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Decision support for different migration types of applications to the Cloud

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Abstract

Cloud computing brings many benefits to the enterprises who decide to migrate their applications to the Cloud partially or completely. This thesis focuses on helping users finding the most cost-efficient between different Cloud offerings which have similar features. Data from several Cloud providers are collected and organized in order to implement a Cloud provider knowledge base exposed as a set of web services. These services are validated against other similar systems and exposed as RESTful APIs. A decision support system is built in this work based on these APIs and evaluated by an existing use case with different migration plans.

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1 Introduction

In this chapter, the motivation of this thesis is explained on both the business market side and the development of IT technologies side. Based on technical practice, this motivation is defined as a specific problem. In order to solve this problem, a feasible solution is executed and described in the rest of this thesis.

1.1 Motivation

An enterprise which needs some support from IT technologies would face either a shortage of resources or an over-investment problem during the enterprise's growth and development. From an economics perspective, enterprises desire to gain a maximum benefit with least resources. In the past, people chose to solve those problems directly. They bought advanced equipment to suit the business growth and employed more IT staff for maintenance and update of this equipment locally. But for small or medium size enterprises they may not have so many funds to achieve this update. They are also less able to bear the risk of more investment. In other words, if the benefit did not reach the expected goal after the investment, they could not afford a big loss. With the help of Cloud computing, such enterprises do not worry about these apprehensions any more. They have a new choice to solve their problems. The advantages of Cloud computing are very obvious. There are a number of providers. Many Cloud services are pay-as-you-use. Even if their desired services have many restrictions, they can also find an appropriate alternative offering. Some large enterprises have even a collaborative relationship with Cloud services providers. For example, currently the worldwide largest software enterprise SAP has a collaborative alliance with Amazon Web Services (AWS). The SAP customers can deploy their SAP solutions on Amazon EC2 instances which are already certified by SAP [6].

During the development of Cloud computing market, more and more applications are migrated to the Cloud. There are already many applications which are even developed for the Cloud. This type of development solves some problems but brings also some new problems.

Because of the different kind of Cloud services providers and different features of one Cloud offering, there are various kinds of Cloud offerings with different pricings. How to obtain a suitable offering is very important for consumers who want to use a Cloud service, or who have already chosen a Cloud service but want to find a better one. They need a system to provide candidate offerings which are selected according to available information from the providers. If a Cloud service can achieve all the user's requirements with the lowest cost, it should be obviously considered as one of the best candidate offerings. If additionally this migration type or migration process undertakes the minimum risk, it is also a good candidate offering. In [7] four migration types are defined. Type I and Type II are partial migration while Type III and Type IV are completely migration. In addition, Type I and Type III are migrated based on application components but Type II and Type IV are based on application layer. The specific definitions of each type are explained in Chapter 2 Section 2.1.

1.2 Problem Definition and Goal

In this thesis, a decision support system is built to help users to find an efficient offering for their needs. In this system, the decision which Cloud offering(s) to use is based on a comparison between the cost of suitable offerings. The system collects information from two sides to support this comparison. One side is the users' side which means all requirements from users; the other side is the database side that summarizes all the information from Cloud services providers.

From the users' requirements, a migration type as defined in Chapter 2 (Section 2.1) can be decided. With different migration type the selection result is different and it undertakes different risk. In the application use case A.1, for example, the European Space Agency process astronomic data which are summarized from one billion stars in our galaxy [8] and migrated all their DBMS to the Cloud with VMs using Migration Type III. Users can also determine which provider he trusts more. Furthermore, there are some restrictions about the migrated component itself. More specifically, the user can restrict the characteristics of the Cloud offering which he wants to rent and the usage time or amount of this offering. These are the most basic conditions for the further comparison.

From the providers' information, the features and pricings of each offering can be summarized together. The same offering with different features is divided into different configurations. These features are for example the number of CPU cores, CPU speed, storage capacities etc. Offerings are represented into cost calculation formulas by different parameters, although they may provide similar services. Simple Storage Service (S3) from AWS, for example, has a cost calculation formula with 4 parameters. They are: storage GB, put, copy, post, or list requests, glacier archive and restore requests, and get and all other requests. Cloud Storage which provides the same service as S3 but is from Google has a formula with 2 parameters. Except from storage GB, it has a transactions parameter to represent the pricing of this offering. The location of the data-center is also a related parameter to separate offering into different pricing.

After that, comparisons are done between each candidate offering. According to users' desires, offerings with the lowest costs are identified for the actual migration of their application to the Cloud.

1.3 Outline

This thesis consists of 6 chapters. Figure 1.1 outlines the core chapters of this work. After introducing the background of this thesis (Chapter 2), the system specification is abstracted from the system requirements in Chapter 3. In addition, according to this specification, a system is described to support all the requirements. In the system design section, a Cloud provider knowledge base is discussed, in order to support all the decision support services. These services, exposed as APIs, can be used in a decision support system. The implementation of this decision support system is explained in Chapter 4. The Nefolog system is presented first. It contains all the decision support services which are based on the Cloud provider knowledge base. Furthermore, a decision support system called MiDSuS (Migration Decision Support System) is presented based on the API supported by the Nefolog system. After that, the correctness and efficiency of these two systems is checked in Chapter 5. The validation of Nefolog system is compared with the results from PlanForCloud [9]. The evaluation of MiDSuS system is based on a case study related to the migration of an existing application to the Cloud.

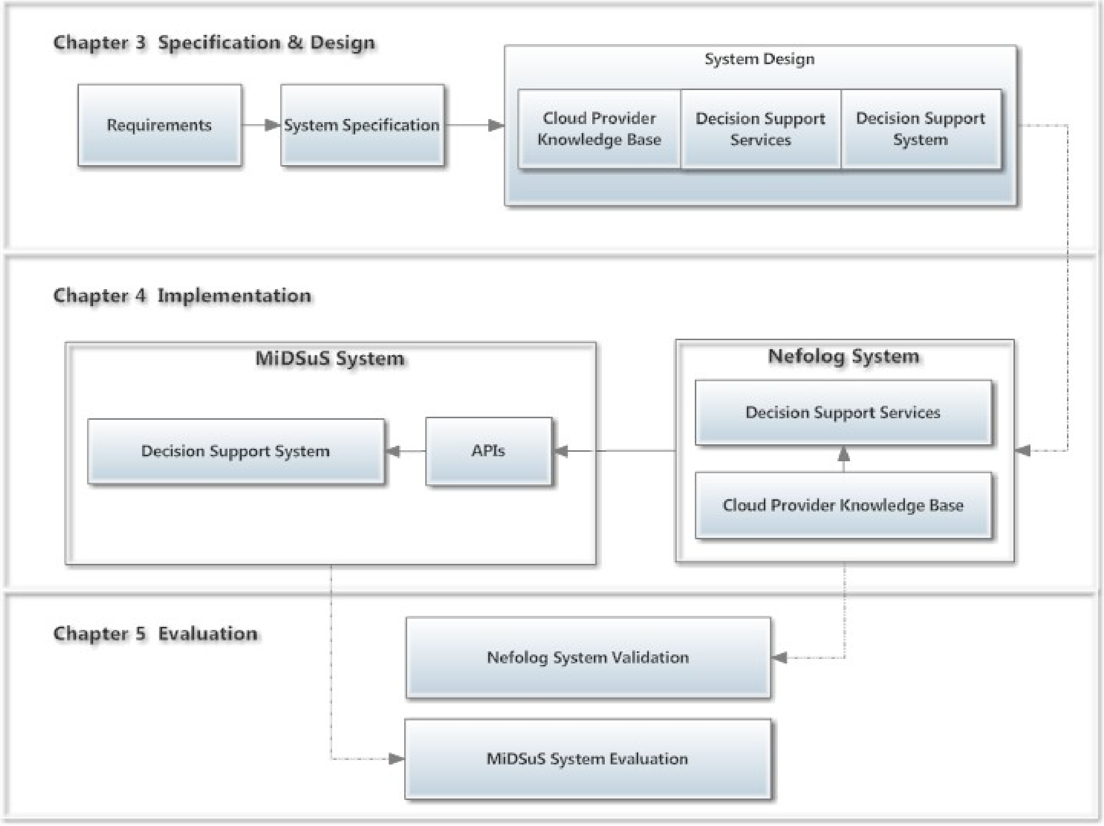


Figure 1.1: Structure of Thesis

2 Background

In this chapter, an analysis of existing works is performed across several dimensions. The result of this analysis shows that providing a decision support system for the Cloud migration is essential.

2.1 Fundamentals

The definition of Cloud computing is a presentation of computing as a service for delivering ubiquitous, convenient and on-demand resource to customers and this service is different to the traditional production definition [10]. Customers do not have to know the design details of the technology infrastructure in the Cloud or need to have an understanding of the related knowledges. This service is based on the network to support dynamic, scalable and virtualized resource. This new technology brings new opportunities and challenges in the IT field.

Current Cloud services are classified by three main service models, software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS) [11]. In the SaaS model, this application software is referred as on-demand software. User does not need to worry about the installation or management of the application. For example Google Apps, user uses it through some clients. In PaaS model, Cloud providers deliver platforms to application developers who want to develop their solutions on a Cloud platform which normally contains operation system, database, web server, programming language execution environment. Google App Engine (GAE) is a typical Cloud service in PaaS model. In the most basic IaaS Model, providers provide some fundamental resources with virtual machines which can help customers to deploy their own systems on Cloud like AWS EC2.

After classifying these offerings by service models, application can be distributed by migration types. An application can be distributed physically into different components. Some components can composite an application layer with logical functionality. In order to recognize whether the user distributes his application physically or logically and whether the user attempts to migrate his application partially or completely, four migration types have been proposed in [7].

- Type I
  Replace one or more components of the application to the Cloud. It is the least invasive and risk migration type. Some measures like configurations, rewiring and adaptation should be done to fix the problems which may happen after replacement.

- Type II
  Migrate a part of the application functionality like a set of architectural components from one application layer to the Cloud. These components should have an interconnection-relationship.

- Type III
  Migrate the whole software stack of the application to the Cloud. Normally it is based on virtualization of application and achievable by a number of VMs.

