. However, given the current technology, there is no runtime KPI index capturing methodology [14].

As a result, the KPIs such as the number of solved issues, number of detected and/or reported issues, number of available certificates, response time and cost were collected from the service providers websites i.e. AWS_[60], google [61]_and [62] Whereas, some of KPIs, like failures reported and the time it took to recover, were collected from a third-party website like, cloud status [63], for all alternatives. In this regard, the data collection period ranges from Jan 1, 2018 to May 9, 2018 i.e. a data recorded for 172,800 minutes.

In addition to the collected data, an experiment has been conducted, with an experiment setup illustrated in Table 5.1, in order to extract performance indicators such as response time with regard to the time it takes to respond for the sign-in scenario. Understandably, as the sign-in scenario requires providers credential, which is not applicable with the currently available technology, the scenario response time was considered from the unsuccessful acknowledgment message perspective. And then, all the collected data are stored in a repository as a snapshot of all the KPI values.

Nevertheless, some KPI that are expected to be extracted from customers and those require privilege are not taken from a real scenario. For instance, the number of password reset request, number of certificate requests, the number of correct responses, number of third party access, number of successful penetrations the number of service used, as well as number of service offered would be collected from cloud customers.

To mitigate this gap, the KPI values are taken by assumption in such a way that the values couldn't not affect the overall score, by referring to the previous works [31] [54]. And, on KPI that needs a pre-defined value such as a maximum acceptable time to complete a specific task i.e. minimum response time is 30ms and scalability grace time 40ms are also taken by assumption.

On the other hand, Decision makers from ASTU information communication technology (ICT) center consisting of five members (i.e. ICT director, team leader and two system admins) were engaged and exposed with the prototype in order to feed their requirement to the prototype. In this case, the data that they feed were the QoS of their choice along with their respective weight, which is believed to be a fact that they want to be informed about for a decision to be made.

The DMs are computer professionals especially from cloud computing and data center background. The experts were asked to select the QoS of their interest and weight them as they go. The value of the weight should be summed to one. The criteria and their respective weights are presented in Appendix A.

5.3 Experiment Setup and Prototype Tools

An experiment has been conducted with frontend JavaFX, backend MYSQL, and editor Netbeans tools. The experiment environment configured as illustrated below in Table 5.1. The reason Java, which is a well-known programming language, selected for a prototype was because of its future compatibility as all cloud providers are using the language and provide java API for monitoring service status than any other programming [64] [65], so does for MYSQL.

Table 5.1 Experimental tool

Tool	***Specification***
Computer	Lenovo, corei5, 7th Gen, 250GB Hard disk, 8GB RAM, 250GHz, 279GHz
OS	Windows 10 Home, 64 bits
Frontend	JavaFX
Backend	MYSQL
Network bandwidth /networx	7.0 kb/s

5.4 Proposed Model Realization

After exhaustive researches that are related to evaluation criteria for cloud services and ranking explored, an evaluating criteria catalog has been developed. However, the developed catalog is a generic one and needs a change on a set of criteria that should be considered in order to meet DMs or any other organization needs.

Thus, in this case, ASTU DMs validated all the criteria, accepting them as an essential criterion for decision making. Service criteria in Fig 5.1 shows the selected evaluation criteria grouped into seven categories.

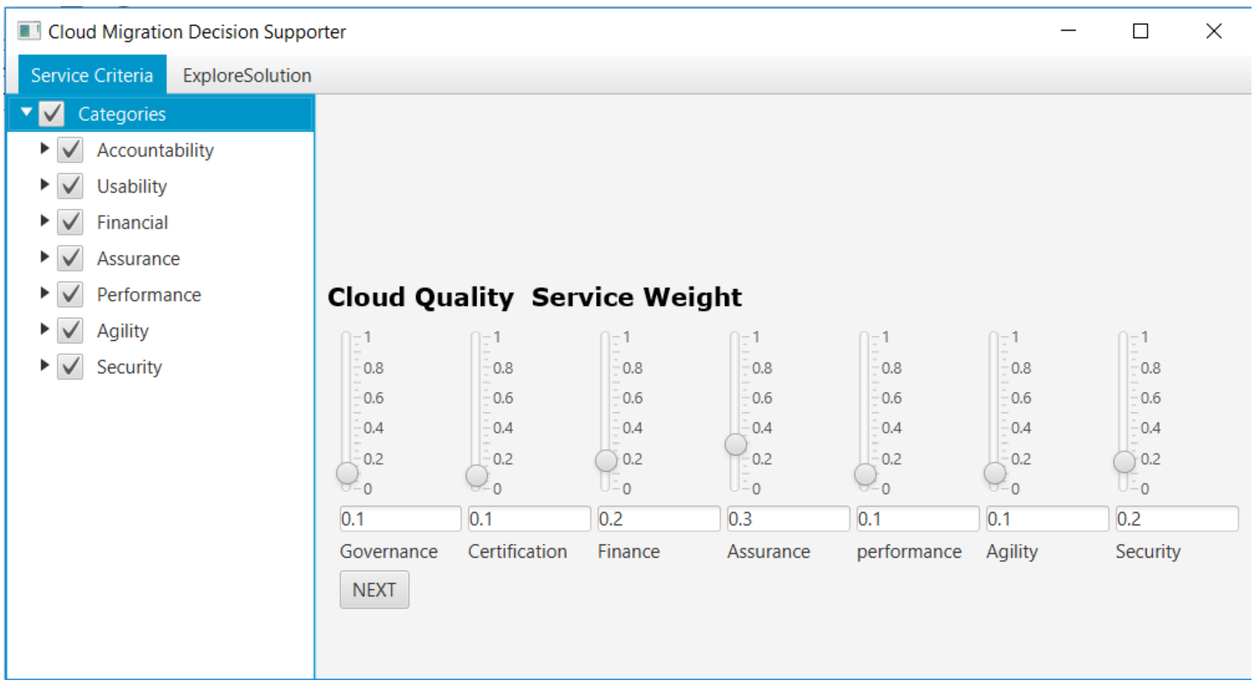

Figure 5.1QoS Criteria Weighting Page

Evaluation of AWS, Microsoft Azure, and Google cloud, in the case study, followed the recipe discussed in the last topic of chapter four. Thus, the case study implemented and narrated in accordance with the cloud provider selection approach called AHP, which is one of known MCDM problem approach. Below is the detail prescription of the case study.

