LEGACY APPLICATIONS MIGRATION ON TO CLOUD

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LEGACY APPLICATIONS MIGRATION ON TO CLOUD

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STATEMENT OF NON-PLAGIARISM PAGE

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ABSTRACT

LEGACY APPLICATIONS MIGRATION ON TO CLOUD

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Cloud computing is defined as a type of computing that depends on sharing computing resources rather than using local computer resources. What makes this technology different than traditional client-server architecture is that the resources are shared through virtualized machines. This technology is becoming popular as a number advantages such as high scalability and reduced IT costs attract potential users. On the other hand, some challenges, such as legacy applications to be moved to cloud computing environment, are to be discussed. In this work, possible stages to manage and undertake such a migration are attempted to be explored and described. The stages are proposed not only to describe the necessary steps but also to itemize related constraints for each level of migration. Main limitations include plans for migration hence a comprehensive/complete work-flow targeting organization specific requirements such as financial, cultural and legislative parameters remains as a future research avenue. Nevertheless, main benefit of this work is to assist organizations who need to migrate legacy applications onto cloud environment is supported as the work-flow is argued be used as a base to determine the constraints/issues that may arise at the stages.

Keywords: Cloud Computing, Migration to Cloud Environment, Virtual Machine, Legacy Applications, Work-flow.

ÖZ

ESKİ UYGULAMALARIN BULUTA TAŞINMASI

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Bulut bilişim, yerel işlem kaynaklarından ziyade paylaşımlı işlem kaynaklarını kullanan bir bilişim modeli olarak tanımlanır. Bu teknolojiyi geleneksel istemci-sunucu mimarisinden faklı yapan özellik, kaynakların sanallaştırılmış sunucular üzerinden paylaşılmasıdır. Bu teknoloji, getirdiği yüksek ölçeklenebilirlik ve düşük bilişim giderleri gibi avantajlarla, olası müşterileri cezbetmekte ve giderek popülarite kazanmaktadır. Öte yandan, eskiye bağımlı uygulamaların bulut ortamına geçirilmesi gibi zorluklar üzerinde düşünülmelidir. Bu çalışmada, eski teknoloji ürünü bir yazılımın, bulut mimarisine geçişi sırasındaki olası aşamaları ve bu aşamaların yönetimi incelenmiş ve tarif edilmiştir. Bu aşamalar, hem her aşamada atılması gereken adımları önermekte, hem de bu aşamalarda karşılaşılabilecek kısıtları listelemektedir. Çalışmanın en önemli kısıtlaması, taşınma planlaması sırasında karşımıza çıkmaktadır, çünkü organizasyonlara has ekonomik, kültürel ve hukuki parametreleri ayrıntılı bir şekilde içeren bir iş akışı gelecek bir araştırmanın konusu olarak ayrılmıştır. Yine de bu çalışmanın en önemli faydası, eski uygulamalarını bulut ortamına taşımak isteyen kurumlara, taşınma işleminin her aşamasında ortaya çıkabilecek kısıtlar ve sorunları belirlemek ve buna göre iş akışı planlamak için bir temel teşkil etmesidir.

Anahtar Sözcükler: Bulut Bilişim, Bulut Ortamına Taşınma, Sanal Makina, Eski Uygulama, İş Akışı.

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LIST OF ABBREVIATIONS

BDW	Boundary Diffraction Wave
CmaaS	Compliance as a Service
D2CM	Developed Desktop-to- Cloud Migration
DMFT	Developed Desktop-to- Cloud Migration
IaaS	Infrastructure as a Service
IdaaS	Identity as a Service
MDE	Model-Driven Engineering
PaaS	Platform as a Service
QoS	Quality of Service
REMICS	Reuse and Migration of Legacy Application to Interoperable Cloud Services
SaaS	Software as a Service
StaaS	Storage as a Service

CHAPTER 1

DEFINITION OF THE PROBLEM

1.1 Motivation

When reading many papers and studies, most focus on one step for migration legacy applications to cloud computing. There is no complete workflow paradigm to describe any possible necessary stages for migration. Some focus on one stage, such as supporting the decision making stage or focusing on the performance migration stage. This thesis defines and describes the workflow focus on migration stages. The migration workflow will consist of four stages. These stages start from supporting the decision making process and then defining the migration planning stage, after which implementation of the migration test stage finally occurs. Further details can be found in Chapter 3.

1.2 Purpose

For organizations that wish to obtain the benefits of cloud computing, such as reduces costs of IT maintenance and operations and greater efficiency for old reliable applications, this thesis will provide the possible steps to assist an organization to migrate legacy applications from traditional computing to cloud computing.

1.3 Scope

This study explains the migration of legacy applications to a cloud computing provider so as to determine a model service (IaaS or PaaS). It does not define migration applications from cloud computing IaaS to cloud computing PaaS. Additionally, it is restricted from using this workflow with modern design applications.

1.4 Research Question

This thesis endeavors to answer the question: What are the possible stages which the migration passes through with any possible constraints and solutions for each stage?

1.5 Organization of the Thesis

The remaining part of this thesis is structured into Chapter 2, which covers an introduction and literature review of legacy applications moving to cloud computing. Additionally, it provides a description of the problem of legacy applications, after which it defines the closed studies that it will support this thesis.

Chapter 3 discusses the definition of the workflow that is used to migrate legacy applications to cloud computing starting from the support decision stages and test migration stages.

Finally in Chapter 4, the conclusion chapter discusses the results, findings, limitations and future work.

CHAPTER 2

INTRODUCTION

2.1 Introduction

The last ten years have seen a strengthening of the idea that the processing of information can be carried out more efficiently centrally, on large farms of computing and storage systems accessible via the Internet [1]. When computing resources in remote data centers are utilized more so than local computing systems, we refer to this as network-centric computing and network-centric content [2]. Development in networking and other areas are responsible for the submission of new computing models, such as utility computing and cloud computing [1-2]. In utility computing, hardware resources and software resources are concentrated in large data centers and users pay as they consume resources [2]. Generally, utility cloud computing needs a cloud-like infrastructure. However, its focus is on the business model for providing computing services. Cloud computing, in contrast, is a path to utility computing investment by many IT companies, such as Amazon, Google, Microsoft, Oracle, and others.

Cloud computing is an abstraction idea established on the thought of pooling physical resources and offer these resources as virtual resources [2]. It is a modern model for supplying resources, for platform-independent and applications platform for customers can access services [2]. There are many types of clouds and the services and applications that execute on clouds may or may not be delivered by a cloud provider [2].

2.2 Cloud Computing Services Models

As cloud computing has advanced, various salesman offered clouds with various services related to them [2]. The set services presented adds else set of definitions known as the service model [2].

Three service types have been universally passable:

- **Infrastructure as a Service:** IaaS supply virtual machines, virtual storage machines, virtual infrastructure resources and else hardware holdings as resources that clients can provision [1-2-3].
- **Platform as a Service:** PaaS provides development frameworks, transactions, and control tools to manage applications that are hosted on the cloud [1-2-3].
- **Software as a Service:** SaaS is an environment that completes operating with applications services and the user interface [1-2-3].

The three different models taken with each other have come to be recognized as the SPI model of cloud computing. Many other models are also established, such as Storage as a Service (StaaS); Identity as a Service (IdaaS); and Compliance as a Service (CmaaS). However, the SPI services cover all else possibilities [2]. It is beneficial to view cloud models in terms of a hardware and software stack. One such representation, named the Cloud Reference Model, is shown in **Figure 1** [2]. The hardware and network are involved in the infrastructure at the lower stack [2]. When moved up on the stack, the remaining models will inherit the capabilities of the model under it. IaaS has the undermost model level on the stack and the SaaS has the upmost level on the stack models [2].