- Type IV
  Migrate the application completely to the Cloud. It means that all the data layer and business logic layer are re-engineered as a composition of Cloud services.

The applications use cases in Appendix A.1 show how these applications are organized before and after migrating to the Cloud by different migration types in Table A.2. In addition, these applications are marked by "Y" to represent which Cloud offering(s) they have chosen already and by "A" to signify which Cloud offering(s) they could use as an alternative, in Table A.1. These 4 types are enough to cover all the migration situations in Appendix A.1. The same application component can be migrated to the Cloud with different offerings in different migration types. For example, the payroll processing has already been migrated to the Cloud with VMs. One of the migrated components is DBMS. For the DBMS, user can also choose a database Cloud service instead of VM. It should be noted that different migration types will bring different risks and difficulties to the migration.

At present, it seems like that Cloud computing brings us so many benefits such as: it is not so expensive; it reduces the IT support team; it allows management to scale his enterprise with demand etc. How can we know whether we really get benefits from it and how many they are? This problem actually is to estimate the total cost of one Cloud project which is assumed that the components would be migrated to the Cloud with a set of suitable offerings. So far, the cost of an offering is considered as the most important criterion in this decision making process. Actually, there are also other decision factors, for example, same migrated application components with different Cloud providers can lead to different benefit and risk; security and compatibility of these Cloud services can also be the criteria for making process; trust of user for one provider may also change the decision etc.

2.2 Migration-related Issues and Concerns

From the previous discussion, if user wants to find an appropriate Cloud offering, a set of decisions should be made at first. Furthermore, the relationships and influences between each decision cannot be ignored either. These decisions call for a system to find a trade-off between cost estimation and performance prediction. In this section, some researches and works are studied to discuss which factors play an important role in this decision making process.

In the research by Andrikopoulos et al. [1], a conceptual model of decision support system is proposed (Figure 2.1) and described by two types of concepts, *decision* and *task*. The decision concept consists of 4 actions (distribute application, select service provider/offering, define multi-tenancy requirements and define elasticity strategy). The transparent arrows in the figure mean that there are influences between each decisions. The task concept consists of 7 activities (work load profiling, compliance assurance, identification of security concerns, identification of acceptable QoS levels, performance prediction, cost analysis and effort estimation). These tasks support these decisions while these decisions depend also on these 7 tasks. According to the previous section, an application can be distributed logically and physically by different migration types [7]. Different migration types bring different risks and troubles in follow-up work to user. It is necessary to choose an appropriate way with the minimum risk. More and more commentators accept multi-tenancy as a feature of Cloud computing. It means that providers let multiple tenants to share a single version of software in order to reduce the total costs of ownership (TCO). The elasticity strategy can be considered from horizontal (more application instances) and vertical aspects (more computational resources). In the task concept part, it can be seen in the figure that the application distribution can decide performance prediction, effort estimation and cost analysis tasks in the meantime these tasks can also in turn send feedbacks to application distribution decision. The rest three decisions have similar situations as application distribution decision. It means that these tasks are determined by decisions at the same time influence the decisions.

Another work presented in [12] discusses 4 sociable factors which should be treated with carefully in decision making process. They are trust reputation management, risk assessment, green assessment and cost and economical sustainability. Trust can be known by reputation mechanisms [12]. It is an invisible presence but can be made aware from some experiences in the past. If a Cloud services provider is in a blacklist which means that he is a dishonest provider, user should be suggested by decision support system that it is not safe to use this provider's services. Risk is suggested to be considered not traditionally but with the cost of reconfiguration and migration, the reliability of Cloud services and also some other factors together [12]. As well as the risk which may happen in application distribution, there are so many other unforeseen incidents. In the research by Khajeh-Hosseini et al. [13], such incidents are proposed, like: IT staff has low morale and sometimes is very anxious while department may make some changes in his work or reduce staff number during migration; a major service interruption may lead to an extensive outages, unavailability of services or data loss etc. All of these risks are collected from five perspectives, security, technical, organizational, legal and financial. Green assessment is a very common viewpoint in our daily life but it is proposed in ICT industry until recently. From the environmental protection, green cloud computing means that providers try to achieve the desired QoS with as low energy consumption as possible.

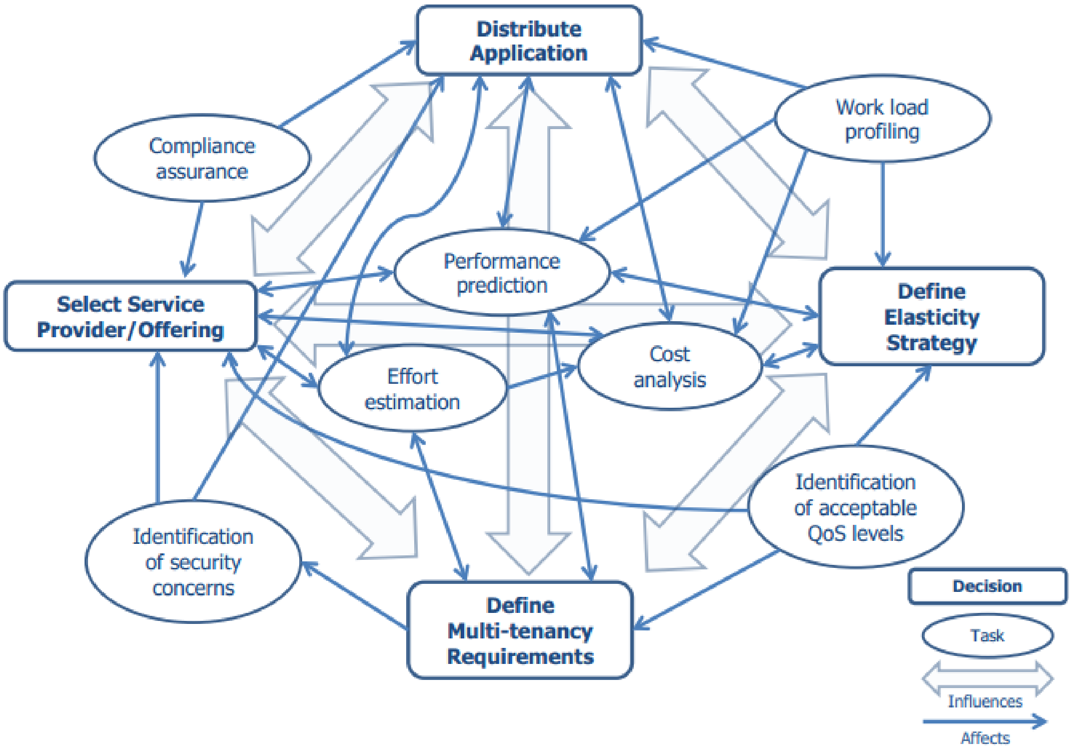

Distribute Application
Work load profiling
Compliance assurance
Performance prediction
Select Service Provider/Offering
Define Elasticity Strategy
Cost analysis
Effort estimation
Identification of acceptable QoS levels
Identification of security concerns
Define Multi-tenancy Requirements
Decision
Task
Influences
Affects

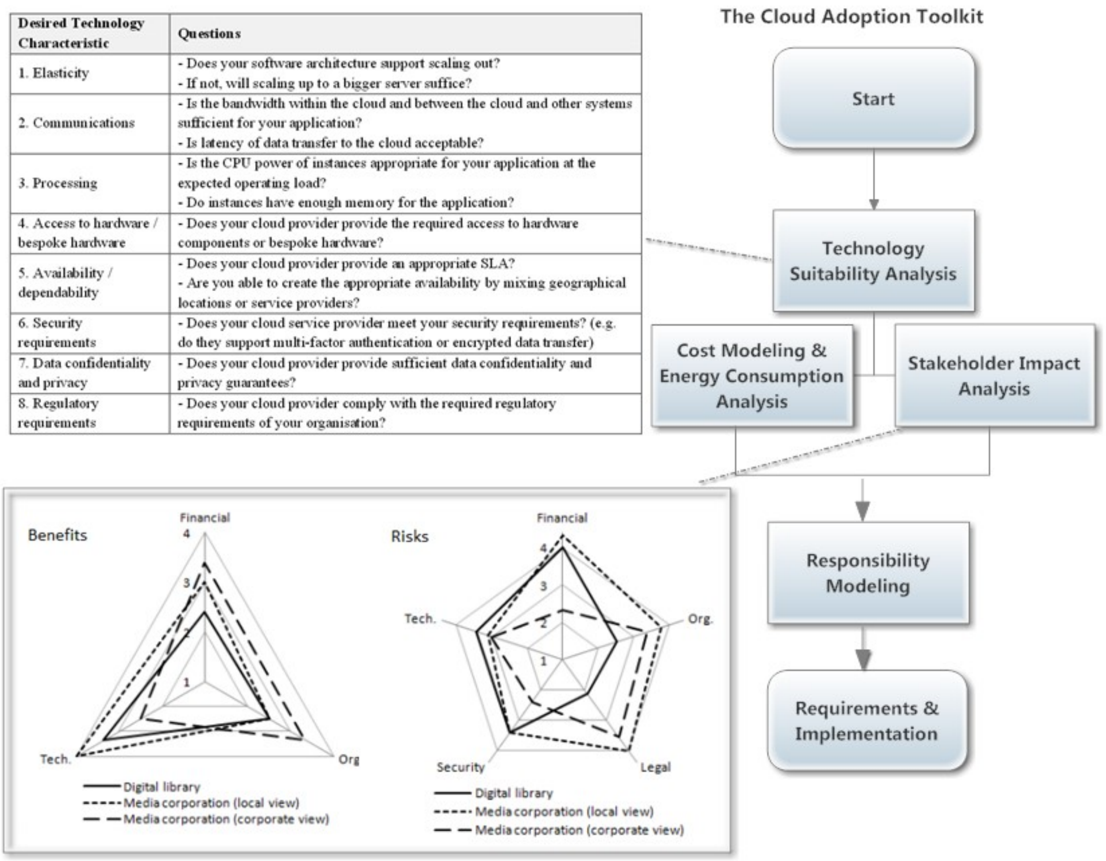
Figure 2.1: Conceptual Model of Decision Support System for Cloud Migration [1]

2.3 Decision Support Systems for Cloud Migration

In this section some existing decision support systems are introduced. Each system is implemented based on cost estimation. Several other factors are also considered.