Decomposing the problem into its constituent elements, the case study is performed with the hierarchical approach, in which DMs are prompted to select QoS category of their choice and assign a weight for each category based on its attractiveness. The sum of the assigned weights summed to one. Under each category, the case study constituent QoS attributes which in turn defined the KPI of those QoS attributes. Accordingly, the snapshot of this procedure and its structure are illustrated in Fig 5.1 and Fig 5.2, respectively.

QoS attribute selection: - After DMs select the category of their choice, they select and validate the descriptors of QoS attributes along with their level of importance. The QoS attributes are then rendered and selected as shown in Fig 5.2.

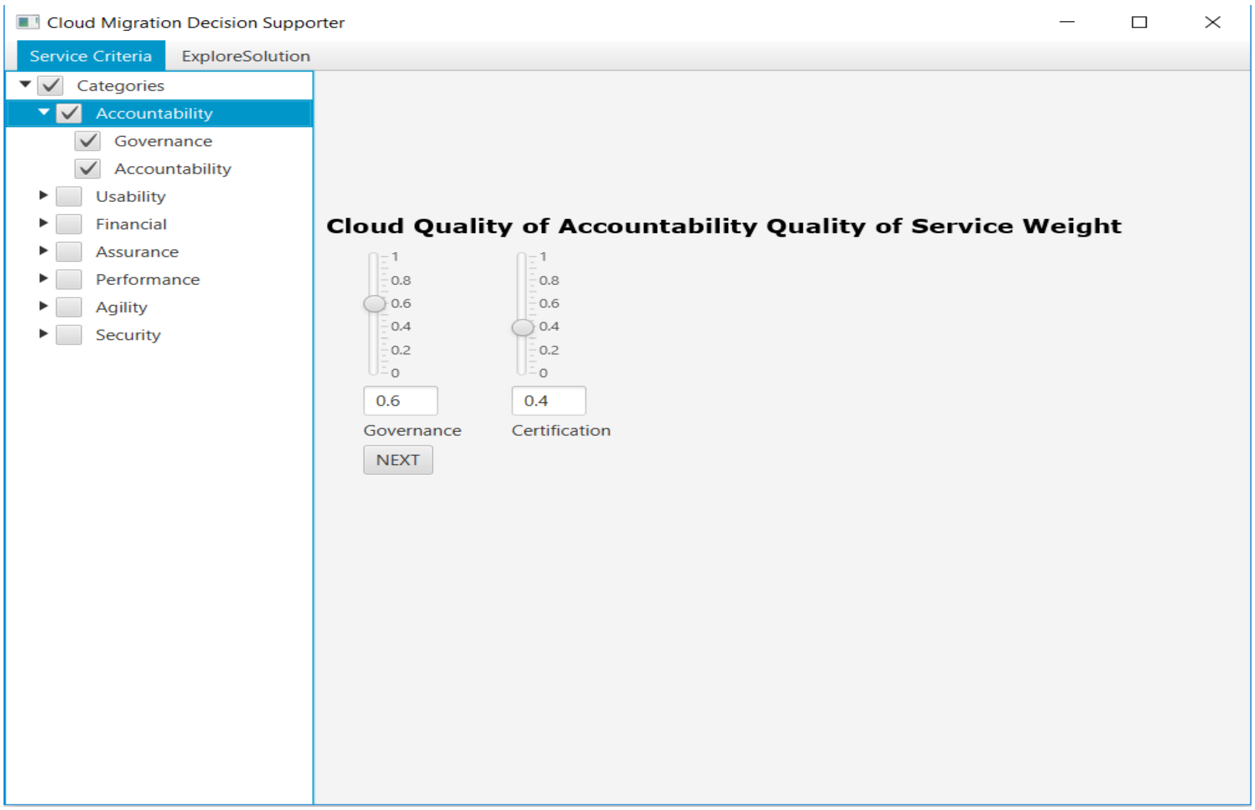

Figure 5.2QoS weight

Fortunately, after a rigorous check, DMs show an interest on all the eighteen QoS attributes i.e. governance, certification, understandability, learnability, operability, service stability, availability, reliability, response time, accuracy, suitability, interoperability, scalability, elasticity, cost, access control and privilege management, data integrity and data privacy and data loss. Then the level of their importance is given by the weight assigned for each QoS attributes. The sum of the weight in each category is added to one.

Then after, alternative cloud providers selection proceeds. In this step, DMs are prompted to set of alternatives called AWS, Azure, and Google cloud. , KPI values of the three alternatives retrieved from repository and secondly, the KPI applied on the proposed model i.e. QoS quantification proceeds. Appendix A is populated with the respective KPI values. Where all the rendered KPI values are captured as a snapshot performance. An example of elasticity mathematical model is given by sample code below. The function takes an array of defect time and grace period and calculate elasticity.

```
public double calculateElasticity(double defectTime[], double graceTime){

    double sum=0;
    double tempResult;
    for(int i = 0; i<defectTime.length; i++)
    {
        tempResult = defectTime[i]/(defectTime[i]+graceTime);
        sum+=tempResult;
        tempResult = 0.0;
    }

   elasticity = sum/defectTime.length;

   return elasticity;

}
```

Finally, the AHP ranking matrix, introduced in Equation 2.1, is constructed using the following method to aggregate the value of based on the calculated QoS values. The matrix is initialized as rendered in sample code below.