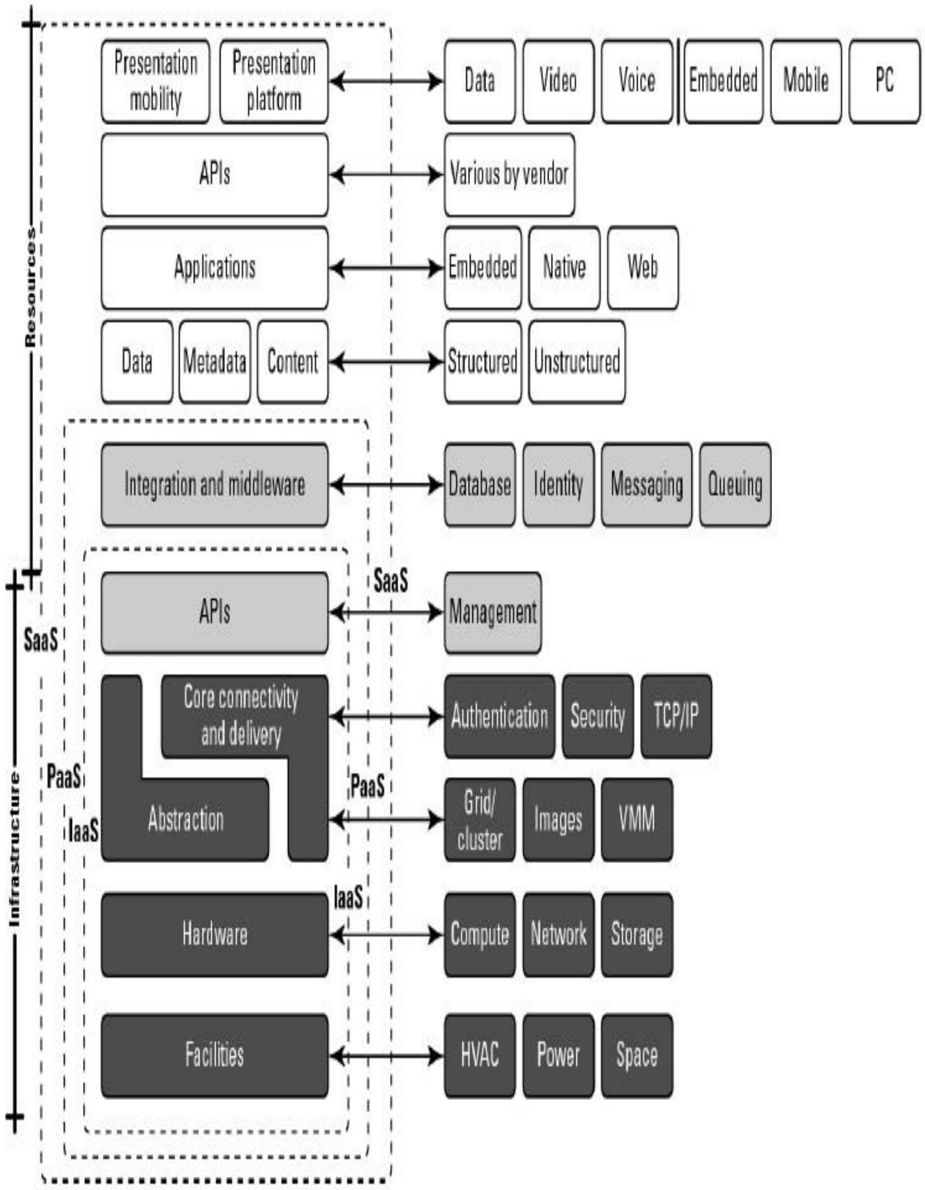

Figure 1 Cloud reference model

2.2.1 Cloud Infrastructures as a Service (IaaS)

If an organization needs to pay a server in the old days, it may have spent between four to twelve thousand dollars or more up front [3]. Nowadays, an organization can pay a virtual server from the infrastructure cloud provider over the Internet. The server rarely comes at our doorstep. Instead, it stays "out on the cloud" where the user can log on and manage a virtual machine server anytime and anywhere over the Internet [6]. Customers can purchase and administer processing time (CPU time), storage, networking and other basic computing power resources without excessive spending upfront. Customers only pay for what they use [3-7].

If a customer has not used a cloud infrastructure before, the concept of using a server over the Internet probably prompts the customer to ask the question, “How can I do that?” In reality, it is easy to rent computers over the Internet. If customers intend the Amazon.com’s EC2 website, they can initiate and administer a real server (small virtual server) for an hour for about 25 cents. Customers need to determine the name of the server; the kind of operating system and other specification information and details to create the instance of a virtual server, after which customers have the ability to log on by using a remote desktop to the server instance [3].

The term “virtual server” means that customers are not actually renting a physical server. That is, customers cannot literally walk into a room and select a dedicated machine. In state, everything is managed by “virtualization” software, such as VMware. In the past, a physical machine can have one operating system running on it [3]. Customers would purchase a Windows server that had a copy of the Windows operating system, or a Linux server that had a copy of the Linux operating system [7]. It was one-to-one. In contrast, virtualization permits users to use more than one operating system on the same machine [3-7]. In the early days of virtualization, this was a “handy trick” [3]. Virtualization made it simple to experiment new software on multiple operating systems without the need for multiple physical machines [2]. Virtualization has also made it simple to operate Windows and UNIX programs on the same physical machine, such as when a program was only available for one operating system, as shown in **Figure 2** [2-3].

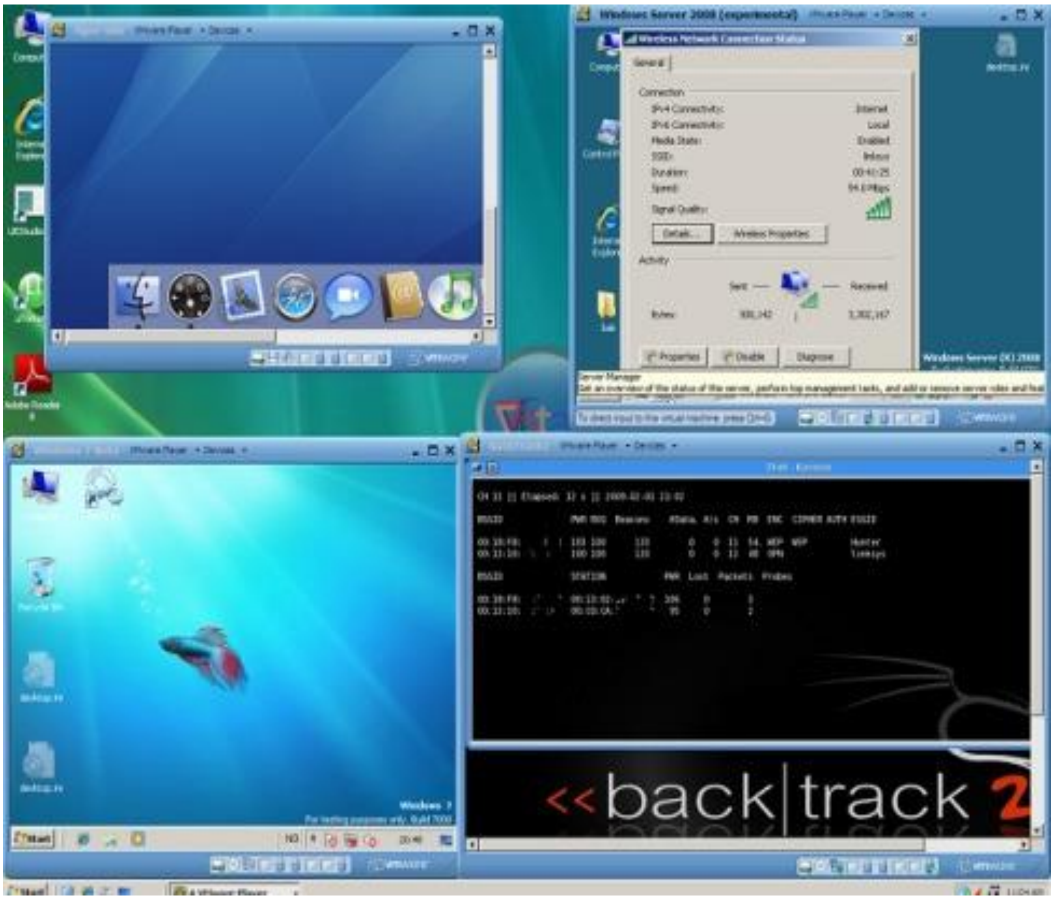

Figure 2 Running a number of operating systems on one physical machine

With virtualization, it is potential to vend the same machines multiple times. That is, the datacenter can turn on the many copies of the Linux server in one physical machine and then sell those copies of the Linux server over the Internet as separate server machines. Virtualization is the basic idea behind cloud infrastructure (infrastructure-as-a-service) [2-3].

The infrastructure cloud is not restricted to multi-servers in one machine. In fact, it relies on the sharing of a server's pool [2]. A user can scale up to gain the advantage of additional computing power when necessary. This works because servers are especially fresh in any case, so there is always some more computing power ready if the pool is sufficiently great [2-3].

2.2.2 Cloud platforms as a service (PaaS)

The Platform as a Service model is a software environment in which a developer can create customized solutions with the development tools that the platform provides [1-2]. The platform cloud can drastically reduce costs for software engineering, reduce risks, provide good revenue margins and reduce time for the market [1-3].Cloud platforms serve as a starting point for cloud software, providing functionality, such as multi-user data management, security for applications, user interfaces and user administration and searching [3].

Clouds platforms are presented as a service, concept that developers can use the cloud through the Internet without any need to set up, host or upgrade [3]. Cloud platforms can be distinct from other platforms which need installation, downloading, uploading and managed hosting. Cloud platform as a Service is very simple to use [2]. Importantly, if developers create cloud software solutions on top of a cloud platform, the solution is inherently cloud-enabled, gaining the benefit of the underlying cloud infrastructure, its elasticity and as-a-service models [2-3].