Khajeh-Hosseini et al. [2] developed the Cloud Adoption Toolkit to support decision making. This toolkit contains a collection of tools which focus on both cost calculation and socio-technique. The conceptual framework of this toolkit is shown in Figure 2.2. Decision maker starts from technology suitability. This technology suitability analysis is built by a checklist in the table of Figure 2.2 which contains 12 questions in 8 technology characteristics. If it is found suitable for the user's work, the next step is to analyze either cost of Cloud services in a public Cloud or cost of energy in his private Cloud. The cost is calculated with the help of a UML deployment diagram which models the deployment of his system on Cloud. At the same time, the stakeholder impact analysis is also done to evaluate the socio-political benefits and risks. The weighted average of benefits and risks which are summarized from some case studies in the research by Khajeh-Hosseini et al. [13] can be calculated and are shown in two radar graphs in Figure 2.2. After these two analyses, if his work is found viable, it goes to the responsibility modelling. This modelling is to check the operational viability of his work. Then the last step is to implement his work in the Cloud.

The second decision support system is called CloudGenius which presented in the work



Desired Technology Characteristic	Questions
1. Elasticity	- Does your software architecture support scaling out? - If not, will scaling up to a bigger server suffice?
2. Communications	- Is the bandwidth within the cloud and between the cloud and other systems sufficient for your application? - Is latency of data transfer to the cloud acceptable?
3. Processing	- Is the CPU power of instances appropriate for your application at the expected operating load? - Do instances have enough memory for the application?
4. Access to hardware / bespoke hardware	- Does your cloud provider provide the required access to hardware components or bespoke hardware?
5. Availability / dependability	- Does your cloud provider provide an appropriate SLA? - Are you able to create the appropriate availability by mixing geographical locations or service providers?
6. Security requirements	- Does your cloud service provider meet your security requirements? (e.g. do they support multi-factor authentication or encrypted data transfer)
7. Data confidentiality and privacy	- Does your cloud provider provide sufficient data confidentiality and privacy guarantees?
8. Regulatory requirements	- Does your cloud provider comply with the required regulatory requirements of your organisation?

The Cloud Adoption Toolkit
Start
Technology Suitability Analysis
Cost Modeling & Energy Consumption Analysis
Stakeholder Impact Analysis
Responsibility Modeling
Requirements & Implementation
Benefits
Financial
4
3
2
1
Tech.
Org
Digital library
Media corporation (local view)
Media corporation (corporate view)
Risks
Financial
4
3
2
1
Tech.
Org.
Security
Legal
Digital library
Media corporation (local view)
Media corporation (corporate view)

Figure 2.2: Cloud Adoption Conceptual Framework [2]

by Menzel et al. [3]. In Figure 2.3, the approach is illustrated. It is a continual and evolutionary migration process. First of all, the decision between Cloud and no Cloud is achieved by a $(MC^2)^2$ framework whose structure is on the top right of this figure. If Cloud infrastructure is viable, this system goes to the core part called CloudGenius migration process which is shown in bottom right of this figure. In the beginning of this migration process, the goal and preferences of the user should be set up. After that, VM image evaluation and Cloud services evaluation are implemented in parallel. These two evaluation methods are implemented by the $(MC^2)^2$ framework which uses Analytic Hierarchy Process (AHP) reducing decision modelling effort instead of Analytic Network Process (ANP). Then the user receives the results which contain some suggestions of VM image and infrastructure. A best combination between Cloud image and Cloud service is selected to achieve this migration. The final step is to make a loop of this making process with some other alternative requirements until the user is satisfied with the solution. This migration process will stop if no more Cloud application is needed. It means that this application is migrated to the Cloud successfully.

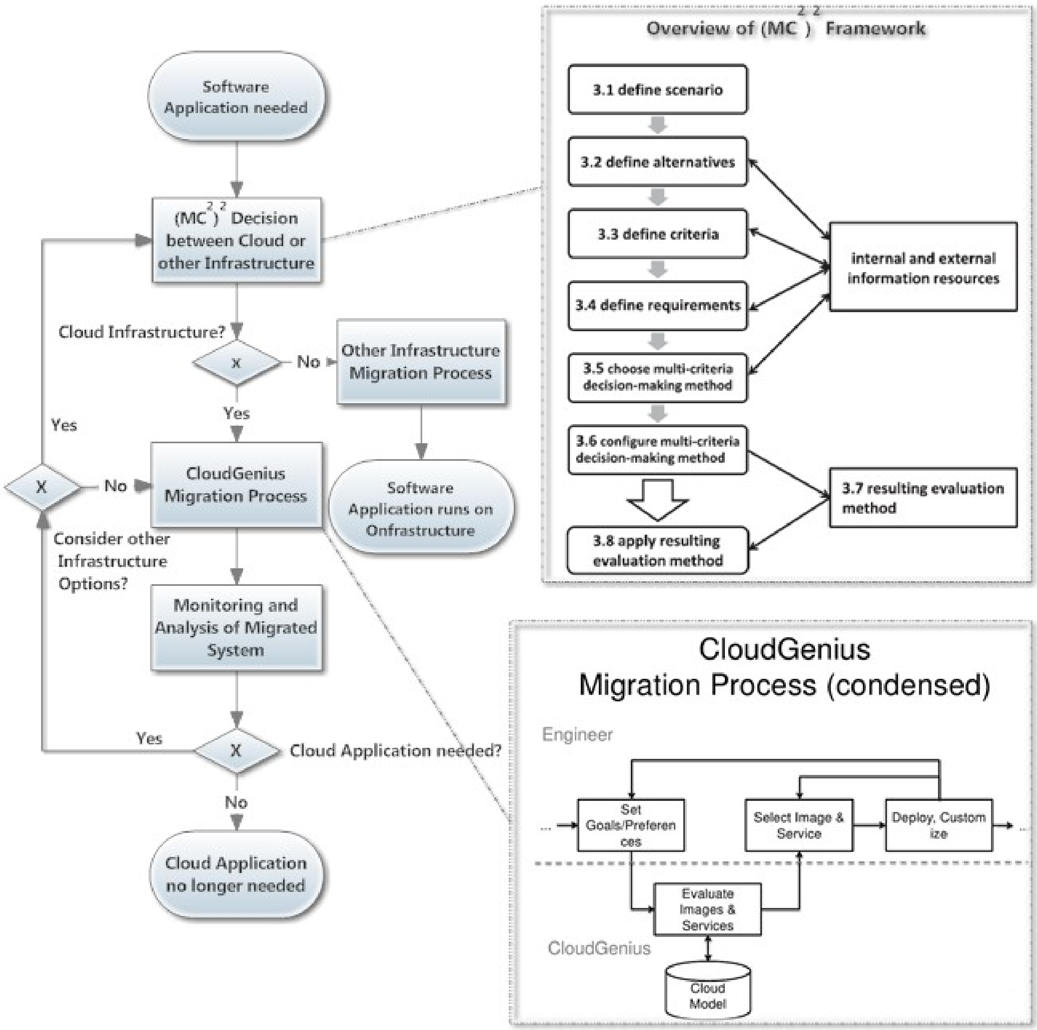

Software Application needed
(MC²)² Decision between Cloud or other Infrastructure
Cloud Infrastructure?
X
No
Other Infrastructure Migration Process
Software Application runs on Onfrastructure
Yes
Yes
X
No
CloudGenius Migration Process
Consider other Infrastructure Options?
Monitoring and Analysis of Migrated System
Yes
X
Cloud Application needed?
No
Cloud Application no longer needed
Overview of (MC²)² Framework
3.1 define scenario
3.2 define alternatives
3.3 define criteria
3.4 define requirements
3.5 choose multi-criteria decision-making method
3.6 configure multi-criteria decision-making method
3.7 resulting evaluation method
3.8 apply resulting evaluation method
internal and external information resources
CloudGenius
Migration Process (condensed)
Engineer
Set Goals/Preferences
Select Image & Service
Deploy, Customize
Evaluate Images & Services
CloudGenius
Cloud Model

Figure 2.3: Overview of CloudGenius Approach [3]

2.4 Cloud Services Cost Calculators

The information about one Cloud service contains the service features, usage conditions, pricing and some other related works. In order to help a user to have a clear understanding of his project or his migrated application cost, it is easy to find a cost calculator on some providers' official website. There are also several other developers who focus on Cloud services cost calculator of several different Cloud services providers but they do not provide any Cloud services themselves.

Table 2.1 is used to show a general introduction of some cost calculators. The first three rows contain cost calculators for Cloud services which are provided by the Cloud provider itself. All of them provide the calculator which can make a hybrid calculation among their offerings and the combination of each offering is selected by user. The last two websites can help the user to calculate his migrated application with some available Cloud providers. PlanForCloud supports a relative all-round system to help user to

Table 2.1: Overview of Cost Calculators

Cloud Services Cost Calculator	**Service(s)**	**Cloud Provider(s) Considered**
Amazon Web Services Simple Monthly Calculator [14]	EC2, S3, RDS, DynamoDB, SimpleDB, VPC, Redshift, SQS, SES, SNS, SWF, Glacier, CloudFront, ElasticCache, CloudWatch, CloudSearch, Direct Connect, Route 53, Elastic MapReduce	AWS
Windows Azure Pricing Calculator [15]	web sites, virtual machines, mobile services, cloud services, data management	Windows Azure
Rackspace Cloud Calculator [16]	Cloud Servers, Cloud Files, Load Balancers	Rackspace
PlanForCloud [9]	Compute, Relational Database, NoSQL Database, Block Storage, Object Storage, Archival Storage	AWS, Rackspace, Google, Windows Azure, SoftLayer, HP Cloud
Cloudorado [17]	IaaS	Atlantic.Net, M5 Cloud Hosting, eApps, CloudSigma, AWS, elastichosts, e24cloud, GoGrid, Linode, JoyentCloud, Ninefold, Server Mule, zettagrid, bitrefinery, VPS.NET, StratoGen, Rackspace, GIGENET, exoscale, SunGard, Dimension Data, vCloud Express

calculate his whole project. In addition, it can calculate the trend of a project cost in a certain term with some defined usage patterns. It contains many different geographical areas of server data centers. It includes more services than Cloudorado which has only IaaS. Cloudorado on the other hand provides a calculator with a lot of Cloud providers. It offers simple mode and advanced mode. In advanced mode, user can also choose more than one server to migrate his application at the same time the data transfer between each server should be considered.