$QoS_{governance}$ (0.6) = AWS: $\left(\frac{556}{2469}\right) * 100\% = 22.5\%$ $Azure$: $\left(\frac{58002}{101873}\right) * 100\% = 56.9\%$ $Google\ Cloud$: $\left(\frac{2391}{4608}\right) * 100\% = 51.9\%$	$QoS_{certification}$ (0.4) = AWS $\left(\frac{4}{5}\right) * 100\% = 80\%$ Azure $\left(\frac{5}{5}\right) * 100\% = 100\%$ Google $\left(\frac{4}{5}\right) * 100\% = 80\%$

```
public static double[][] initialize_AHP_matrix(double[] criteria)
{

    double a[][]=new double[criteria.length][criteria.length];
    int k=0;
    for(int i=0; i<criteria.length; i++)
    {
        k = 0;

        for(int j=0; j<criteria.length;j++)
        {
            if(i==j)
                a[i][j]=1;
            else if(i<j)
            {

                a[i][j]=criteria[k];
                k++;
            }

            else if(i>j)
                a[i][j]=1/a[j][i];
        }
    }
    return a;
}
```

Computing for the $QoS_{governance}$ and $QoS_{certification}$ of accountability (0.1) category attributes using proposed mathematical model, we have;

And then computing for accountability category with AHP relative ranking matrix, we get,

$$Accountability = \begin{pmatrix} Alt & Governance & Accountability \\ Weight & 0.6 & 0.4 \\ AWS & \frac{22.5}{56.9} & \frac{80}{100} \\ Azure & \frac{56.9}{56.9} & \frac{100}{100} \\ Google & \frac{51.9}{56.9} & \frac{80}{100} \end{pmatrix} = \begin{matrix} 0.557 \\ 1 \\ 0.867 \end{matrix}$$

Similarly, the calculated QoS for usability attributes i.e. $QoS_{operability}$, $QoS_{understandability}$ and $QoS_{learnability}$, are given by;

QoS$_{operability}$ (0.3)	QoS$_{understandability}$ (0.4)
AWS: $$\left(\frac{\left(\frac{41}{253}+\frac{41}{254}+\frac{41}{253}+\frac{41}{251}\right)}{4}\right)*100\% = 17\%$$ Azure $$\left(\frac{\left(\frac{41}{169}+\frac{41}{171}+\frac{41}{167}+\frac{41}{169}\right)}{4}\right)*100\% = 24.3\%$$ Google $$\left(\frac{\left(\frac{41}{41}+\frac{41}{42}+\frac{41}{41}+\frac{41}{40}\right)}{4}\right)*100\% = 100\%$$	AWS $$= \left(\frac{2}{5}\right)*100 = 40\%$$ Azure $$= \left(\frac{7}{9}\right)*100 = 77\%$$ Google $$= \left(\frac{3}{5}\right)*100 = 60\%$$
QoS$_{learnability}$ (0.3) considering all users of the provider AWS $$= \left(\frac{672{,}000}{1{,}200{,}0000}\right)*100\% = 56\%$$ Azure $$= \left(\frac{550{,}000}{1{,}100{,}0000}\right)*100\% = 50\%$$ Google $$= \left(\frac{460{,}000}{1{,}000{,}0000}\right)*100\% = 46\%$$	

Then, computing for Usability category as a relative ranking matrix, we get

$$Usability = \begin{pmatrix} Alt & oberbility & understadability & Learnability \\ Weight & 0.3 & 0.4 & 0.3 \\ AWS & \frac{17}{100} & \frac{40}{77} & \frac{56}{56} \\ Azure & \frac{24.3}{100} & \frac{77}{77} & \frac{50}{56} \\ Google & \frac{100}{100} & \frac{60}{77} & \frac{46}{56} \end{pmatrix} = \begin{matrix} 0.5588 \\ 0.741 \\ 0.858 \end{matrix}$$

For finance category the calculated QoS is given QoS_{cost};

QoS_{cost} (1) as a function of computing and storage unit

AWS

$$\text{on demand unit cost} = \left(\frac{1128}{8^{0.2} * 28^{0.2} * 400^{0.6}}\right) = \$10.498/volume$$

$$\text{discount factor cost} = \left(10.498 * \frac{75}{100}\right) = \$6.244/volume$$

$$\text{cost} = \frac{1}{(10.498 - 6.244)} = 0.381$$

Azure

$$\text{on demand unit cost} = \left(\frac{932}{8^{0.2} * 28^{0.2} * 400^{0.6}}\right) = \$8.673/volume$$

$$\text{discount factor cost} = \left(8.673 * \frac{72}{100}\right) = 6.244$$

$$\text{cost} = \frac{1}{(8.673 - 6.244)} = 0.412$$

Google

$$\text{on demand unit cost} = \left(\frac{817.6}{8^{0.2} * 28^{0.2} * 400^{0.6}}\right) = \$7.609/volume$$

$$\text{discount factor cost} = \left(7.609 * \frac{47.8}{100}\right) = 3.637$$

$$\text{cost} = \frac{1}{(7.609 - 3.637)} = 0.252$$

Then after, the relative matrix finance is given as a function of cost by;

$$Finance = \begin{pmatrix} Alt & oberbility \\ Weight & 0.3 \\ AWS & \frac{0.381}{0.412} \\ Azure & \frac{0.412}{0.412} \\ Google & \frac{0.252}{0.412} \end{pmatrix} = \begin{matrix} 0.925 \\ 1 \\ 0.612 \end{matrix}$$

Next, we compute for assurance attributes, as it is given by $QoS_{availability}$, $QoS_{reliability}$ and $QoS_{stability}$;