Cloud platforms have online APIs and tools that they create for developers to use the cloud options and deploy the developer application inside it [2-3]. When selecting a cloud platform, it is necessary to ensure that the API is turned on, permitted for integration with the third part, open source, legacy software and web services [3-7].
The cloud platform is found between the infrastructure layer and the software layer, so it is represented as the middle layer. Cloud platforms, in fact, do far more than only provide core functionality for software. They also reduce the time and risks of engineering software [1- 2- 3].

There are many shapes and sizes for cloud platform providers based on the application services at hand [2-3]. For example, Google is presently dominating the consumer application platform, while Facebook is predominant in the platform of social networking, and Salesforce.com is attempting to create a footprint as an enterprise software platform [3]. Several other players, Yahoo included, serve e-commerce platforms, which have driven lower the time, risk and cost of e-commerce solutions [3].

2.2.3 Cloud software as a service (SaaS)

SaaS has a full platform software and solution as an offer of service. Software as a Service (SaaS) is perhaps defined as software that is deployed on a hosted service and can be login via the Internet, often in a browser [1-2]. With the exclusion of the user interaction with the software, other sides of the favors are abstracted away [2].

A good example for SaaS that serves end-users is offered by Google, Gmail and Books online, and others [2]. SaaS applications appear in all sizes and shapes, and involve custom software, such as Customer Relationship Management (CRM), billing and invoicing systems, Human resource solutions, Help Desk applications, as well as plentiful online versions of conventional applications [1-2].

Customers have more advantages when using a common code base for SaaS applications because the SaaS provider continuously enhances the program and pushes out any enhancements to each user based on time [3]. This is not limited to creating better software; it also allows for pay-per-use sharing between many users [3]. Each end user may be able to select from many software components to make a SaaS application that more specifically meets their own particular needs [2]. Not unlike most types of on-premises software, SaaS applications permit end users to apply their own user preferences and custom configurations [2-3].

2.3 Cloud Computing Types

There are three main types of cloud computing based on the implementation and deployments of applications: the hybrid cloud, the public cloud and the private cloud.

2.3.1 Private clouds

A Private cloud is defined as a cloud that is deployed inside an organization on-premises and all devices are deployed as in-sources. This type of cloud does not benefit from the economy of scale; however, it does provide security advantages [1-2-5]. The Private cloud is becoming a new form which re-architects the datacenter mentioned as the datacenter inbox [2,3]. For example, if a private cloud requires setting up, a developer may use VMW services, such as vCenter, vCloud and vSpher [5]. VMW also offers standardization for the cloud through the (Distributed Management Task Force) DMFT organization (See **Figure 3**) [5].

2.3.2 Public clouds

The original idea of cloud computing is the public cloud. This type of cloud depends on the ubiquity of the Internet [1-2-5]. By using this type of cloud, all benefits of economy of scale are gained, such as rising elasticity and facility of management [1]. The main issue of this type of cloud is security of deployment [1-2-5]. For this reason, there are other types of cloud computing that are used (See **Figure 3**) [5].

2.3.3 Hybrid clouds

The Hybrid cloud is a site between the private cloud and public cloud [1]. This type of cloud offers a good solution to gain maximum benefits in relation to private and public clouds [2-5]. Hybrid cloud computing is usually a combination of public and private cloud types. It is usually managed using the same monitoring consoles and administration. The importance of cloud standardization can be seen in **Figure 3** [5].

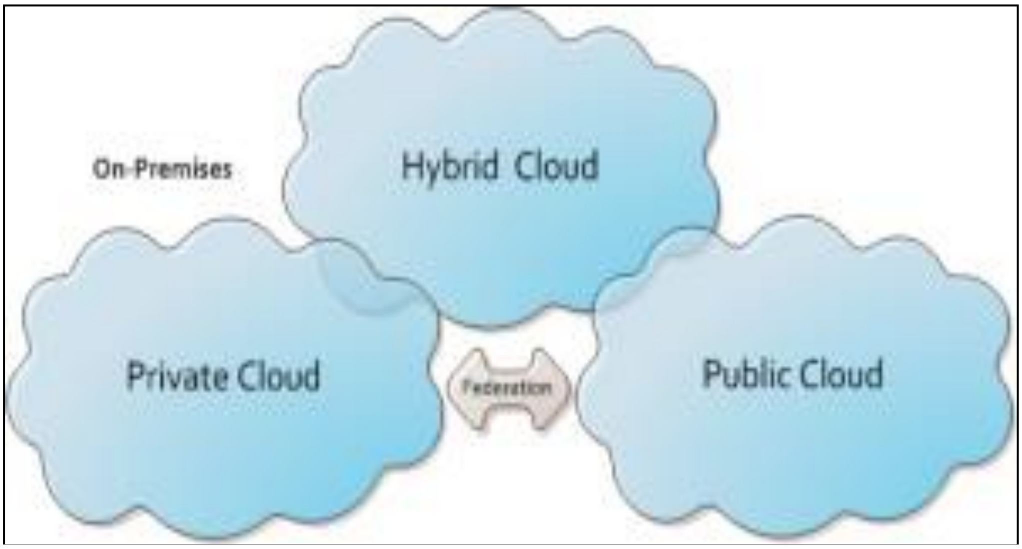

Figure 3 Cloud types

2.4 Benefits and Challenges

2.4.1 Benefits of cloud computing

1- **On-demand self-service:** Without the need for interaction with cloud provider personnel, a customer can obtain computer power resources according to customer needs [1-2-3-5].

2- **Broad network access:** The resources of the cloud are available over a network. These resources can be accessed over a network using the standard methods that provide an independent platform [2-3].

3- **Resource pooling:** Cloud computing creates one pool for resources that are pooled together in the system to support the multi-usage of resources [1-2-7].

4- **Rapid elasticity:** Computer power can be rapid and elastic provisioned. The customer can add or change computer power resources either by scaling up resources to be more powerful or by scaling down system resources of the same type. Scaling may be manual or automatic [1-2-7].

5- **Measured service:** Based on a metered system, the usage of cloud resources is reported to the user and measured [2].

6- **Lower costs:** Because cloud computing networks work with greater utilization and at higher efficiencies, important cost reductions often occur [1-2-3-7].

7- **Ease of utilization:** At times users do not need hardware or software licenses to implement services [1-2-7]. This is dependent upon the type of service being offered [2].

8- **Quality of Service:** QoS is something that can be obtained under contract with a cloud provider [1-2].

9- **Reliability:** The reasons making the cloud highly reliable include the scale of cloud networks and their ability to provide balancing and failover [6-7].

10- **Outsourced IT management:** Cloud computing allows a user to manage system infrastructure resources [2]. Additionally, the customer manages and focuses on business [5] and achieves considerable reductions in IT staffing costs [2].

11- **Simplified maintenance and upgrade:** The system has centralized computing, so the user can simply do upgrades and patches [1-2-5-7]. This allows the user to access the latest software versions [2]

2.4.2 Challenges of cloud computing

1- Legacy applications system: Organizations have applications and computer power such as datacenters with servers where all devices will need to be eliminated and transitioned so as to reduce costs and increase flexibility with cloud providers [4-5-7].
2- Existing security, operations and processes within organizations which need to adjust to the new cloud computing model [5-7].

2.5 Literature Review

2.5.1 Support decision for migration to cloud computing

Patricia V. Beserra and colleague et al. fill the gap that describes the steps that help organizations to overcome the difficulties they face when deciding to migrate legacy applications to cloud computing; such difficulties may include constraints related to organization policy and human resources. After that, they define applications profiles and attempt to collect information related to each application, including the number of users who login or use an application as well as determining the costs required to operate these applications. Additionally, they describe constraints relating to cloud providers, such as three types of virtual machines and types of platforms. The aforementioned study describes the most constraints in the decision-making step for migrations. The authors show the cloud steps workflow with nine activities, as shown in **Figure 4** [6].