2.5 Migration Decision Support System

The current work is a continuation and is based on MDSS which is developed by Song [5] in early 2013. In this section, the work of MDSS is explained in detail.

MDSS consists of a database, data handler and user interface. The database called Cloud provider knowledge base contains 2 providers, Google and Windows Azure and works on SQL Server 2008. Each provider contains a set of offerings and according to various performance characteristics with different values an offering can be divided into several configurations. In the database, 16 features are summarized for each offering. Pricing of each offering is represented by a formula with multi-parameters. These pricing formulas are collected by different locations and different usage amounts. After explaining the information which is collected from the providers, the developer defined also 5 service types to organize these offerings from system side.

The data handler contains two main functions, offerings matcher and costs calculator. The offerings matcher function is implemented by a comparison between user's requirements and the data in the database. These user's requirements should include: which service type is migrated to the Cloud; which offering user prefers to choose; which performances the Cloud offering should have according to user's demands. The costs calculator is achieved by calculating the pricing formula with certain values which are assigned by user. A user can also choose his desired data center location and usage pattern with a certain rate in a fixed period of time.

All these requirements both for offerings matcher and for costs calculator are given on the first page of MDSS UI. The results are listed in the second page with configurations, locations, details, providers, costs, sums and parameters. In the end of each row in this list, there is a button called "Info". With this button, user can get more information concerning this configuration's performance characteristics and a graph of cost in each month. In the bottom of this page, there's a drop down list to select a parameter to rank. The Ranking result is shown in the third page.

2.6 Summary

Knowledge of service models and migration types are set up as foundation in this work. As studying some researches about decision support for Cloud migration, a number of factors are introduced and should be considered in making process. Furthermore, two existing decision support system are illustrated step by step. If all these factors are considered, the decision making process may be separated by amount of evaluations and comparisons. A mature decision support system should be generated by a long-term data collection and based on a lot of migration practices. An attempt to build a decision support system is done by Song. In his work, he introduced a system called MDSS which achieves to a trade-off between cost and performances. The composition and operation of MDSS are summarized in this chapter.

3 Specification & Design

This chapter focuses on extracting requirements and presenting the specification and design of a decision support system for Cloud migration. To complete all the requirements a decision support system is established which is based on some RESTful APIs. These APIs are working with a database named Cloud providers knowledge base. This knowledge base summaries information of several Cloud services providers. The information is about features and pricings of each offering.

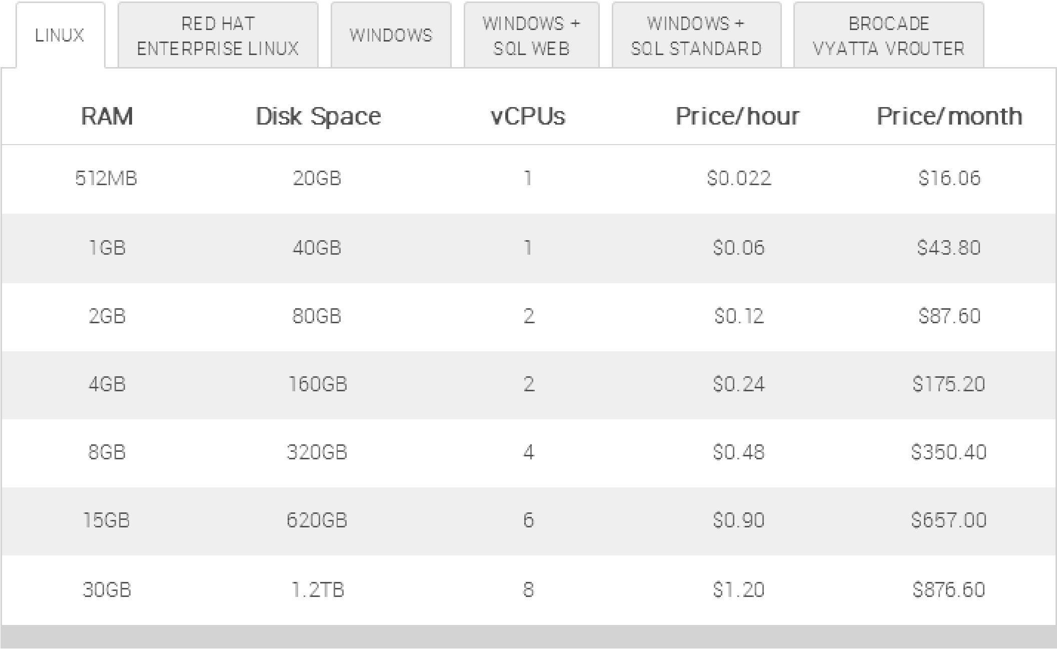
3.1 Requirements

Cloud service is a better solution for a private consumer or an enterprise to expand the service coverage area or to reduce the IT support team members or the calculation time of big data processing. It is reliable, flexible and scalable. Besides these characteristics, some of these Cloud services are pay-as-you-use. It is an efficient way to reduce the cost. In today's market, there are a few providers which provide a variety of Cloud services. It means that there are many different available offerings for consumer to achieve his strict requirements about the cost, the provider or even the data center from which to be served.

In Figure 3.1, the shown provider is Rackspace and this Cloud offering is Cloud Servers. It supports VMs with different performance on different operating system with different database manager. In addition, the pricing for each configuration is different. Higher performance has a little more expensive price than the lower one. For one single provider, it has already many different configurations. For many providers, the possible options are larger. Consumer spends too much time on choosing a practical and cost-effective Cloud offering among them. Supporting the user in this task is perceived as this work's goal. A decision support system is built to help consumer to find a set of suitable offerings quickly and directly.

As a whole system, a friendly user interface should be developed. It will support a concrete and intuitive interaction for user. A comparison between the initial application and migrated application is necessary to help user to choose an appropriate migration type. The migration types are already explained in Section 2.1. Choosing the appropriate migration type can reduce the risk during migrating to the Cloud and save investments.

It should be considered as the first step for an application which would like to be migrated to the Cloud. Second step, a description of application will be asked for. Actually, the definition of service type is described more obviously and directly by the application components and application layers. After that it's time for the initial requirements part. The requirements may contain which provider user wants to choose, which kind



RAM	Disk Space	vCPUs	Price/hour	Price/month
512MB	20GB	1	$0.022	$16.06
1GB	40GB	1	$0.06	$43.80
2GB	80GB	2	$0.12	$87.60
4GB	160GB	2	$0.24	$175.20
8GB	320GB	4	$0.48	$350.40
15GB	620GB	6	$0.90	$657.00
30GB	1.2TB	8	$1.20	$876.60

Figure 3.1: Cloud Servers from Provider Rackspace Pricing Details [4]

of performances he hopes the Cloud service has, how long he wants to use this services, etc.

All these requirements will be collected and transferred to the data processing part. This system will search for several candidate offerings which could reach or even exceed the demands of user in all offerings. For each candidate offering, the service cost and data transfer between this offering and local or another offering will be calculated with the help of cost formulas with multiple parameters whose values are already given as initial conditions. The total cost is a sum of the usage amount of the service, cost of data transfer and the upfront of this service. User can also know the trends of the total cost by giving different usage patterns in order to decide which offering is worthy to utilize during a long-term plan.

3.2 System Specification

The envisioned functionalities of the system are illustrated using a Use Case diagram in Figure 3.2. It is abstracted from the requirements in Section 3.1. All the requirements of user are separated into 3 parts. The first is to Select Application Description. It is used to determine the appropriate migration types. The second is to Enter Candidate Requirements. It provides finer initial values for candidate offerings search like provider name and service type which is based on the migrated components. Using these requirements and necessary data from the database the candidate offerings can be found. According to the user's desire a number of candidate offerings can be selected to get concrete evaluations of these offerings' costs. The third is Enter Cost Requirements. For different configurations the calculation variables are different. These optional evaluation variables are collected by a service in backend. With the help of these requirements and cost formulas from database the costs and cost trends can be calculated. All these results can be returned and visualized for the user. There are also several sorts of Rankings to help the user to have a better view of the costs, update dates or data centers comparisons.

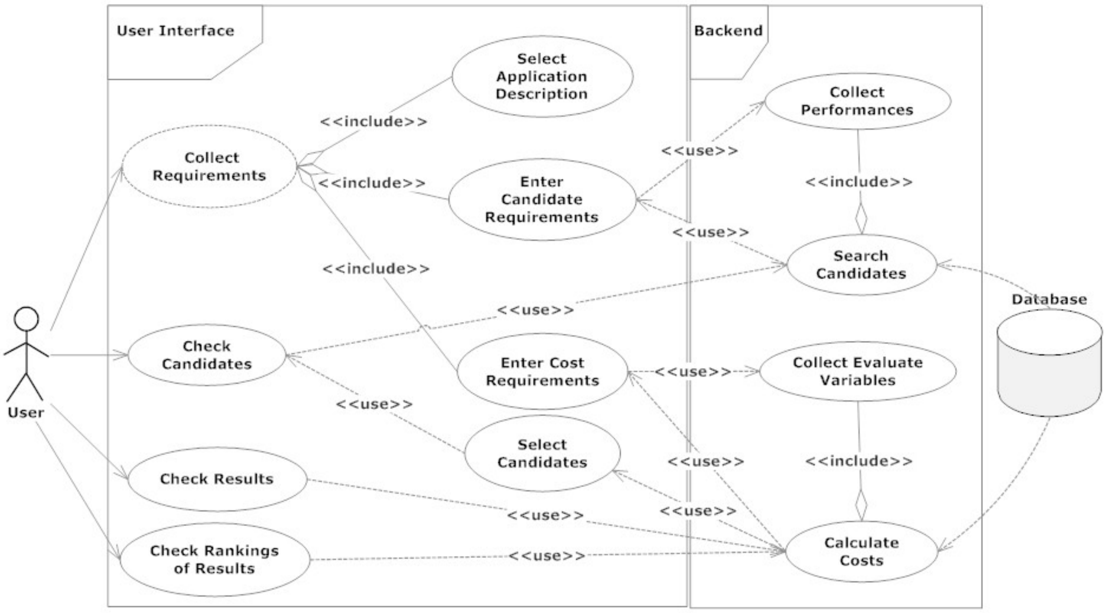


Figure 3.2: Envisioned System Functionalities

Extending the work in [5], this new system is composed of two main parts. One is called Cloud Services as back-end of the system while the other is called Cloud Migration as front-end of the system. Cloud Services part is built up by web services and database. It implements the offerings matcher and costs calculator functionality. Cloud Migration part is a web application part which is based on the Cloud Services part. It contains UI components and some logic behind it which is used to transfer data between front-end and back-end.