$QoS_{availability}$ (0.2)	$QoS_{stability}$ (0.3)
AWS $\left(\frac{184953}{184953 + 807}\right) * 100 = 99.56\%$	AWS $\frac{\left(\frac{13.6}{36} + \frac{17.9}{50}\right)}{2} * 100\% = 36.75\%$
Azure $\left(\frac{184953}{184953 + 5261}\right) * 100 = 97.23\%$	Azure $\frac{\left(\frac{16}{38} + \frac{23}{48}\right)}{2} * 100\% = 38.95\%$
Google $\left(\frac{184953}{184953 + 3685}\right) * 100 = 98.05\%$	Google $\frac{\left(\frac{7}{36} + \frac{12}{50}\right)}{2} * 100\% = 43.44\%$

QoS$_{reliability}$ (0.5)	
AWS $MTBF = \frac{185760}{10} = 18576\ minutes$ $= \left(\frac{18,204}{18576}\right) * 100\% = 98.04\%$ Azure $MTBF = \frac{185760}{16} = 11,610\ minutes$ $= \left(\frac{11,610}{18576}\right) * 100\% = 62.5\%$ Google $MTBF = \frac{185760}{34} = 5463.5\ minutes$ $= \left(\frac{5463.5}{18576}\right) * 100\% = 29.4\%$	

Similarly, assurance is computed as a function of relative ranking matrix as shown below;

$$Assurance = \begin{pmatrix} Alt & availability & reliability & stability \\ Weight & 0.2 & 0.5 & 0.3 \\ AWS & \frac{99.56}{99.56} & \frac{98.04}{98.04} & \frac{36.75}{43.44} \\ Azure & \frac{97.23}{99.56} & \frac{62.5}{98.04} & \frac{38.95}{43.44} \\ Google & \frac{98.05}{99.56} & \frac{29.4}{98.04} & \frac{43.44}{43.44} \end{pmatrix} = \begin{matrix} 0.954 \\ 0.783 \\ 0.647 \end{matrix}$$

On the other hand, for performance category we compute QoS$_{response_time}$, QoS$_{accuracy}$, QoS$_{sutability}$, and QoS$_{interoperability}$ attributes as follows;

QoS$_{response_time}$ (0.3)	QoS$_{sutability}$ (0.2)
AWS $= \left(\frac{30}{253}\right) * 100\% = 11.85\%$	AWS $\left(\frac{3}{3}\right) * 100\% = 100\%$

Azure $= \left(\frac{30}{169}\right) * 100\% = 17.75\%$ Google $= \left(\frac{30}{41}\right) * 100\% = 73.17\%$	Azure $\left(\frac{3}{3}\right) * 100\% = 100\%$ Google $\left(\frac{3}{3}\right) * 100\% = 100\%$
$QoS_{accuracy}$ (0.4) AWS $= \left(\frac{2438}{2469}\right) * 100\% = 98.74\%$ Azure $= \left(\frac{100942}{101873}\right) * 100\% = 99.08\%$ Google $= \left(\frac{4492}{4608}\right) * 100\% = 97.48$	$QoS_{interoperability}$ (0.1) AWS $= \left(\frac{2}{2}\right) * 100\%$ Azure $= \left(\frac{2}{2}\right) * 100\% = 100\%$ Google $= \left(\frac{2}{2}\right) * 100\% = 100\%$

As always, the relative ranking matrix for performance category is given by;

$$performance = \begin{pmatrix} Alt & response\ time & accuracy & sutability & interoperability \\ Weight & 0.3 & 0.4 & 0.2 & 0.1 \\ AWS & \frac{11.85}{73.17} & \frac{98.74}{99.08} & \frac{100}{100} & \frac{100}{100} \\ Azure & \frac{17.75}{73.17} & \frac{99.08}{99.08} & \frac{100}{100} & \frac{100}{100} \\ Google & \frac{73.17}{73.17} & \frac{97.48}{99.08} & \frac{100}{100} & \frac{100}{100} \end{pmatrix} = \begin{matrix} 0.727 \\ 0.773 \\ 0.993 \end{matrix}$$

Agility of a particular service is also computed using the developed model with two attributes called $QoS_{elasticity\ and}$ $QoS_{scalabilit}$ and give by;

QoS$_{elasticity}$ (0.5)	QoS$_{scalability}$
AWS $= \left(1 - \frac{\left(\frac{40}{80} + \frac{80}{120}\right)}{2}\right) * 100\% = 41.5\%$ Azure $= \left(1 - \frac{\left(\frac{480}{520} + \frac{740}{780}\right)}{2}\right) * 100\% = 6.41\%$ Google $= \left(1 - \frac{\left(\frac{0}{20} + \frac{160}{200}\right)}{2}\right) * 100\% = 20\%$	AWS $= \frac{100\text{GB}}{100GB} * 100\% = 100\%$ Azure $= \frac{100\text{GB}}{100GB} * 100\%$ Google $= \frac{100\text{GB}}{100GB} * 100\%$

Whereas, the relative ranking matrix of agility category is calculated with the following matrix;

$$agility = \begin{array}{c} \\ \\ \end{array}\begin{pmatrix} Alt & elasticity & accuracy \\ Weight & 0.5 & 0.5 \\ AWS & \frac{41.5}{41.5} & \frac{100}{100} \\ Azure & \frac{6.41}{41.5} & \frac{100}{100} \\ Google & \frac{20}{41.5} & \frac{100}{100} \end{pmatrix} = \begin{matrix} 1 \\ 0.577 \\ 0.740 \end{matrix}$$