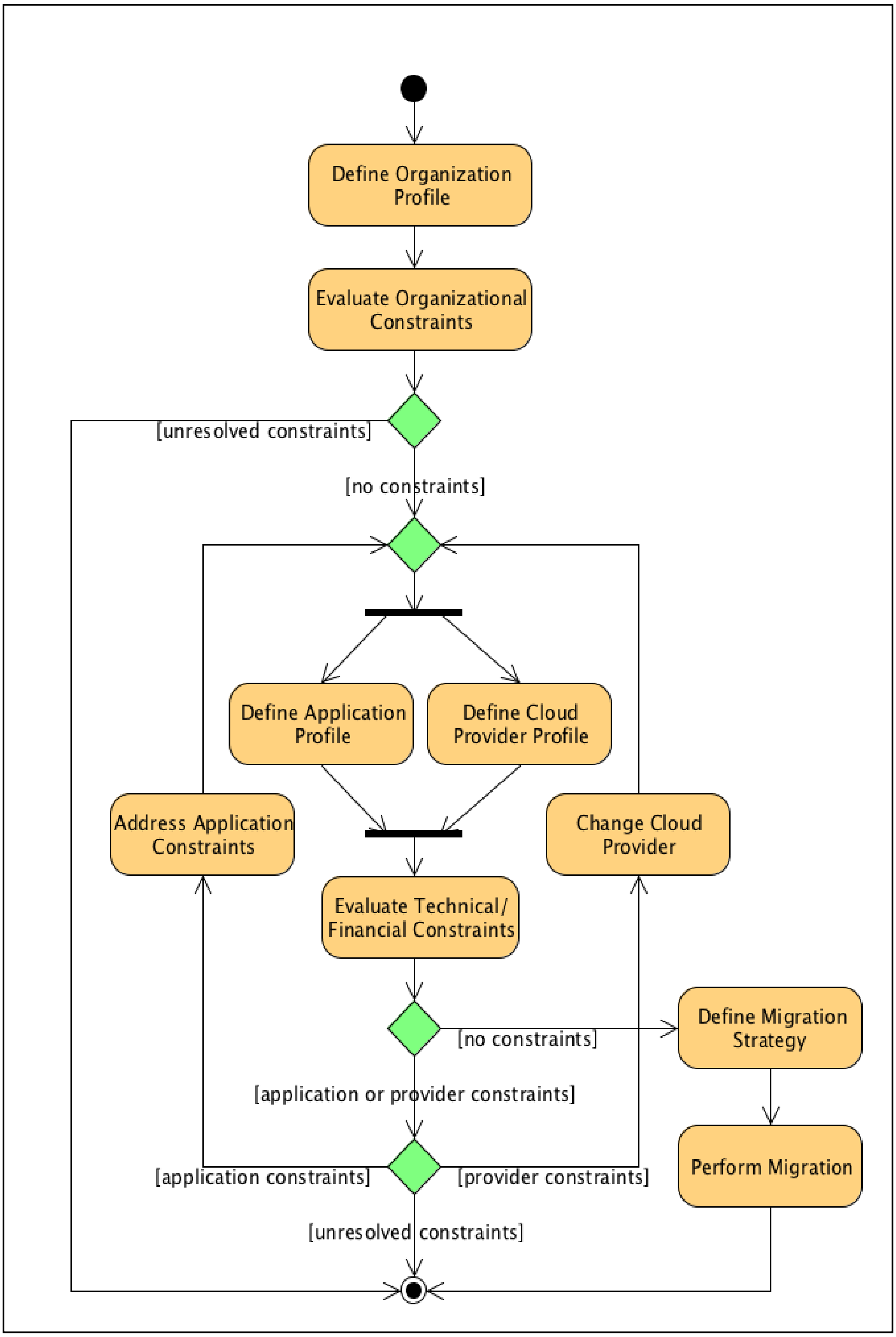

Figure 4 Cloud steps workflow

Ali Khajeh-Hosseini and colleague et al. define the challenges and constraints that arise when deciding to move to cloud computing using the cloud adoption tool. This tool supports decision making by using some analysis tools for applications that aim to move to the cloud. The authors use a cost model as a base model for decision making. This model is a very important analysis because it estimates the cost so as to save money. Moreover, the authors use other models, such as technology suitability analyses and responsibility modeling [7].

Ali Khajeh-Hosseini and colleague et al. show the risks and benefits of migrating applications to cloud computing. The authors use the financial and technical analysis for applications. These analyses show how much is saved if 'EC2' is used for cloud computing. The result of the aforementioned study depended on a case study showing how to migrate applications to an "EC2" IaaS cloud by estimating the infrastructure costs in addition to the supporting and maintenance costs that are delivered from an IT support company. Additionally, stakeholders' impact analyses define the risks and benefits of migration to cloud computing. The IT system is changing when the use of cloud computing becomes cheaper, simpler and more scalable. In the aforementioned study, one can see the *cloud adoption toolkit* that helps in migration. This tool carries out a technology analysis followed by a cost analysis simultaneously with a stakeholder impact analysis. Then they define the responsibility analysis and finally the requirements of implementation [8].

Kun Bai and colleague et al. describe how enterprises can build new applications that can take advantage of a cloud's "pay-as-you-go" pricing and elasticity. Additionally, the authors address the risks and challenges before migrating an application to cloud computing. The authors endeavor to define the complex relationship for this server-to-server and application-to-server migration. The authors use the novel Kall Baek-Leibler method to migrate applications to the cloud. First, the authors used migration planning. Then the problem of formulation was to find the relationship problems among the hosts' "middleware component that was installed in the hosts". Then analyses hosts based on dependency. These analyses help engineers to create good migration planning and reduce costs [9].

Ali Khajeh-Hosseini and colleague et al. define cost modeling and use spreadsheets to describe the outline of benefits and risks of using cloud computing. Their study used this tool to support decision making for migrating applications to the IaaS cloud. The outcome of this study was to use tools to help IT staff to support decision making to migrate applications to cloud computing. It uses cost modeling to help in remodeling the application deployment in the new infrastructure. Furthermore, it describes the benefits and risks in order to support decision making to migrate an application to the IaaS cloud. One limitation of the aforementioned study is that it is only used for migration to an IaaS cloud [10].

2.5.2 Steps of migration

Satish Narayana Srirama and colleague et al. used the tool named “Developed Desktop-to-Cloud Migration” (D2CM) as a migration software environment that is usually used in high performance computing solutions by scientists, who set up and conduct their experiments directly to the cloud. They used D2CM to move the virtual machine images to a cloud, such as (EC2), or to a compatible infrastructure, such as Eucalyptus. Not only migration but also optimization, calculation and analysis make it easy to deploy the API application [11].

Quang Hieu Vu and colleague et al. say that in any organization that owns stable applications, those applications are deployed on the traditional computing platform. In order to gain the advantage of cloud computing, one needs to migrate old or legacy applications to the cloud. Generally, it needs to describe some analyzing features for cloud services and focus on the practicability and methodology for moving to cloud. The authors describe the important steps that will happen in migration of the application to the cloud. Furthermore, the authors define steps that occur upon migration to an IaaS cloud and the steps of migration to a PaaS cloud. Using cost analyses and the compatibility of the application, the application is deployed inside the cloud (IaaS, Paas). Additionally, other check points such as a supporting library are found inside the PaaS cloud [12].

Joydipto Banerjee et al. define the classification for applications depending on workload levels and the environment for enterprises without re-architecting or re-engineering of existing applications. They explore the steps of migration with its challenges and issues and describe the framework for migration. On the cloud, each application must have an instance/image inside which applications are run. Moreover, they define the map of references architecture for migration to cloud computing; in other words, they describe the fundamental architecture elements consistent with the cloud environment. Additionally, they create standardizations for workload applications to be used with the appropriate model of cloud (IaaS, PaaS or SaaS). Finally, we can know the challenges and issues that appear during migration [13].

Alexander Bergmayr and colleague et al. write about gaining the benefits of cloud computing by improving the quality of software and lowering costs. The aim of their study pertained to moving the software as a product strategy to delivering software as services in an SaaS cloud. ARTIST is a project for modernization of software by using Model-Driven Engineering (MDE) and Model-Driven Modernization (MDM) approaches for the migration of legacy software to cloud based SaaS. This project is creates a method of migration and a comprehensive tool to support modernization legacy software through the **ARTIST project**. ARTIST aims at reverse engineering legacy software onto a model that is compatible with the cloud software base. They encountered some challenges and issues such as planning and assessment of software modernization, operations of software modernization and finally validation and certification of the modernized software [14].

Muhammad Aufeef Chauhan and colleague et al. used the open source software framework Hackystat. This software aims to report all process and technical challenges faced in migration. Additionally, it reports strategies that help to address those challenges. The main goal of the study is to provide process and product measurement software as services to manage a large scale distributed computing system. Furthermore, the authors identify and understand the migration process for a SOA based system to the cloud. The outcome of the their study after using Hackystat software includes authors identification of some requirements such as the system needing to scale up or scale down, the system needing to be deployed on the cloud and system components that have high performance needing to take advantage of storage resources in the cloud. The authors further stipulate that the target IaaS infrastructure should be considered in the design of systems software [15].

2.5.3 Selection of a suitable cloud provider

Siew Huei Liew and colleague et al. help the user to select a suitable cloud provider. They find ways to show the estimated costs of running legacy applications on different cloud computing providers by using CloudGuide, which describes the steps to estimating costs and performance of host applications on different clouds without actual deployment. It first shows the cloud provider pricing schema. CloudGuide provides a systematic methodology to estimate costs for deployment. Finally, it dynamically defines the provision of computing resources for workload changing [16].