As it can be seen in Figure 3.3, the consumer can give his requirements in the web application which is called Decision Support System in Figure 3.3. In the Decision Support System, there is a description of the consumer's application and the components which are meant to be migrated on the Cloud. Consumers can choose one Cloud services provider or all of them. After some necessary values are ready for the data processing part, it's time to begin candidate offerings search then the system works about offerings' cost calculation. All these requirements are considered as requests to web services. Many web services are built to support this system. One of them is to look for the candidate offerings. Another one is to calculate the total cost of offerings and the trends of this cost in the each following month. This search and calculation part is called Decision Support Services in Figure 3.3. All the necessary data are stored and retrieved from the Cloud Provider Knowledge Base. After that the responses of this service are sent back to the consumer and displayed through the web application.

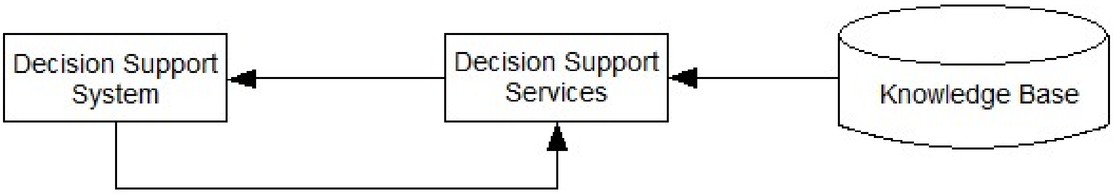


Figure 3.3: Modules of new System

The knowledge base is expanded based on the previous knowledge base in MDSS while the functions of data handler are transplanted as services in the new system. The similar parts will therefore not be described again; only the different part will be given an account here. More specifically:

- Interaction
  The UI of this work is different from MDSS. It will support consumer to complete his selection from 4 migration types not only from service types. In addition, for each type all the necessary initial conditions will be given in a table, in order to help consumer to clearly see which components his application contains and which one or ones he wants to migrate to the Cloud. Instead of choosing the service types in MDSS, this system separates all the service types into application components and collects them into different service types for Type I & III and into different application layer for Type II & IV. He does not need to choose which Cloud offering he wants to use but to choose which Cloud provider. This way supports consumer to get more apposite available offerings than in MDSS.

- Web Service instead of Function
  All the functions in MDSS will be transplanted to the new system as restful web services. A platform-independent and program language-independent system is a goal for this work. All the services can be put in a WAR file in the end and run on any platform. The 2 main functions in MDSS, offerings matcher and costs calculator, will be changed into candidate search service and cost calculator service, respectively. Some algorithms will be kept while others will be overridden. But the general idea is identical.

- Data
  There are more providers covered than MDSS, 6 (Google, Windows Azure, Amazon Web Services, Hp Cloud, Rackspace and Flexiscale) instead of 2 (Google and Windows Azure). More providers mean more service types of an application and more factors of calculating a total cost and even more process time of one service. A refinement and reworking of service types must be done to make a better organization among all the offerings in the knowledge base. Cost of data transfer between two offerings or between offering and local will be considered as one factor. In addition, upfront costs of one Cloud service cannot be ignored. The definition

of location in MDSS will be changed to geographical area and a definition of zone will be added into the Knowledge Base in order to make a better partition for different provider's Cloud service which is from different data-center. In the data collection, the pricing of the Cloud services from the provider Flexiscale[1] is different. During the processing of costs calculator, the provider Flexiscale should be separately treated with.

3.3 Cloud Provider Knowledge Base

This knowledge base refines and extends the equivalent base from MDSS. Figure 3.4 shows the Entity-Relation diagram of the MDSS's database while Figure 3.5 shows the new Entity-Relation diagram. All the MDSS's basic entities are information included in the new ER diagram. At the same time, some more information has been added to supply the users with more possibilities when they intend to utilize the Cloud services.

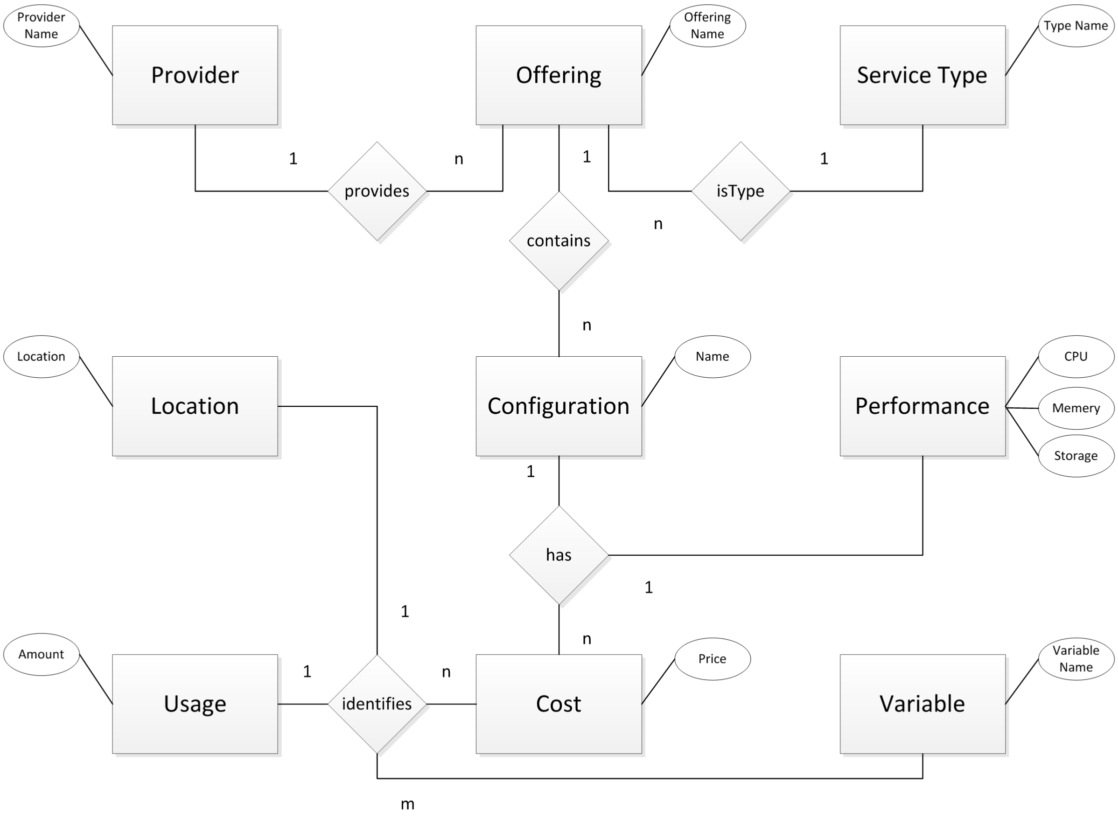


Figure 3.4: Entity-Relation Diagram of MDSS [5]

In Figure 3.4, there are six main entities and relationships among them. The providers' information is abstracted as the Provider entity and it has a one-to-many relationship with the Offering entity which is also classified by the Service Type entity. One offering