Then after, an individual QoS of Security and privacy computed, the aggregated security and privacy relative matrix is given by:

$$security\ and\ privacy = \begin{pmatrix} Alt & integrity & privacy\ and\ data\ loss & access\ control \\ Weight & 0.4 & 0.3 & 0.3 \\ AWS & \frac{98.75}{98.75} & \frac{91.11}{97.78} & \frac{20}{50} \\ Azure & \frac{98.75}{98.75} & \frac{94.44}{97.78} & \frac{33.33}{50} \\ Google & \frac{98.75}{98.75} & \frac{97.78}{97.78} & \frac{50}{50} \end{pmatrix}$$

$$security\ and\ privacy = \begin{matrix} 0.979 \\ 0.889 \\ 1 \end{matrix}$$

Finally, security and privacy category attributes are computed by using the proposed expression as it is given by:

$QoS_{privacy\_and\_data\_loss}$ (0.4) AWS $1 - \frac{5}{400} * 100\% = 98.75\%$ Azure AWS $\frac{5}{400} * 100\% = 98.75\%$ Google AWS $\frac{5}{400} * 100\% = 98.75\%$	
$QoS_{access\_control}$ (0.3) AWS $\frac{\left(\frac{250 + 280 + 290}{300}\right)}{3} * 100\% = 91.11\%$ Azure $\frac{\left(\frac{280 + 270 + 300}{300}\right)}{3} * 100\% = 94.44\%$ Google $\frac{\left(\frac{290 + 300 + 290}{300}\right)}{3} * 100\% = 97.78\%$	

Having, the calculated QoS category the final relative ranking matrix is developed by aggregating and introducing Equation 2.1 again, we get;

$$Alternatives\ rank = \begin{pmatrix} Alt & c1 & c2 & c3 & c4 & c5 & c6 & c7 \\ Weight & 0.1 & 0.1 & 0.2 & 0.3 & 0.1 & 0.1 & 0.2 \\ AWS & 0.557 & \frac{0.5588}{0.858} & 0.925 & 1 & \frac{0.727}{0.993} & 1 & 0.979 \\ Azure & 1 & \frac{0.741}{0.858} & 1 & \frac{0.783}{0.954} & \frac{0.773}{0.993} & 0.577 & 0.889 \\ Google & 0.867 & 1 & 0.612 & \frac{0.647}{0.954} & 1 & 0.740 & 1 \end{pmatrix}$$

$$Alternatives\ rank = \begin{matrix} 0.975 \\ 0.946 \\ 0.887 \end{matrix}$$

Thus, based on the result we get from the final relative ranking matrix the following alternative, result and rank is specified in Fig 5.3 below.

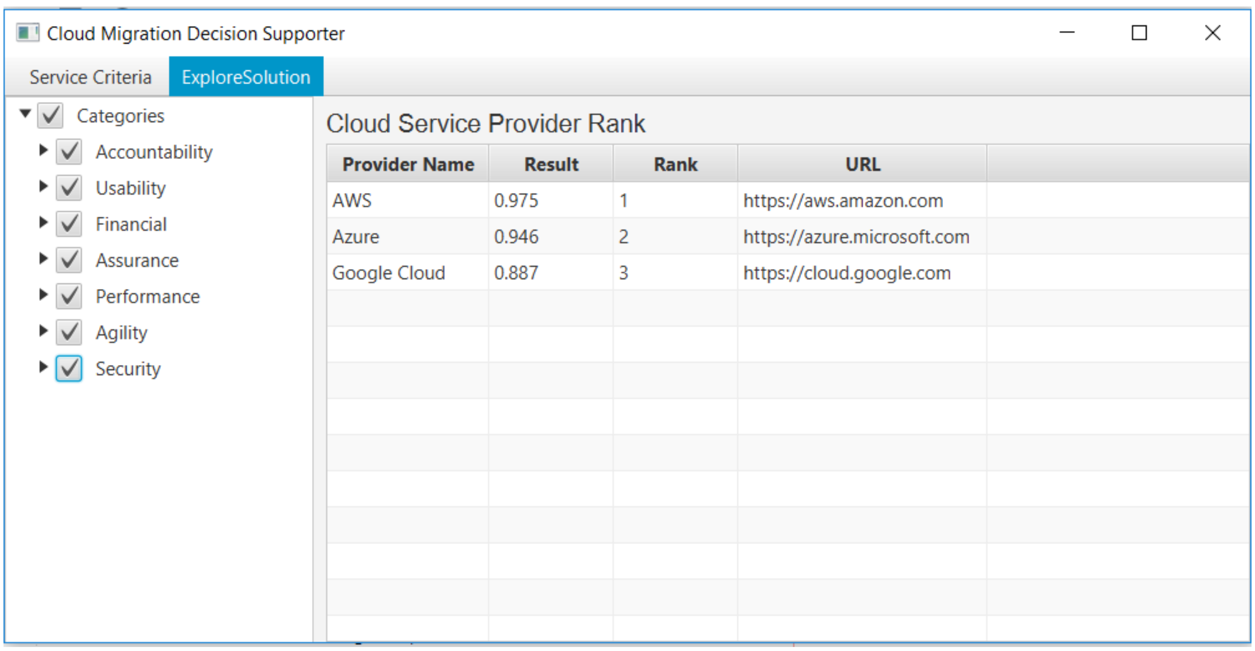

Figure 5.3 Cloud service provider rank screen

CHAPTER SIX

6. Evaluation and Result

6.1 Overview

In this section, the evaluation of DSRM, which is a crucial step that aim to show how the proposed work supports and measures a solution of the problem, is discussed. It verifies the contribution of the solution for the identified problem as well as its utility, quality and efficacy are asserted. DSRM provided five design evaluation method such as, observation, analytical, experimental, testing and descriptive [38]. Having defined such evaluation path, some researches have given direction on how to achieve them [36]. Accordingly, the model evaluated against Evaluation framework, Moody and Shanks Quality Framework, and four principles of Osterle et al.