Silviu Panica and colleague et al. define some tools or platforms that help the owner of a legacy application to select a suitable cloud by explaining the risks and challenges. They also describe some solutions by using an open source platform named “mOSAIC”. The authors explain the reason for legacy migration and why companies push to use cloud computing. They also describe migration strategies, elasticity issues and degree of automation. Next, they describe how to use the mOSAIC platform. The main idea of designing the mOSAIC’s API and platform is to guarantee the portability of cloud-compliant applications between multiple clouds and to permit the development of new services on top of cloud services [17].

Parastoo Mohagheghi and colleague et al. define the methodology for migration to the cloud through analysis and modernization of applications. In their study, they endeavor to understand the technologies of the cloud computing environment that are suitable. Furthermore, they use the project REMICS (Reuse and Migration of legacy application to Interoperable Cloud Services). The REMICS project helps to define the problems and constraints that arise in migration. It describes the constraints relating to consumers and cloud providers. Some of these constraints relate to establishing the context and understanding the modern technology and business model [18].

2.5.4 Special considerations

Xavier Etchevers and colleague et al. provide solutions for the distribution or deployment VMs inside the cloud. This process is still difficult if using automatically configured distribution. In this article, they give solutions to self-configuration of legacy applications in the cloud. They first define the formalities for distributed applications that are put in VMs by addressing the description with (ALD) architecture description language. Second, they define protocols for dynamic and decentralized self-configuration [19].

Bin Cai and colleague et al. use the idea of the private cloud, meaning to re-build or "re-computing" the information systems by using cloud computing technology. The authors use CloudStack cloud, which uses virtualization technology. The authors describe and analyze the platform problems that appear while using old applications, similarly to resource utilization, by lowering the security level for data and system hosting for subsystems in order to provide a good solution for an organization that is beset with the above problems. They create a private cloud and migrate the legacy system to new computing [20].

Liang Zhou *et al*. in their study measure the performance of FTPserver that migrates to the platform cloud "Windows Azure" by using a case study to describe the benefits and technical issues that arise when moving traditional applications to the cloud. The study describes the architecture for CloudFTP on Azure in addition to describing the file system inside the cloud. Then, an evaluation is made for this migration to define the benefits, such as 'cost saving, high availability, less management and scalability. Moreover, they describe other issues, such as file system and network issues [21].

Tauhida Parveen and colleague et al. describe the test method for system activity. The testing addresses two issues. The first test requires significant computing resources and the second test is the length or executing time. Cloud computing addresses these issues by offering resources such as virtualization hardware unlimited storage and software services that can assist in decrease running time. The authors test the migration of software from tow perspective characteristic of application under test and type of testing applied on applications such as unit test, high volume automated testing and performance testing [22].

2.5.5 Sample study of migration of a legacy application to cloud computing

The study “Moving to the Cloud: Workload Migration Techniques and Approaches”. Migrating workloads into cloud models is inherently an “application centric” activity where each image/instance in the cloud typically runs a single application workload so as to have those applications running correctly in the targeted cloud environment. First, the targeted applications need to be identified and separated from the other applications running on the same server. Then an image of that application, its underlying Operating System and infrastructure management agents need to be created and added to the cloud catalog. Finally, the image needs to be instantiated in the cloud environment and verified to run with acceptable Quality of Service (QoS) characteristics. The technical considerations for a migration can be summarized as [13]:

- Software compatibility;
- Reference architecture;
- Workload characteristics; and
- Platform dependencies.

Across all of the migration patterns, there are some common themes. These themes are described here in the context of the five phases/steps of moving the workload to the cloud and forming a high-level reference model. **Figure 5** illustrates the phases [13].

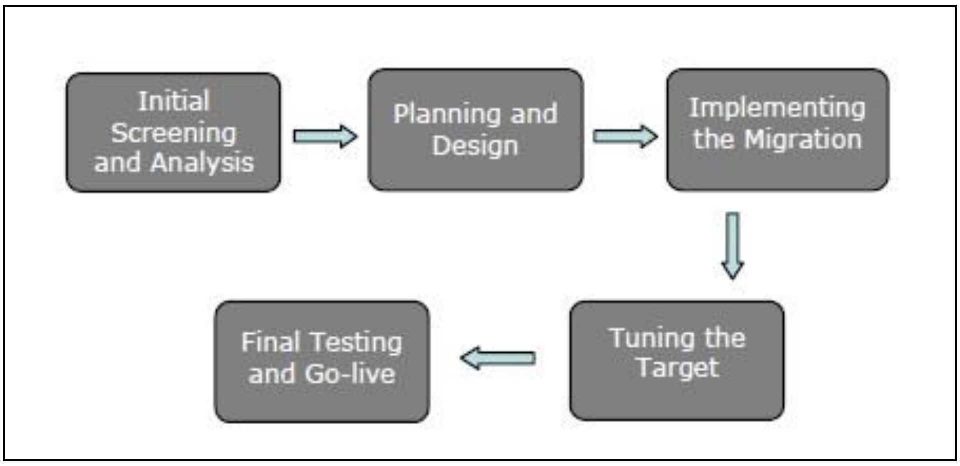

Figure 5 The five step methodology to cloud migration [13]

A) Initial Screening and Analysis

This involves collecting key data on existing workloads, applications and their dependencies, analyzing these data and determining possible migration candidates. The main activities for this phase are:

- Server Inventory Verification;
- Server Affinity Analysis; and
- Measuring Server Utilization.

The result of this phase is commonly the identification of workloads (e.g., Web Serving, Web applications) that are suitable to be hosted in a given cloud environment and the costs involved. The same is usually provided in the form of the ‘Application Report’ [13].

B) Planning and Design

Once the inventory of the targeted applications has been identified and prioritized, the logical design of the applications in the cloud needs to be accomplished. This step involves detailed planning and design of the objective environment (memory, processor, disk storage etc.) as a given requirement. This includes making key architectural decisions and hardware sizing after studying the software stacks and patterns of utilization. The rationalization criteria considered during design and planning activities are: Application Criticality, Availability/Downtime Tolerance, Migration Complexity, Application Scheduling Factors, Application to Application Interfaces and Business Constraints [13].

C) Implementing the Migration

This step is where the workloads are moved to the cloud platform using the most appropriate technique. It involves the following multi-step process [13]:

1) Prepare the target – At this stage, it is important that an organization has a clear vision of the target cloud environment. Depending on whether the type of cloud is a public cloud, private cloud or a hybrid cloud, the target infrastructure preparation is tailored accordingly. The level of preparation also depends on the actual migration scenario. However, the common requirement is usually building a virtual machine instance from one of the available images in the target cloud catalog [13].

2) Migrate – Migrating/creating images from existing workloads, or reinstalling the software stack of the existing workload on the target cloud platform [13].

3) Data Migration – Data migration from the current environment to the target cloud environment [13].

4) Standardization – Standardizing or adjusting the created image so that it is compliant with the infrastructure management services of the cloud environment [13].

5) Integration – Complete integration wherever required to insure connectivity from the moved workload to dependent application services and data in the cloud environment [13].

D) Tuning the Target Environment

Once the customer's existing instances have been moved to the aim cloud platform, these instances are to go through an modification step to configure them to the aim cloud environment's architecture standards. These include [13]:

- Removal of any non-standard tools and agents;
- Applying any operating system level security patches;
- Conforming to the target environment security policy or regulatory requirements; and
- Installation of the target cloud environment's management tools

E) Final testing and go-live

This is the last phase where it is assured that the moved workload is performing as expected and the cloud platform now becomes the production environment for the moved workload [13].

2.5.5 Summary

There are many studies that have been carried out in the area of migration from legacy applications to cloud computing. Some of them focused on support decision making by carrying out a cost analysis and technical analysis, such us the studies in section 2.5.1. Other studies helped to select suitable cloud computing providers and define steps to perform the migration of legacy applications to cloud computing, as discussed in sections 2.5.2 and 2.5.3. An organization which wishes to migrate an application to the cloud needs to follow the order stages content, that is, many steps to ensure that this migration will provide benefits when using the cloud.

CHAPTER 3

DESIGN WORKFLOW FOR MIGRATION

In this thesis, we endeavor to describe the workflow for migration steps to cloud computing. The workflow shows the possible stages to migrate legacy applications to public cloud computing. It is important to decide which type of cloud computing is to be the target of migration. It is better to determine the cloud model in order to deliver clear steps and consider probabilities for migration. The developer writes a report that explains the suggestion stages to help the organization in migration.

3.1 Support Decision Making Stage

The organization defines the applications target that migrates to the cloud and selects a suitable cloud after collection and analyses of the cloud provider. After this stage, the costs for migration and deployment of the applications in the cloud are described. It shows all possible constraints for each step and attempts to solve them.