[1] http://www.flexiscale.com/products/flexiscale/

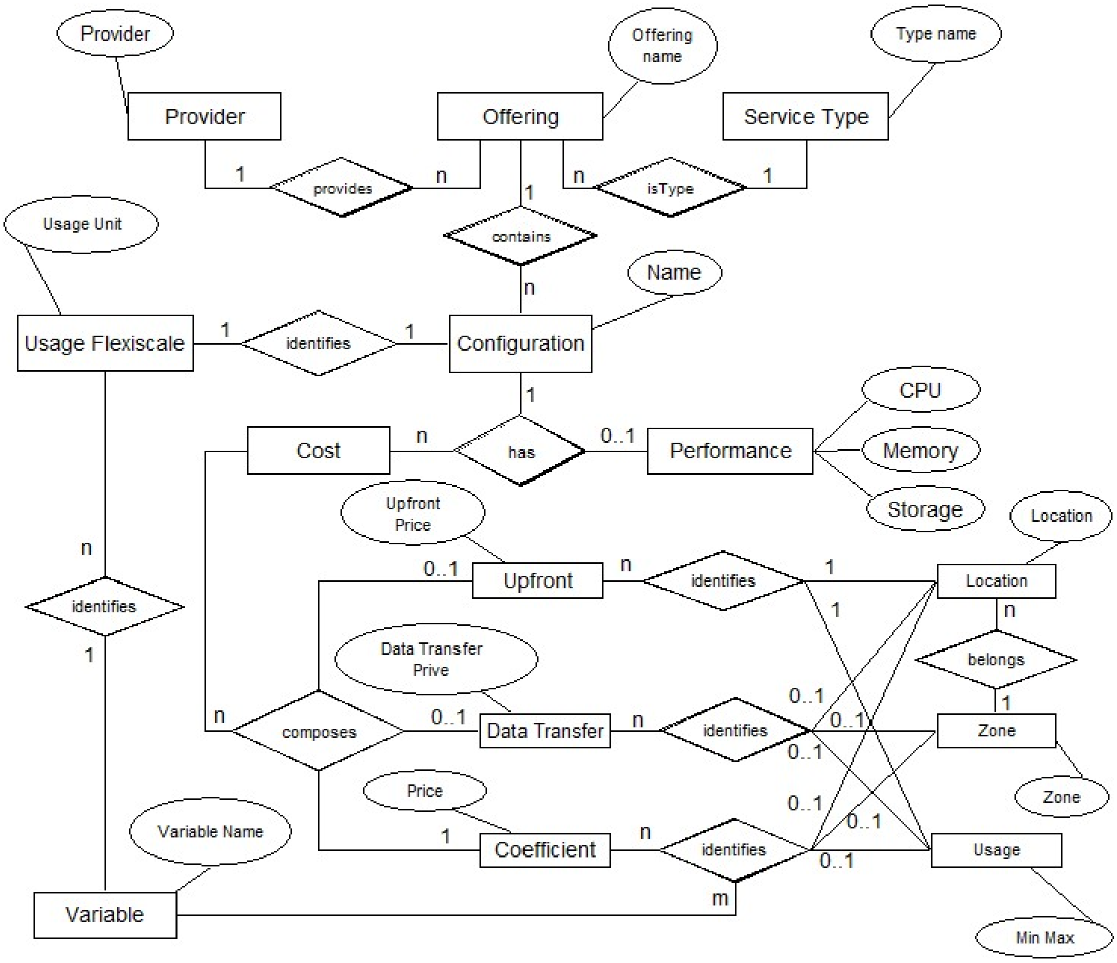


Figure 3.5: Entity-Relation Diagram

may supply more configurations that are sorted by different performance. The cost of each configuration is calculated by some variables according to different location and usage amount.

It can be seen in Figure 3.5, the six main entities are kept. The Cost entity is divided into three parts. The reason is that there are three factors which are not independent on each other but can affect the final cost. One of these factors is the upfront cost of using the service. It is only required by Amazon Web Service (AWS) offerings. MDSS does not include the AWS provider, so it does not have this entity. Another factor is the price of data transfer. MDSS also considers this cost but only as a single service type. In this work, the data transfer is considered as a part of the cost calculation, because there must be some data which transfer in or out from a cloud service. The last part is the pricing of the Cloud service as provided in MDSS. These three factors have a one-to-many relationship with the Cost entity. To make a final cost estimate, a sum of these three parts must be done.

There's a special provider in this new system, Flexiscale. The cost calculation for this provider is related to the number of units which the configuration utilizes and not to a fixed price. It has a one-to-one relationship with the Configuration entity and can be represented by a one-to-many relationship with the Variable entity.

The location of the new system is specific to each geographical area that related to all the providers. The areas are classified to several zones. The two entities have a one-to-many relationship.

3.4 Decision Support Services

To achieve these requirements which were already mentioned in Section 3.1 there are many possible solutions. A web application which is based on web services has been determined to be the more appropriate design which fits the system specification described in the previous.

In this work, we choose web service and abandon the use of functions which have been developed in MDSS. Beside the ease of interoperation with a Web-based system, there are also some other reasons to explain this decision.

Web service is platform-independent and program language-independent. It means that the client side can be programmed in C++ and running under Windows, while the server side is programmed in Java and running under Linux. In other words, what the client side looks like is not important in this work. The task is about the server side and developing it with web services is easier for the next developer who wants to continue this work later.

In short, all the resources in Figure 3.5 should be identified by URIs. The 2 decision support functions are transformed into decision support services. The consumer's requirements are transported to the server side through the query part of URI. The appropriate results are returned back in 2 standard representations, XML and JSON.

Before a search or a calculation starts, the initial conditions must be checked whether it is in the range. If not, an error message will be returned back and new initial conditions should be given.

3.4.1 Candidate Search Service

The candidate search service in [5] is called offering matcher. The filter has been separated by the numerical-performance characteristics and non-numerical-performance characteristics. In the new system, the non-numerical-performance characteristics contain performance characteristics of operating system, software licence and I/O (it is described by providers with low, moderate, high and very high); the rest of the performance characteristics are numerical-performance characteristics. The necessary performance characteristics for one configuration are given to consumer before he starts the candidate searching. Except all the requirements which are defined by the consumer, the rest of the performance characteristics which are also defined by providers are not considered in the matching process.

Under the consideration of the expansion of database the algorithm of candidate search service is modified from the offering matcher algorithm in MDSS. It is showed in in Algorithm 1. The data type of a few parameters is $HashMap$ class instead of $List$ class in MDSS. $HashMap$ class is used to implement a mapping between *key* and *value*. It is easy to search and compare with another *value* of the same *key*. But it has also some disadvantages that the sequence of one map is unfixed and for one *key* there can be only one *value*. It means if one *key* maps to more than one *value*s, the class $List$ could be used otherwise the last *value* will be overridden all the previous *value*s. The input parameter is M_p. It's a collection of the requirements from the URI query part. The parameter M_c is identified by the configuration id as *key* and maps to a performances-list called L_{cp} as *value* which contains all the performances of this configuration. L_{cp} is received by a database sql query search. Then comparing each performance of L_{cp} with M_p, if the performances are the same or L_{cp}'s value is bigger than M_p's, this configuration is a candidate configuration. Otherwise the configuration id will be deleted from M_c.

Algorithm 1 Candidate Search

```
procedure CANDIDATESEARCH($M_p$)
    $M_c := SQLquery(M_p("servicetype"), M_p("offering"), M_p("provider"));$
    for each $c \in M_c$ do
        $L_{cp} := M_c(c);$
        for each $p \in L_p$ do
            if $\neg M_p(p) = NULL$ then
                if $\neg L_{cp}(p) = NULL$ then
                    if $p = "os" \vee p = "io" \vee p = "licence"$ then
                        if $\neg L_{cp}(p) = M_p(p)$ then
                            remove $c$ from $M_c$;
                            break;
                        end if
                    else
                        if $L_{cp}(p) < M_p(p)$ then
                            remove $c$ from $M_c$;
                            break;
                        end if
                    end if
                end if
            end if
        end for
    end for
end procedure
```

3.4.2 Cost Calculator Service

In the cost calculator service part, the algorithm is completely changed with respect of the cost calculation algorithm of MDSS. The specific reasons for this change are listed in the following:

- In MDSS, for the static unit-price the initial condition for no input-value is a default value (1); for the dynamic unit-price the initial condition is the minimum and maximum consumption in every amount range and a list of costs was shown to consumer. An appropriate default value should be re-defined. This value should be at least help consumer to get a general idea of the cost of this service. For static unit-price the initial value is 5000 except the time value. If this service is calculated by hour, the initial value is 500. In addition, the utilization time of a Cloud service is 10 months as default. For dynamic unit-price the initial vale of no input-value is the maximum consumption of the biggest amount range.

- Some new providers are added to the new knowledge base, so the cost calculator should contain all the situations for each provider. There are 2 special providers, Amazon Web Services and Flexiscale. If the provider is Amazon Web Services, the variable which is used to separate the usage amount range should be processed carefully. Because only for the provider AWS, there is upfront for some Cloud services and it is charged per 1 year or 3 years. It means this variable's unit is maybe "Hour" but the unit of usage amount range is "Year" or "Month". There should be a unit-transformation for the "Hour" unit and a check-process for the value of "Hour" variable which cannot be more than 730 hours per month. If the provider is Flexiscale, the usage amount is a formula with multiple variables that the result is static according to pricing table. The pricing is divided into different tariff by the amount of units.

- The cost calculator is divided into static-calculator and dynamic-calculator. The static-calculator part is relatively straightforward; the dynamic-calculator part however requires additional logic. The formula's usage amount range should be checked always as long as the variable value changes. So all the results which are selected by user's requirements are retained whether the minimum or maximum values of these cost formulas does not reach the requirement. If the cost formula is determined by a fixed rang as what has been done in MDSS, there may be mistakes when the value of the dynamic variable is out of range.

- The total cost consists of service usage amount cost, data transfer cost and upfront. Before adding these 3 parts together, the condition should be checked whether they stay at the same data-center. Especially, if the service data-center is worldwide but the data transfer data-center is in EU, the total cost should be calculated differently. The result is built up by 2 parts, service cost with data transfer cost in EU and service cost without data transfer in other geographical areas.

Actually, the process method of all the providers except Flexiscale is using the same idea, but what are mentioned above must be treated with carefully and all the possible situations should be included in the implementation part. The provider Flexiscale is a dynamic unit-price but for the usage amount not for the cost calculation formula.