6.2 Design Science Research Evaluation Framework

The framework designed as a three distinguished evaluation dimensions with their respective aspects. This framework is designed passed on three questions, i.e. when does evaluation take place? how is it evaluated? and what is actually evaluated? The first dimension is concerned with the moment in time of the evaluation which is known as ex ante, meaning that the evaluation takes place before the artifact developed, or ex post, meaning that the evaluation is conducted with the artifact already developed. Whereas, the second dimension is linked to the nature of the evaluation, i.e. it can be artificial, where the solution is considered in a non-realistic way, on the other hand, naturalistic, meaning that the evaluation consists on exploring the performance of a solution within its real environment. At last, the third dimension distinguishes the artifact between design process, in which the result of a particular process that can be considered tangible, and design product, in which a set of activities, tools, methods, and practices that can be used to guide the flow of production is defined.

6.3 Moody and Shanks Quality Framework

The Moody and Shanks Quality Framework is the result of research on how to evaluate and improve the quality of data models from the perspective of the multiple stakeholders and proposes the following quality factors

- Completeness: refers to whether the model contains all user and information requirements.
- Integrity: refers to whether the data model defines all business rules that apply.
- Flexibility: measures the ease with which the model can reflect changes in requirements without changing the model itself.
- Understandability: measure the ease with which the concepts and structures in the model can be understood.
- Correctness: refers to whether the model conforms to rules and conventions.
- Simplicity: refers to whether the model contains the minimum number of entities needed for the model.
- Integration: refers to whether the consistency of the model with the rest of the organization.
- Implement ability: measures the ease with each the model can be implemented according to defined constraints.

6.4 Four Principles of Osterle et al.

These principles were drafted by 10 authors being supported by 111 full professors. The principle is mainly intended to provide: rules for scientific rigor and improved guidance for researchers; criteria for journal and conferences reviewers work; criteria for selection of young researchers and tenure procedures; criteria for evaluation of researchers and research organizations; and design-oriented information systems research in the international research community. In summary, it tries to provide a contribution to the rigor of research. These principles are:

- Abstraction: the model's applicability to a class of problems.
- Originality: the model's contribution for the advancement of the body of knowledge.
- Justification: the model's must justification in a comprehensible manner and must allow for its validation.
- Benefit: the capability of the model to yield benefits, either immediately or in the future, for respective stakeholder groups.

6.5 Result of the Evaluation

In this section, the proposed model is validated against the well-known DSRM validation criteria, in the order described above. The result is also summarized accordingly.

6.5.1 Design Science Research Methodology

When did the evaluation takes place? The evaluation strategy was ex post as the proposed mathematical model was evaluated after demonstration.

How was it evaluate? The evaluation was semi naturalistic as the target alternatives and customers are real, whereas, some data were taken by assumption because of the technology advancement it requires to extract the data.

What was actually evaluated? The main intention of the research was quantifying cloud QoS expression for cloud migration decision support. In order to meet the specified objective, DSRM was followed. Thus, the evaluation represents a mathematical model design process and validation method, as it defined a set of activities that can be used to help the decision process of DM.

6.5.2 Moody and Shakes Quality Framework

The demon which is applied in ASTU for ranking three alternatives has produced the following result by applying the Moody and Shakes Quality Framework. In addition to the demonstration, a feedback which is the result of brainstorming during demonstration which is also considered. The results of Moody and Shakes Quality Framework were:

Completeness: in terms of selecting the most important criteria, from which cloud services are evaluated for cloud migration decision support, an extensive study have been made based on majority vote rule by taking into account those scored below the majority rule threshold. In addition to this, DMs prompted to select a criterion of their choice before they were introduced with the prototype and they have listed 98% of the criteria from the quantified QoS catalog. Moreover, each DM can include or remove criteria to better assess their evaluation. On the other hand, all QoS that are meant to be important for cloud migration decision support are completely quantified.

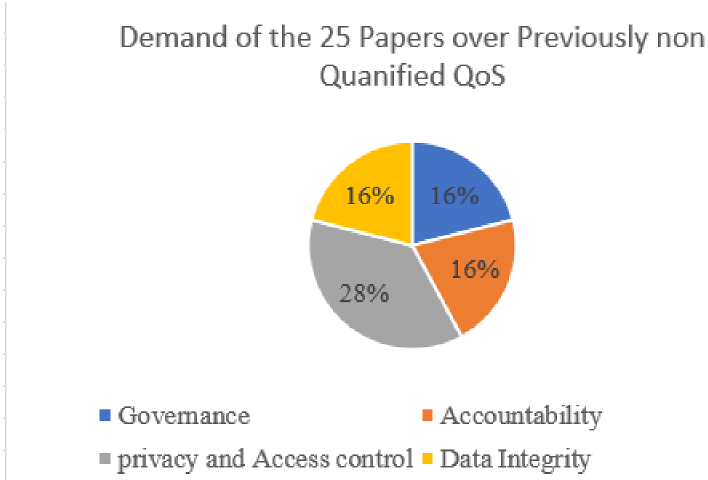

Figure 6.1 Demand of previously non-quantified QoS out of 25 papers

As shown in Figure 6.1, the pie chart illustrates the distribution of non-quantified QoS over different twenty-five papers listed in Table 3.1 to 3.7. the result shows the probability of governance, certification, data integrity and, access control and privacy management independent demand for cloud migration support witnessed to be 28%, 16%, 16%, 16%, respectively. In particular, making those QoSs quantifiable and keeping them in a catalog helps customers to consider them as a quality factor, where security and accountability parameters needed to make unambiguous and informed decision, as compared to the previous works. However, the probability of being demanded unitedly seems insignificant but still grasps 4% better than the previous works.

Integrity: the selection and application of the criteria as well as the process of mathematical model development was not guided by a business rule or other constraint that prevents errors. The common reason behind this is lack of common standard SLA and protocols across cloud providers. Thus, the proposed work, mainly depends on previous research works, QoS operational definitions and the collected data as it relies on literature review and collected KPI values.