- **Technical analyses**

'Technical analyses' means preparing a description profile for each application. This profile contents are the characteristics for each application. Those characteristics may influence its migration to the cloud. Additionally, the developer must identify the characteristics related to use and operation. The developer should also capture the characteristics that are related to how to run this application-like environment, type of OS, API and Platform. Furthermore, the developer needs to know how many users have access to the application. In this step, the developer determines which applications will migrate to the cloud and which ones will not migrate. Finally, it is axiomatic that modern applications are easier to migrate to the cloud and old applications are difficult to migrate.

This step captures all the constraints related to applications and environments. For example, network connections and devices are difficult to migrate. In addition, the systems for monitoring are used to monitor the performance of applications. It is not necessary to move these are to the cloud. (See **figure 6**).

- **Organization analyses**

In this step, the developer captures information related to organization characteristic such as the policy of organization and the routine of running applications. Moreover, in this step, captured information is related to the responsibility that determines the operational viability for the applications. The developer can describe the constraints that are related to this step, such as the laws or any else rule by which the organization must be stay, and which somehow might impact its adoption of cloud-based solutions, similarly to the policy of an organization preventing to store database servers outside the organization building. (See **Figure 6**, Support Decision Stage).

- **Selecting a suitable cloud provider cloud analyses**

This step captures the necessary information for the cloud provider. The characteristics of the cloud are very important because in this step, the type of cloud and cloud model is determined. Generally, more applications are migrated to the public cloud or use the hybrid cloud technique. The private cloud uses other computing techniques to gain the benefits of cloud computing. Furthermore, the cloud model is important for the next step of cost analysis and a suitable application with the cloud provider. There are two important migrations for legacy applications to the cloud which depend on the cloud provider model. (See **Figure 6**, Support decision stage).

> ***Legacy application to public cloud IaaS:*** In this migration, the user is granted full privileges on the virtual machines. The user has the ability to select an OS and any necessary software to run an application. Moreover, the developer must know about all the information that assists the selection of the machine. For example, some cloud providers offer elastic services such that the consumer can change the instance machine specifications (CPU, RAM and HD) similarly to Elastic Cloud Computing (EC2) for Amazon Web Services (AWS) cloud

provider. Amazon EC2 provides the selection of selecting between 10 different instance types which are distributed across many instance families, as shown below.

- *General-Purpose family*: This family includes the M1 and M3 instance types which have a balance of CPU, memory, and network resources.
- *Compute-Optimized family*: These instances include C1 and CC2 types. Examples of such applications include front end fleets for high-traffic web sites.
- *Memory-Optimized family*: These instances are designed for memory-intensive applications. Instances in this family have the lowest cost per GB of RAM.
- *Storage-Optimized*: These instances are designed for large-scale data warehouses.

Legacy Application to Public Cloud PaaS: In this migration, the user just creates and manages applications. The developer in this case of migration should be aware of more information that relates to the cloud provider, including:

- PaaS supporting the programming language used to implement the application. For example, Google Apps Engine (GAE) simply supports two programming languages: Python and Java, while Microsoft Azure supports a set of .NET programming languages;
- which databases are supported by the PaaS;
- Checking restrictions and limitations of the selected PaaS, such as whether the application requires a long processing time.

- **Cost analyses**

In this step, the developer should describe the financial state for migration. After marking which application is suitable to migrate and after selecting the suitable cloud provider, the developer explains the cost for each application running in the cloud environment. Additionally, this step describes the costs of running applications in traditional computing to make financial comparisons with costs of running applications in the cloud in order to gain maximum benefits from using external cloud services. The resolution of this step is to give information related to the cost of running all applications that will move to the cloud to help in the support decision making as seen on **Figure 6**.

- **Defining constraints**

There are many constraints that appear in this stage. Each constraint relates to each step. The constraints relate to technical matters, such as security usage for applications and communication among applications. The constraints relating to the organization include resistance from organization members to the change of computing for applications or legal issues regarding physical location; for example, governmental data that must be stored regionally. The constraints related to cloud providers such as the available services inside the cloud and the model of cloud.

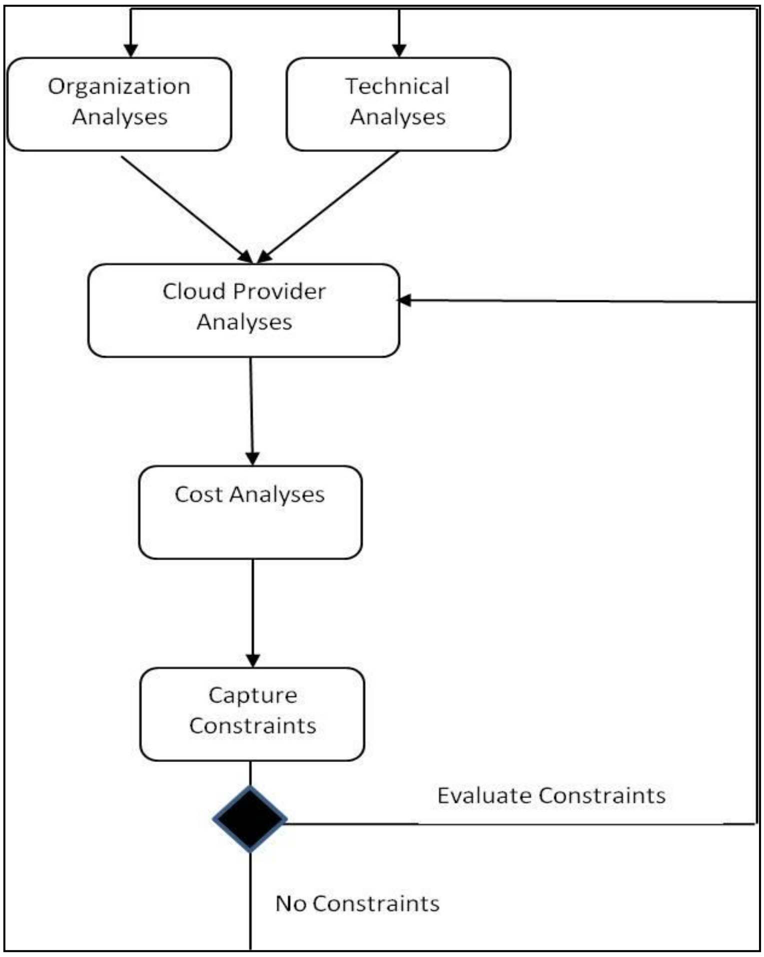

Figure 6 Support decision stage

The figure above explains the important steps in the decision-making stage. In the first step, the developer should analyze the application with the organization because these two analyses can determine the target application which will migrate to the cloud. After these steps the developer analyzes the candidate cloud provider so as to select the suitable cloud for migration. Then the developer carries out a cost analysis for each application to explain the various costs of running applications inside or outside the organization. Finally, all possible constraints will appear.

3.2 Defining the Migration Planning Stage

This stage has two important steps: Migration Applications Planning inside the Cloud and outside the Cloud.

- **Migration applications planning inside the cloud**

In this step, the instances are selected from the cloud provider in order to deploy the target application inside cloud computing. Moreover, the developer must describe the logic design for the target application inside the cloud as the target application must define the power resources (CPU, memory, HD, etc.) that will be selected in the cloud environment. After that the interconnections among the application instants are defined.

- **Migration applications planning outside cloud**

The developer needs to define the order for moving the applications; for example, when an organization has two servers (web server and database server) and the web server has a dynamic site that connects to the database server. In this case, the first server migrates the database server because when the web server migrates after the database server, the test for the dynamic site is possible. Other considerations to be made by the developer include the utilization of target applications. Moreover, the developer needs to consider Application to Application Interfaces.