Algorithm 2 Cost Calculator

```
procedure COSTCALCULATOR($id$,$M_v$,$M_{cd}$,$M_p$,$months$)
    $service_c := 0$;
    $upfront_c := 0$;
    $datatransfer_c = 0$;
    $L_c := SQLquery(id)$;
    $M_c := SQLquery(id)$;
    $L_v := getVars(L_c)$;
    $M_v := unitCheck(M_v)$;
    for $index = 0 \rightarrow Size(L_c)$ do
        $cid := L_c(index)$;
        $L_p := M_c(cid)$;
        if $\neg Flexiscale$ then
            if $staticunit - price$ then
                $upfront_c := Upfront(cid, M_v)$;
                $service_c := costCalculator(formula, M_v)$;
                $datatransfer_c := dataTransfer(cid, M_v)$;
                if $static - rate$ then
                    $service_c$,$datatransfer_c$,$upfront_c$ do not change for each month;
                else
                    if $month < max(M_p)$ then
                        $month := max(M_p)$;
                    end if
                    for $i = 1 \rightarrow month$ do
                        for each $vp \in M_p$ do
                            if $i \in M_p(vp)$ then
                                $M_v(vp) := M_v * (1 + rate/100)$;
                                $M_v := unitCheck(M_v)$;
                            end if
                        end for
                        $service_c := costCalculator(formula(cid), M_v)$
                        $datatransfer_c := dataTransfer(cid, M_v)$;
                    end for
                end if
            else
                get $min$, $max$ from $L_p$;
                $v :=$ the variable which identifies the usage amount range;
                if $\neg(M_v(v) < max \wedge M_v(v) > min)$ then
                    for $start := 0 \rightarrow Size(L_c)$ do
                        $cid := L_c(start)$;
                        $L_p := M_c(cid)$;
                        get new $min$, $max$ from $L_p$;
                        if $M_v(v) < max \wedge M_v(v) > min$ then
                            get new $cid$;
                            $index := start$;
                            break;
                        end if
                    end for
                end if
                $upfront_c := Upfront(cid, M_v)$;
                $service_c := costCalculator(formula(cid), M_v)$;
                $datatransfer_c := dataTransfer(cid, M_v)$;
                **if** $static - rate$ **then**
                    $service_c$,$datatransfer_c$,$upfront_c$ do not change for each month;
                **else**
                    **if** $month < max(M_p)$ **then**
                        $month := max(M_p)$;
                    **end if**
                    **for** $i = 1 \rightarrow month$ **do**
                        **for** each $vp \in M_p$ **do**
                            **if** $i \in M_p(vp)$ **then**
                                $M_v(vp) := M_v * (1 + rate/100)$;
                                $M_v := unitCheck(M_v)$;
                                **if** $vp(name) = v(name)$ **then**
                                    **if** $\neg(M_v(vp) < max \wedge M_v(vp) > min)$ **then**
                                        **for** $start := 1 \rightarrow Size(L_c)$ **do**
                                            $cid := L_c(start)$;
                                            $L_p := M_c(cid)$;
                                            get new $min$, $max$ from $L_p$;
                                            **if** $M_v(vp) < max \wedge M_v(vp) > min$ **then**
                                                get new $cid$;
                                                break;
                                            **end if**
                                        **end for**
                                    **end if**
                                **end if**
                            **end if**
                        **end for**
                        $upfront_c := Upfront(cid, M_v)$;
                        $service_c := costCalculator(formula(cid), M_v)$;
                        $datatransfer_c := dataTransfer(cid, M_v)$;
                    **end for**
                **end if**
            **end if**
        **else**
            get $min$, $max$ from $L_p$;
            $value_u := UsageamountCalculator(formula(cid), M_v)$;
            **if** $\neg(value_u < max \wedge value_u > min)$ **then**
                **for** $start := 0 \rightarrow Size(L_c)$ **do**
                    $cid := L_c(start)$;
                    $L_p := M_c(cid)$;
                    get new $min$, $max$ from $L_p$;
                    **if** $value < max \wedge value > min$ **then**
                        get new $cid$;
                        $index := start$;
                        break;
                    **end if**
                **end for**
            end if
            $service_c$ :=cost value in $L_p$;
            $datatransfer_c := dataTransfer(cid, M_v)$;
            if $static - rate$ then
                $service_c$,$datatransfer_c$,$upfront_c$ do not change for each month;
            else
                if $month < max(M_p)$ then
                    $month := max(M_p)$;
                end if
                for $i = 1 \rightarrow month$ do
                    for each $vp \in M_p$ do
                        if $i \in M_p(vp)$ then
                            $M_v(vp) := M_v * (1 + rate/100)$;
                            $M_v := unitCheck(M_v)$;
                        end if
                    end for
                    $value_u := UsageamountCalculator(formula(cid), M_v)$;
                    if $\neg(value_u < max \wedge value_u > min)$ then
                        for $start := 1 \rightarrow Size(L_c)$ do
                            $cid := L_c(start)$;
                            $L_p := M_c(cid)$;
                            get new $min$, $max$ from $L_p$;
                            if $value < max \wedge value > min$ then
                                get new $cid$;
                                break;
                            end if
                        end for
                    end if
                    $service_c$ :=cost value in $L_p$;
                    $datatransfer_c := dataTransfer(cid, M_v)$;
                end for
            end if
        end if
    end for
end procedure
```

The details of how to realize this algorithm are illustrated in Algorithm 2. This algorithm will be explained from 2 parts, initial conditions ($line2 - line8$) and concrete steps ($line9 - the\ end$). Concrete steps is separated into 2 sub-parts, the provider is Flexiscale ($line84 - line130$) and other providers ($line12 - line83$). Furthermore the sub-part of other providers consists of static unit-price ($line13 - line33$) and dynamic unit-price ($line34 - line83$). For each unit-price situation, static rate and dynamic rate are considered.

There are 5 input data which are *id*, M_v, M_{cd}, M_p and *month*. *id* is the configuration's id. M_v is the start values which are given by consumer through the URI query part. M_{cd} is a mapping between coefficient id and a list of data transfer ids. M_p is a mapping between necessary variable for cost formula calculation and a list of $[start, end, rate]$s which are from the URI query part with *usage_pattern* parameter. *months* is the utility time of this offering. Additionally, some initial values are retrieved with the help of $SQLquery()$ method and $getVars()$ method. The $SQLquery()$ method is to find all the coefficient ids in a list assistance of SQL database query. L_c is a list of coefficient ids and M_c is a mapping between coefficient id and a list which is built up by a collection of values and each index's meaning is cost formula, location id, zone id, usage amount id, minimum value and maximum value. The location id and zone id are used later to check whether there is a restriction of geographical area while the usage amount id is used later to identify whether this cost formula is a static unit-price or dynamic unit-price. L_v is a list of all the necessary variables for this configuration's cost formula to calculate. Besides this initial conditions, there are two maximum-usage methods, $unitCheck()$ and $dataTransfer()$. $unitCheck()$ method is used to control which variable is over range, e.g. "Hour" is bigger than 730. $dataTransfer()$ is to calculate the data transfer cost if this configuration has a data transfer cost.

The static rate means the value is not changed. In other words, there's no input value of *usage_pattern*. The rate is changed by usage pattern which are given by consumer with the help of URI query part. In the dynamic rate, if the variable is the one which has a usage amount range, its value should be checked whether it still satisfies the range after the new value is calculated. If not, the new range should be found. As long as the value is changed, the following step must be $unitCheck()$ method.

For the provider Flexiscale, it is an obvious dynamic unit-price situation. But for each range the coefficient cost value is fixed, the usage amount is a cost formula. It is different with different input values. The result of the formula is compared with the minimum and maximum of the range. If it is in the range, the coefficient cost value is the cost of this offering. If not, a new range will be searched in order to get a new coefficient cost value.

3.5 Decision Support System

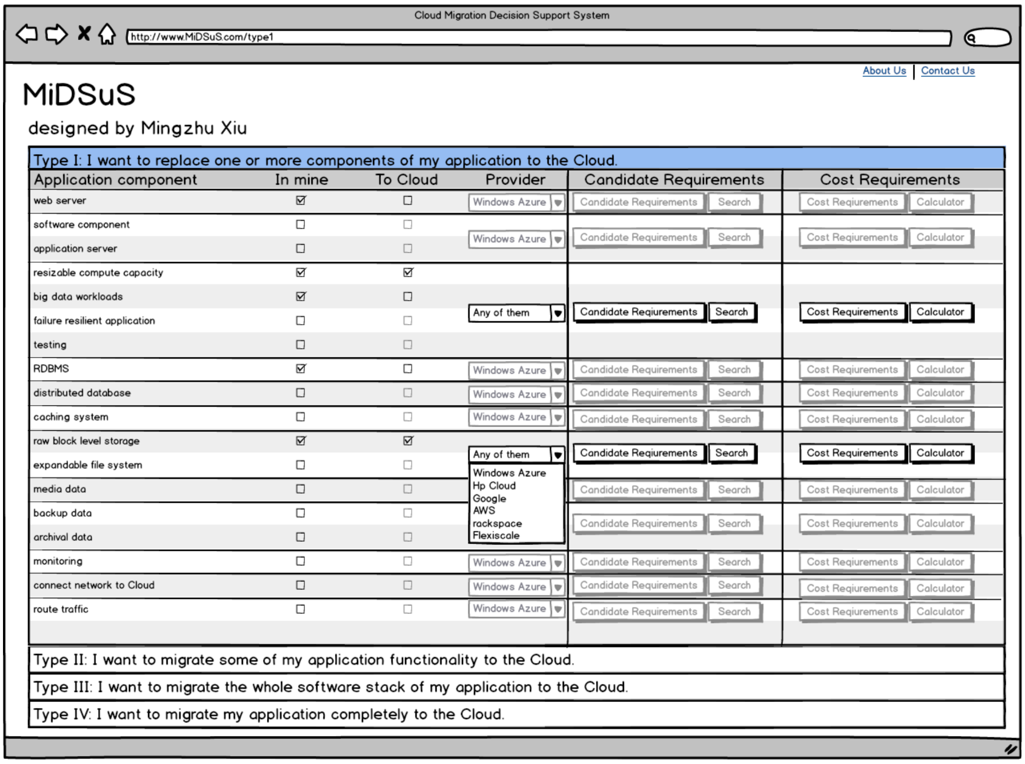
In this section, the envisioned Decision Support System is described through a series of User Interfaces. Balsamiq Mockups[2] is used to build these user interfaces. All the UIs

[2] http://balsamiq.com/

are summarized by the following figures. These figures are combined with some tables and buttons. Tables are used to described an application or some requirements while buttons are working with submitting information together and sometimes it will start a new page to collect more information.

Migration Type I and Migration Type II are interpreted in this section. All the necessary requirements of Type I are listed in Figure 3.6, Figure 3.7, Figure 3.8 and Figure 3.9. In general, the user has to provide input to the system by answering one or more of the following questions:

1. Which component/components his application contains.
2. Which component/components he wants to migrate/replace to the Cloud.
3. Which Cloud service provider he prefers.
4. Which performance characteristics of his Cloud offering he hopes to constrain.
5. Which configurations among all the candidate offerings he wants a cost calculation for.
6. How long he wants to rent this offering.
7. Where he wants to his data-center to be located.
8. Which usage variables should be assigned with specific values.
9. What kind of trend among these variables is.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Type I: I want to replace one or more components of my application to the Cloud.