Flexibility: the proposed model is structured hierarchically so that DM can remove or include both categories and QoS of their choice, based on their organization business and strategies. The hierarchical structure empowered the inclusion, exclusion and easy management of the criteria for the implementation as well. In addition to easy of filtering, DM has got an option of defining priority over the selected items which is one way or the other would influence the result produced.

Table 6.1 Number of Quantified QoS services in the previous works

Previous work reference	Number of QoS attributes	Number of quantified QoS	%Quantification
[51]	8	5	62.%5
[30]	6	1	16.67%
[50]	8	6	75%
[40]	22	5	22.72%
[31]	13	9	69.23%
[39]	18	9	50%
[48]	6	2	33.33%

By considering Table 6.1, and flexibility from the point of stretch or probability of hitting customer's preference having a combination of variation, for instance, if a customer needs a combination of two QoSs and having varies set of QoSs the probability of hitting the right combination depends on the number of available QoSs. Thus, having a combination of previous works quantified important QoS, having 13 important QoS, the underlined work increased the variance toll to 18. Thus, preference over QoS can be expressed in variety of multiple combinations.

Understandability: since the DMs have an understanding both on the quality as well as cloud background, they found easy to understand the propose model. In addition to that, they have found that the process of selecting the best cloud providers easy as the criteria are unambiguously stated and quantitatively defined. The proposed model was also defined and described the elements of each mathematical model. On the other hand, as compared to the previous works that are a combination of subjective and objective analysis techniques as shown in Table 6.1 the probability of being understandable is given by #Quantified QoS column. Because subjective analysis, which is an integral of false interpretation, leads to miss-understanding, ambiguity, and hence misinterpretation of cloud quality aspects, which often results to faulty decision making. From this we can conclude comparatively that the underlined work outperforms in understandability as it has been quantified 100%.

Correctness: when we consider the proposed mathematical model, the tendency of the result of all QoS were expected to be high i.e. whenever, a high value KPI signaled then the result is always high and the reverse is true. It has been observed from the case study the proposed model achieved this property 100% and we can say it is sufficiently correct and robust for the given scenario. A high-performance DMs found the proposed model correct and valid for their intentions. Moreover, the proposed model was developed based on each quality of service operational definition.

Simplicity: the proposed work was made simple to follow and apply. The criteria were reduced, by taking into account their importance of being demanded for cloud migration decision support. As the proposed work constituents more than 30 KPI that are structured into 18 QoS which in turn arranged into seven categories for simplicity. The aforementioned structure is taken from the the best possible practice of SMI cloud in the field.

Integration: the proposed work is consistent with the customer's need. Considering, ASTU DMs, which has doubts about what cloud service should buy, the proposed model would help them in making informed and unambiguous decision, as soon as the technology is available in Ethiopia.

Implementation: DMs showed interest to use the proposal, but within existing technology, the implementation will not be realized as the credential is required in order to buy and use the service.

To sum up, the proposed model was verified against all quality factors. In general, factors as completeness, understandability, correctness, simplicity, and integration were totally accomplished. However, integrity was half accomplished. The reason for this was lack of rule that support all integrity. Whereas, the factor implement ability was not verified. This is because of lack of advanced technology in order to lease the service and pay as we go.

6.6 Four principles of Osterle et al

Finally, the four principles of Osterle et al applied in order to evaluate the proposed mathematical model. The result of the evaluation is discussed as follows.

Abstraction: it has been proofed that the proposed model can be applied to any cloud company by exposing the model with three different alternatives, namely, Amazon Web Service (AWS), Microsoft Azure and Google Cloud. On the other end, any organization who is in doubt between any cloud criteria can use the service by adding and removing criteria to meet their requirement.

Originality: as far as a catalog of mathematical model for cloud QoS considered, no similar research found and none of related work similar was found. Apparent to that, out of eighteen QoS mathematical model thirteen were studied and adopted from previous works, whereas five additional original works, namely, governance, certification, cost, data integrity and privacy and access control were introduced in the catalog.

Justification: the proposed work is supported by the motivation of the problem as well as by the related work. In addition to that the model itself was described and justified in a broad scope in its discrimination power using AHP MCDM with clear steps and instructions.

Benefit: according to DMs, there would be worthful as it gives an easier, complete, and unambiguous evaluation of the cloud service, which they are taking into account.

In summary, the four principles to evaluate a DSRM model were achieved, thus it shows the validity of the proposed QoS mathematical model.

CHAPTER SEVEN

7. Conclusion, and Future Work

7.1 Conclusion

Currently, there are two types of service provisioning mechanisms called on promises and in-premises, in the IT industry. The in-premises approach, which is known as cloud computing, is introduced earlier that the former. However, it is attracting both IT industries, academic as well as customers and becoming one of fast growing technology, now a day.

Cloud computing provide three type of services such as SaaS, PaaS and IaaS with four alternative deployment models called private, public, community and hybrid. And, it is Characterized by a shared pool of on-demand self-service, which is accessed through broad band network in a pay as you go bases, which is considered as the main reason of migration, for varies organizations as a customer. On the other hand, more than two thousand companies are providing the service to accommodate customers' need. Most of these industries deliver the same kind of features with different quality, where it leaves room to be differentiated with QoS they possess. However, service quality is specified and defined in different way by different providers, in their respective SLA. As a result of this a decision to be made becomes time taking, ambiguous, and subjective by its nature. Alongside with its importance, selecting the best cloud provider from such a large number is considered a crucial step in this area. And, to mitigate this gap, a mathematical QoS model is proposed for cloud migration decision support problem, specifically.