- **Obtaining and solving constraints**

After achieving the above two steps, the developer can obtain the constraints related to this stage and attempt to solve them; for example, the need to change application power resources inside the cloud instance in order to appropriate target applications or changes in applications design for fitting into the cloud environment. Finally, the developer should identify the sequence in which applications are to be moved to the target cloud. (See **Figure 7**, Planning Migration Stage)

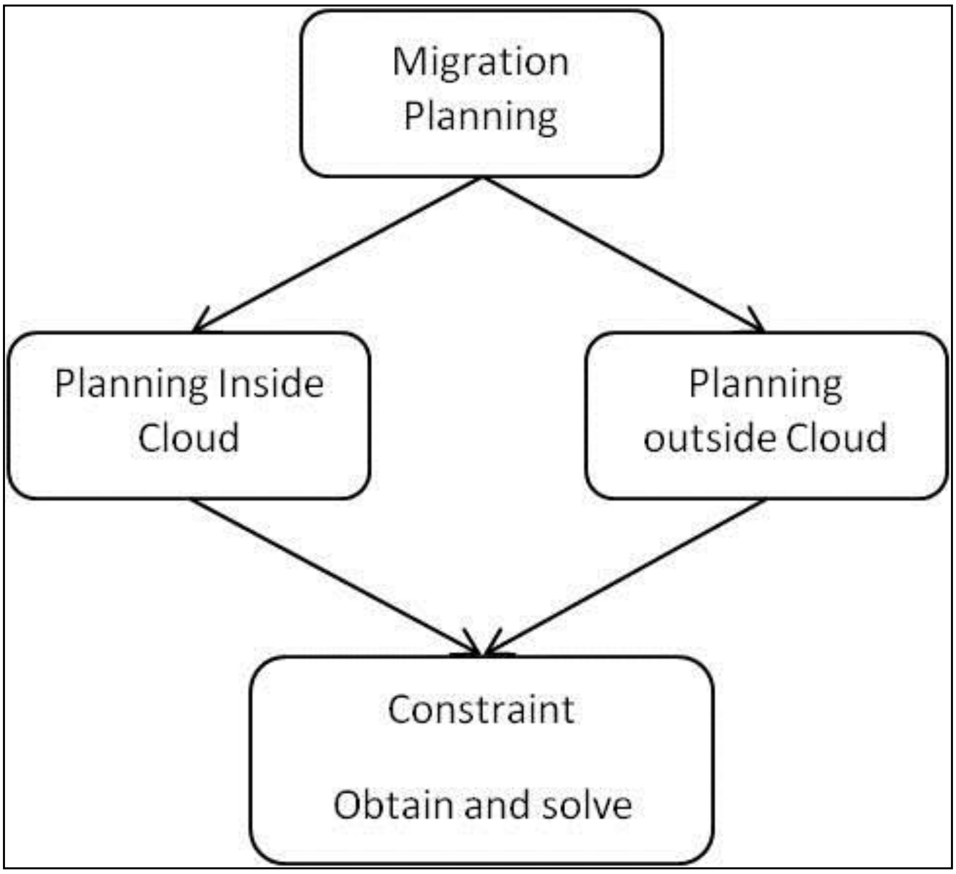

Figure 7 Planning the migration stage

3.3 Implement Migration Stage

In this stage, the developer should be considering the outcome of the planning stage. The reality of the migration to cloud computing starts in this stage. The difficulty of implementing migration depends on the model of cloud computing and target applications. For example, in order to migrate a server to an IaaS cloud provider, the developer needs to prepare the instance (a virtual machine) after configuring this instance to deploy the server on it. To migrate applications to a PaaS cloud provider after checking the platform environment, the developer can deploy applications directly. (See **Figure 8**)

There are three main steps in this stage.

- Preparing the target application and cloud.
- Migrating application and images server.
- Migration of configuration files and data.

3.3 Implement Migration Stage

After the developer gains the clear vision of the cloud model and the target application, the developer tries to adopt the planning to migrate applications to the target cloud. For example, images are created for servers to prepare them for deployment in the cloud. Moreover, it is very important in this step to follow the sequences found in the previous stage. Finally, the cloud side is prepared for the migrated the target applications; for example, create virtual images (instances).

- **Migrating application and images server**

There are many possible methods for performance in this step. The first one is to direct the migrated server images to instances (virtual machines); in other words, from physical machine to virtual machine. The other method is to migrate applications to the platform cloud without any change or reconfiguration. Some server migrations need to change in the server operating system to obtain more cost benefits for cloud computing. The former method depends on the model of cloud and type of application. Additionally it is possible to use solution tools to carry out the migration without the need to re-install a virtual machine in the cloud side or re-deployment of applications such as the ‘Zapp Migration Tool’ from AppZero, which extracts only the in-scope application from the source machine and enables it to run on the target cloud computer.

▪ **Migration configuration files and data**

In this step, the developer needs to transfer the configuration file that relates to the migrated applications after changing it to work inside the cloud environment. An example is the configuration file for the web server ‘Apache web server.’ Additionally, the web pages file relates to the web site that is hosted on the web server. Finally, the developer needs to move any necessary data to the virtual machine to make this machine more reliable and make it a utility; for example, migrating the data to the database server by using a dump file or backup file that is extracted inside the virtual machine server.

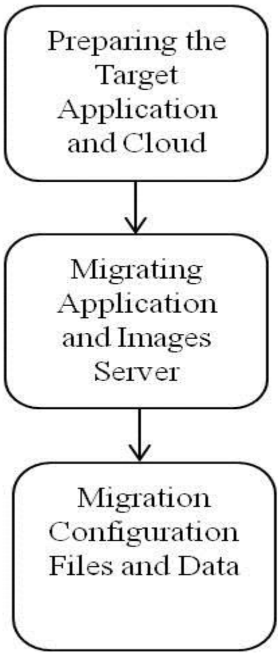

Figure 8 Implementing migration

3.4 Test Migration Stage

This is the final stage which ensures the developer that the migrated applications or server work well. The testing tool depends on applications and services. Moreover, it is possible to use monitoring software that is used at the source side ‘local datacenter.’ It can also use traditional methods to check the Windows operating system such as the Task Manager to test the CPU and memory usage. The important job for this stage is discovering any problems and constraints for the migration and specifies each problem or constraint to its previous stage. Finally, this stage is necessary to confirm the migration, the migrated applications and the performance of the servers. (See **Figure 9**).

3.5 Creating a Documentation Report for Referencing

The developer writes the report to manage the migration consistent with the above stages. The form of this report depends on developer style. It is important to follow the order of stages of the workflow migration, which contains stages for starting the migration of the legacy applications to cloud computing. (See **Figure 9**).

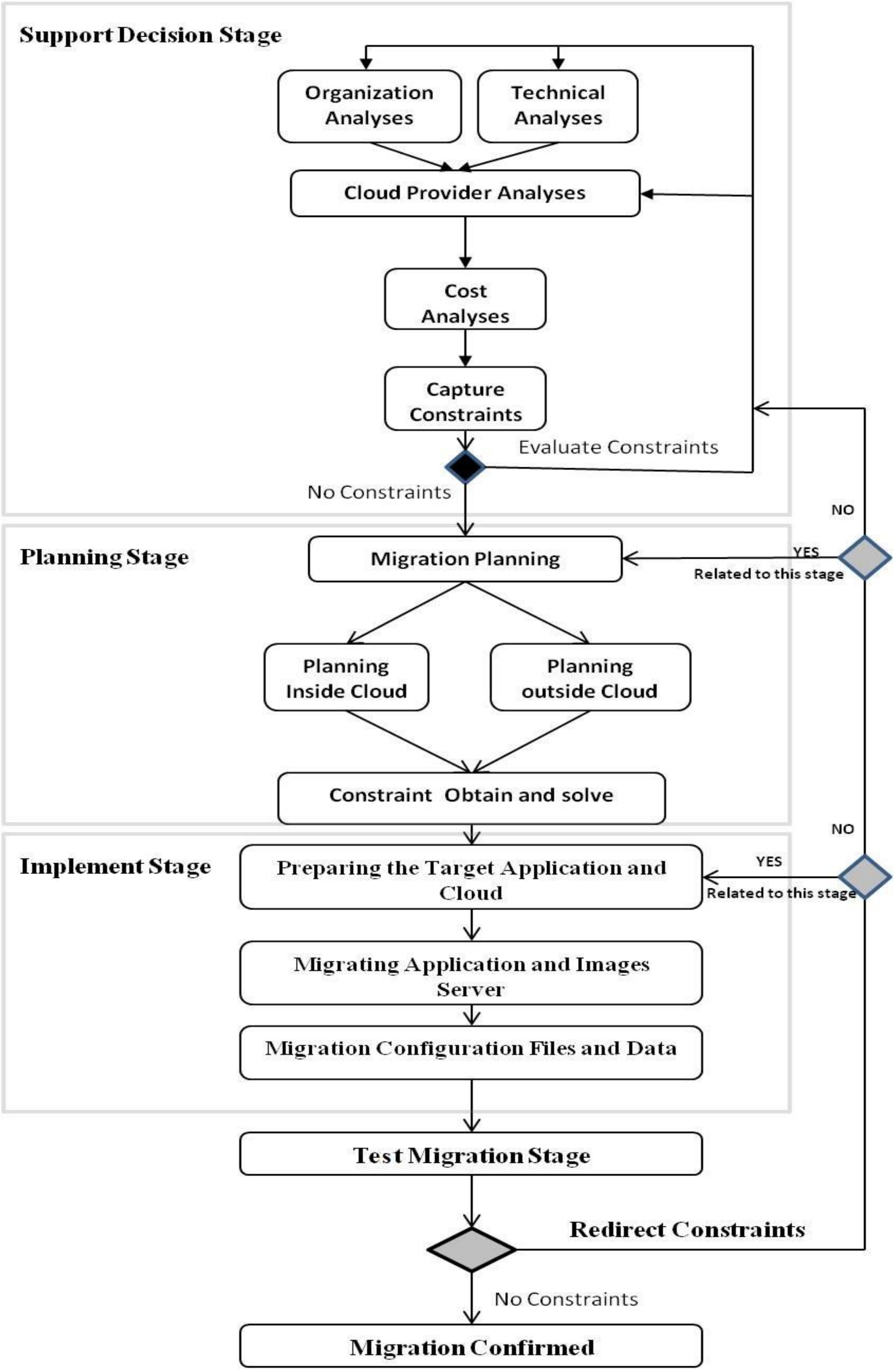

Figure 9 Workflow migration

3.6 Validation

The model proposed in this chapter is based on the reported works to the literature as well as information available on cloud providers' websites. As the topic is quite new to both the industry and to academia, we are challenged by the scarcity of material to build a research instrument with a grounded theory focusing directly on the research question. However, the final product is questioned by two local interviewees in order to spot weaknesses and strengths of the model. This section represents quick feedback from the interviewees.