In order to solve this problem, DSRM is followed by taking problem centered initiation as entry point. On the entry point, the problem was identified and its feasibility justified with respected to previous works, and then, proposed quantification of cloud migration decision support. In the second step, QoS that are meant important for cloud migration decision support are extracted through an extensive literature study. In this step, a total of 140 literatures are revised and twenty-five papers identified through inclusion and exclusion criteria and systematic literature review. Then, the twenty-four papers are used to extract the most important QoS services i.e. QoS that are demanded by at least 4 papers and categories that are demanded by at least 9 papers are selected as the most important QoS and Categories, for cloud migration support. Then, a mathematical model is proposed for the selected QoS, and a quantified QoS catalog developed. Out of eighteen

QoS, thirteen are already quantified for varies purposes while including for a cloud decision to be made by different scholars. In this case, an appropriate mathematical model is selected. On the other hand, five out of eighteen, like, governance, certification, cost, data integrity, privacy and access control are originally quantified. The process of eliciting the most important QoS and proposing the mathematical model are performed in design and development phase of DSRM.

In the next phase, the applicability of the proposed QoS mathematical model is demonstrated with three cloud provider alternatives, namely, AWS, Azure and Google, and as a potential cloud customer ASTU case is considered. The demonstration is mainly intended to help understand the applicability of the proposed method. Here, KPI, of cloud provides are introduced in the proposed QoS mathematical model and the result is applied in AHP, which has already demonstrated on more than 1000 papers for MCDS problems as a relative ranking mechanism to discriminate and rank providers chronologically. In this step, first, AHP is applied on QoS of the same category and then, the result of each category is used in AHP and the result is taken as a ranking mechanism in which an alternative with higher value i.e. AWS with a score of 0.975 considered as the better one for ASTU.

Finally, evaluation of the proposed work takes place against DSRM evaluation framework, Moody and Shakes Quality Framework, and four principles of Osterle et al. And, the result of the evaluation shows the proposed mathematical model is complete, flexible, understandable, correct, simple. And, it is also proved that it can be used for varies customers on different alternatives. Its use and benefits justified positive.

7.2 Recommendation

Because of the advantage, IT technology providing in all aspects of business, it is an inevitable step to run with advanced technology like cloud computing. Thus, in order to enjoy a maximum gain and reduce risk before migrating to the cloud, we recommend the proposed mathematical model for DM that are looking for a service provider in cloud market so that the decision to be made became unambiguous, objective, and informed.

7.3 Future Work

Due to lack of advanced technology, domestic cloud customers and providers, and limited time during the course of this research, it was difficult to work with continuous KPI, as well as, address other quality parameters that are not covered in this research. However, in the presence of the limited resource, the proposed model can be boosted with an extended research.

Specifically, the proposed mathematical would be enhanced on the following features:

- Although we have devoted everything to identify QoS and thereby quantify them, there are other QoS that are not covered yet, which is the ground that needs built upon.
- The proposed mathematical model can be enhanced and well-justified by considering continues and real data instead of semi real data and snapped-shot KPI values.
- The proposed work is generic and which is not dedicated to specific cloud service and deployment model, that can reinforce additional constraints on the proposed mode. Thus, the impact of such specific service and deployment model on the proposed model would be studied in such a way that to enhance the model.
- By increasing the range of KPI values, the proposed model would be validated and enhanced well. Thus, additional study would enlarge the contribution the proposed model.
- The discrimination power is not verified from other MCDM mechanism; thus, the proposed work would be enhanced, in order to meet all the MCDM mechanism by exposing it with another MCDM.

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Appendixs

Appendix A: Key performance index and QoS data set

Table 8.0.1 AWS, Azure, Google cloud KPI values

Category	Weight	QoS	Weight	KPI	AWS	Azure	Google cloud
Accountability	0.1	Governance	0.6	No of solved issues	556	58002	2391
				No of detected or reported issues	2469	101873	4608
		Certification	0.4	No of available certificate	4	5	4
				No of requested certificate	5	5	5
Usability	0.1	Learnability	0.3	No of users using the service	672,000	550,000	460,000
				total No of users	1.2 million	1.1 million	1 million
		Understandability	0.4	No of services used	5	7	3
				No of services offered	7	9	5
		Operability	0.3	min response time	41ms	41ms	41ms
				Operation time	Avg. 253ms	Avg. 169ms	Avg. 41ms
Financial	0.2	Cost	1.0	cpu(0.2)	8core	8core	8core
				RAM(0.2)	28GB	28GB	28GB
				storage(0.6)	400GB	400GB	400GB
				p	$932/month	$1128/month	$817.6/month

Assurance	0.3	Availability	0.2	MTTR		807min	5261min	3685min
				MTTF		184953min	180499min	182075min
		Reliability	0.5	MTBF	Total service time	185760min	185760min	185760min
					Number of failure	10	16	34
				P_{MTBF}		185760min	185760min	185760min
		Service Stability	0.3	P_{SLA} resource performace (CPU, storage)		36, 50	38, 48	36, 50
				Avg resource performance (CPU, storage)		13.6, 17.9	16, 23	7, 12
Performance	0.1	Response time	0.3	t_i		253ms	169ms	41ms
				t_{max}		30ms	30ms	30ms
		Accuracy	0.4	number of correct responses		2438	100942	4492
				total number of requests		2469	101873	4608
		Suitability	0.2	No of essential services provided		3	3	3
				total No of essential services requested by user		3	3	3
		Interoperability	0.1	No of platforms offered by the provider		2	2	2
				total No of platforms required by user		2	2	2
Agility	0.1	Elasticity	0.5	defect time of resource		40s, 80s	480s, 740s	0, 160
				total time		80s, 120s	520s, 780s	20s, 200s
		Scalability	0.5	available resources		4	4	4
				requested resources		4	4	4
Security and privacy	0.2	Data privacy and data loss	0.4	No of third party access		400	400	400
				total No of access		5	5	5
		Data integrity	0.3	$validity_{dsi}$		250	280	240
				$accuracy_{dsi}$		280	270	300

				$consisteny_{dsi}$	290	300	290
		Access control and privacy management (mgt).	0.3	No of password reset request	5	3	2