3.6.1 Who are the interviewees?

As explained previously in section 2.1.1, the decision to migrate the legacy application to the cloud should be taken at management level of organization, such as by the Senior Manager or Chief Technology Officer since this kind of decision is a long term decision. This decision provides an organization with financial success by improving management activities and many other effects. For this reason, we need to know the position of the interviewees in their respective organizations.

Question 1: What is your position and what are your responsibilities in the company?

3.6.2 Reference about benefits

It is necessary to address some of the benefits of using the cloud in addition to some of the benefits related to organizations and human resources in the firm. Furthermore, some benefits relate to the technology of applications, such as improved running environments for the applications.

Question 2: What are the benefits of moving to the cloud?

3.6.3 Feedback for the migration guide

We will obtain feedback for the migration guide after answering the questions below. This migration guide is explained in **Figure 9**.

Question 3: Can you evaluate the migration guide in this thesis?

Interview 1:

Question 1:

What is your position and what are your responsibilities in the company?

Answer:

Senior Development Engineer

Question 2:

What are the benefits of moving to the cloud?

Answer:

There are many benefits to using cloud-based systems in an organization including:

1. Cost being the main factor in choosing a cloud-based system. This also covers the cost for other aspects of running day-to-day operations compared to legacy systems such as infrastructure costs for running security, maintenance, ready-made tools and applications for defense purposes.
2. Besides costs, the reliability of running services is a major decision such that IT professionals today are choosing to use cloud-based systems. There is no need to worry about updating servers and paychecks that at times may cause environmental changes which may result in services stopping.
3. Accessibility is the ease of mind for businesses and IT staff because they can access cloud-based management services while disregarding the location of the information. The management of user information and accessibility of users to information changes according to organization requirements.
4. Scalability and distribution of data with automated backup of resources offered by cloud-based service providers complements the growth of businesses as IT infrastructure grows as needed.

Question 3:

Can you evaluate the migration guide in this thesis?

Answer:

Prior to moving a legacy system to a cloud based system, the feasibility study has to be carried out for some projects with all technical analyses of the system migrated in mind to find out if it is deemed feasible, profitable and possible for the system to operate.

The analyst of an organization can also include the organization type, what the environment of the staff operation is, and the security level that is needed for the data.

An exit strategy must be realized if the migration plan fails due to other factors or recovery reevaluated with new factors realized in the analysis stages.

The planning stage covers more evaluation that has not been covered before in the analysis stage. One may have hardware or software constraints in terms of availability or performance issues that had not been realized before. The testing of the cloud system is essential as initial planning is necessary to decide whether the system will perform in a new cloud-based environment or not.

At the stage that everything is as expected with migration, the implementation stage must ensure that the performance of the system is good as the cloud server is distributed. At times, performance testing is essential to determine if adding resources or upgrading plans for operations reasons is needed. Migration for some applications would be essential in order to have modular testing or stress testing of a part of the system using the resources. Modular testing can also be carried out during the planning stages as required.

Interview 2:

Question 1:

What is your position and what are your responsibilities in the company?

Answer:

Senior chief engineer

Question 2:

What are the benefits of moving to the cloud?

Answer:

1. Cost savings

   No need for high-speed servers, switches, routers and storage devices, all of which are expensive, plus the cost of regular maintenance as well as the need for these devices to be stable and continuously powered for a length of time. These factors lead to thinking in the move towards the cloud.

2. Network

   No need to build a large network (wired and wireless) campus that needs large expenditure in terms of both the cost of devices or periodic maintenance. Instead, we only need an Internet connection to access services on the cloud.

3. IT

   No need to prepare a highly experience IT team in the maintenance of servers or the networks.

4. Disasters

   In case of wars and natural disasters such as earthquakes, it is useful to move to the cloud.

Question 3:

Can you evaluate the migration guide in this thesis?

Answer:

1. In the support decision stage, you need to mention the cloud planning before the cloud provider analysis. In this planning, you will make a decision to select the type of cloud model services, such as IaaS or PaaS.
2. You should put an exit row for each stage to cancel the migration in cases of appearance of any constraints which cannot be handled or solved.
3. You should put the final stage at the end of the migration guide and go to the end if the testing migration stage is not related to any of the above stages.

3.6.4 Results

The author conducted interviews with two persons working in different organizations. The first interviewee works as a senior development engineer, and the second works as a senior chief engineer. Both key informants address benefits of cloud computing, such as in cost, availability, reliability and accessibility. Additionally, they provided feedback for workflow migration as follows:

Interview 1 feedback:

There are many notes addressed from this interview. First of all, the feasibility study: this study should be written before the stage of making a decision in order to find out if it is deemed feasible, profitable and possible for the system to operate. Then the planning stage needs a test step. The testing of the cloud system is essential as initial planning is necessary to decide if the system will perform in the new cloud-based environment. Finally, the workflow needs to show modular testing or stress testing to ensure that the performance of the applications is good as the cloud server is distributed and at times performance testing is essential to determine if adding resources or upgrading plans for operations reasons are needed.

Interview 2 feedback:

From this interview, the interviewee addresses three feedbacks. First, in the support decision stage, we need to select the cloud model service step prior to the cloud provider analysis step. Then the work flow needs to stop the migration step at the end of the decision stage. Finally, the workflow should have an end step after confirmation of migration.

CHAPTER 4

CONCLUSION

This thesis presents migration workflow with possible stages for the migration of applications to cloud computing. These stages help organizations to make decisions for the migration of applications from traditional computing to cloud computing by supporting a decision and then defining many plans for migration, after which the following actions are taken: selecting a suitable plan and implementing the selected plan and finally testing the applications in the cloud environments to confirm this migration. The research question has been addressed with the following findings and related limitations.

4.1 Findings

Following findings are reported:

- The studies in the literature review did not describe any complete steps or stages for migration to our knowledge.
- When an organization decides to migrate the legacy application to cloud computing, the IT staff should make a complete plan depending on the type of analysis steps. However, there is no workflow that helps IT staff to organize this migration as far as the author knows.
- This thesis defines migration workflow as having four main stages.

  1. Support decision making stage with possible steps such as technical analyses, selecting the suitable cloud provider, organization analyses and constraints obtained in order to be solved.

  2. Defining the migration planning stage has many steps, such as planning for migration applications inside the cloud and outside cloud followed by the need to obtain and solve the constraints step.

3. The implement migration stage has a migrating application and images server step followed by the migration configuration files and data step.

4. The test stage to confirm the migration after checking the application operation.

- The migration workflow needs to be evaluated for each stage and step.
- From the interview feedback, the migration workflow should have feasible research before the support decision making stage. Then the workflow needs the testing step in the planning stage. After that, modular testing is needed to ensure that application performance is satisfactory as the cloud server is being distributed. Finally, the workflow needs a stop migration step at the end of the decision stage.

4.2 Limitations

These are the limitations related to the findings.

- The workflow explains migration to the IaaS or PaaS cloud computing model.
- Some studies focused on only one stage, such as the support decision stage and others worked to implement the steps of migration without sufficient analyses for cost, applications, IT staff and organization.
- The author did not find an organization willing to move legacy applications to cloud computing.
- It is somewhat difficult to capture the constraints at the end of each stage of the migration workflow especially in the third and second stages because it is unclear which previous stages or steps can fix these constraints.
- Some feedback in the interview was included in the analysis steps in the support decision stage, so the interviewees needed to use this workflow to provide clear feedback.

4.3 Future Work

In future work, it is possible to define migration workflow for applications which are deployed in the cloud computing IaaS model to move to the cloud computing PaaS model and to try to explain the changes that are implemented on applications to become more suitable to work in the new cloud PaaS environment.

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APPENDICES A

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EDUCATION

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High School	Ali Ibn Abi Talib High School	1998

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2007	Education College in Diyala University	Software Engineer
2010	Computer Center in Diyala University	Manager Program Unite

FOREIGN LANGUAGES

Native Arabic, Advanced English, Beginner Germany, Beginner Turkish.