Application component	In mine	To Cloud	Provider	Candidate Requirements		Cost Requirements	
web server	☑	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator
software component	□	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator
application server	□	□					
resizable compute capacity	☑	☑	Any of them ▼	Candidate Reqiurements	Search	Cost Requirements	Calculator
big data workloads	☑	□					
failure resilient application	□	□					
testing	□	□					
RDBMS	☑	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator
distributed database	□	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator
caching system	□	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator
raw block level storage	☑	☑	Any of them ▼ Windows Azure Hp Cloud Google AWS rackspace Flexiscale	Candidate Reqiurements	Search	Cost Requirements	Calculator
expandable file system	□	□					
media data	□	□		Candidate Requirements	Search	Cost Reqiurements	Calculator
backup data	□	□		Candidate Requirements	Search	Cost Reqiurements	Calculator
archival data	□	□					
monitoring	□	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator
connect network to Cloud	□	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator
route traffic	□	□	Windows Azure ▼	Candidate Requirements	Search	Cost Reqiurements	Calculator

Type II: I want to migrate some of my application functionality to the Cloud.

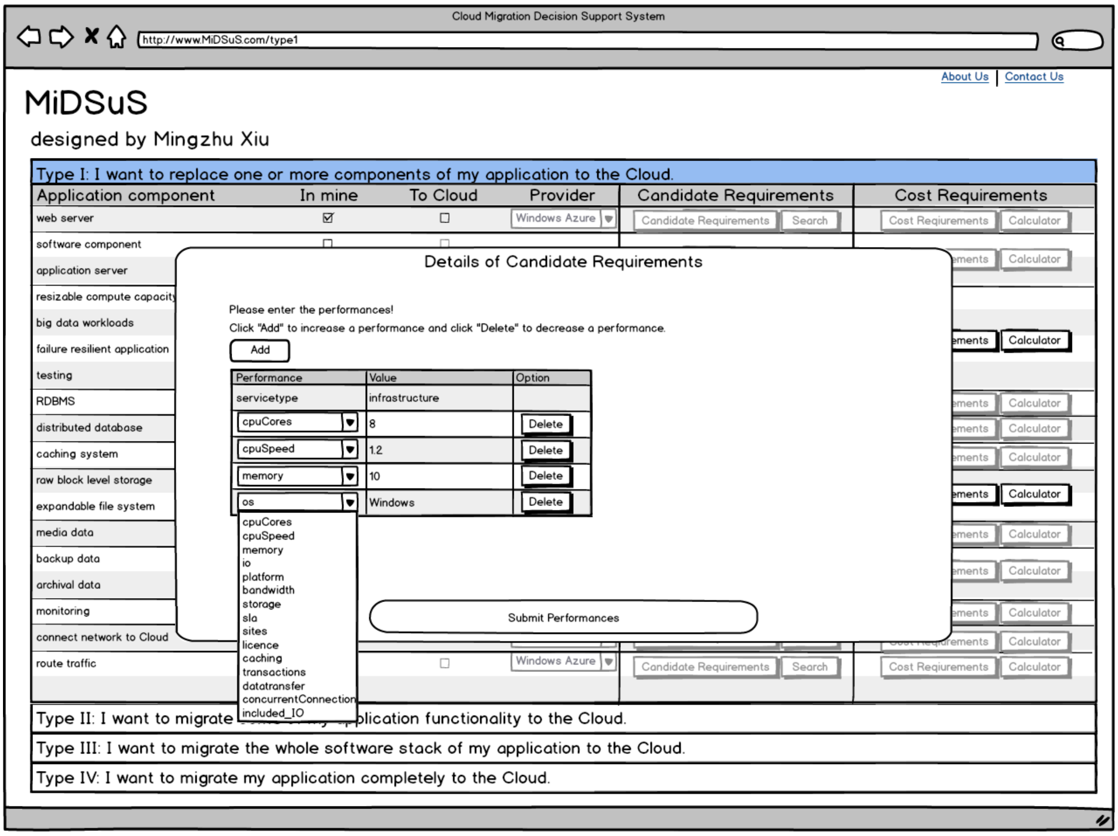
Type III: I want to migrate the whole software stack of my application to the Cloud.

Type IV: I want to migrate my application completely to the Cloud.

Figure 3.6: Details of Type I

Generally, if the user finishes answering these questions, it means he has already found these offerings which he wants. The concrete implementation of Type I is explained as follows: in the beginning, user answers the first three questions above as shown in Figure 3.6. These three questions can be thought as application description like what was talked in Figure 3.2 of Section 3.2. In Type I, this application description is collected by different components of one application. In this example, the existing application components are web server, resizable compute, big data workload, RDBMS and raw block level storage. Two of these components are attempted to migrated to the Cloud, they are resizable compute component and raw block level storage component. Obviously, resizable compute component belongs to infrastructure service type while raw block level storage is in the block storage service. The providers for these components are selected by "Any of them". It means the user wants to get all these appropriate offerings but does not care about their providers.

Afterwards all the possible performance characteristics are collected by a new window in Figure 3.7. Before user enters his new requirements, more than one performance have already been determined in the application description step. As what is said above, they are the service type and provider. In Figure 3.7 for infrastructure service type, a set of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Type I: I want to replace one or more components of my application to the Cloud.

Application component	In mine	To Cloud	Provider	Candidate Requirements	Cost Requirements
web server	☑	□	Windows Azure	Candidate Requirements Search	Cost Reqiurements Calculator
software component	□	□			
application server					Calculator
resizable compute capacity					
big data workloads					Calculator
failure resilient application					
testing					
RDBMS					Calculator
distributed database					Calculator
caching system					Calculator
raw block level storage					Calculator
expandable file system					
media data					Calculator
backup data					Calculator
archival data					
monitoring					Calculator
connect network to Cloud					Calculator
route traffic		□	Windows Azure	Candidate Requirements Search	Cost Reqiurements Calculator

Details of Candidate Requirements

Please enter the performances!

Click "Add" to increase a performance and click "Delete" to decrease a performance.

Add

Performance	Value	Option
servicetype	infrastructure	
cpuCores	8	Delete
cpuSpeed	1.2	Delete
memory	10	Delete
os	Windows	Delete

Type II: I want to migrate ... plication functionality to the Cloud.

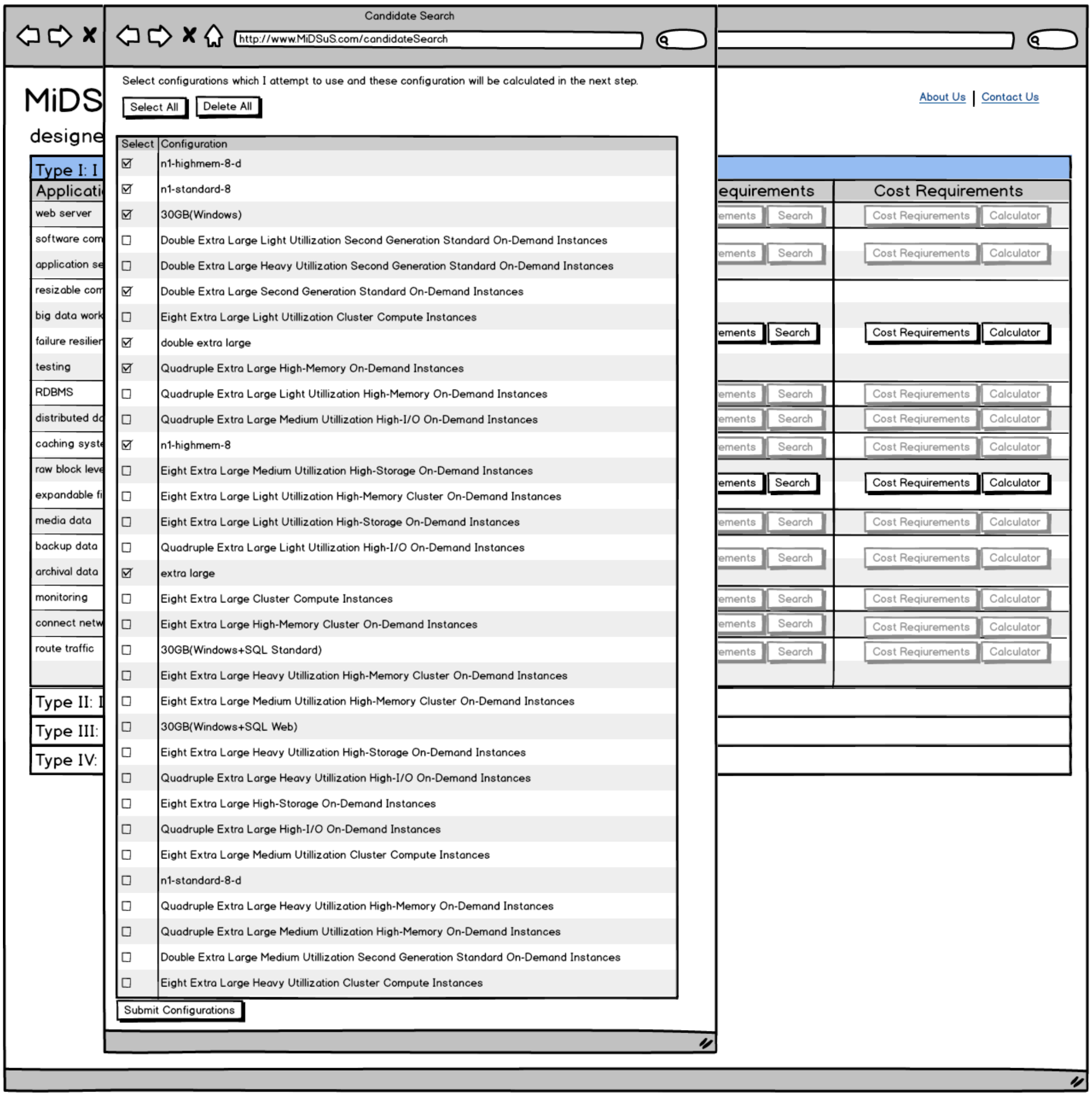
Type III: I want to migrate the whole software stack of my application to the Cloud.

Type IV: I want to migrate my application completely to the Cloud.

Figure 3.7: Candidate Requirements Details of Type I

performances are entered by user. In this example, 4 features are give. CPU cores is 8; CPU speed is 1.2 GHz; RAM of this offering is 10 GB; Operating system is Windows. As long as these necessary performances are entered, the candidate search service can be started.

All the candidate configurations will be listed in a new page like in Figure 3.8. It's time

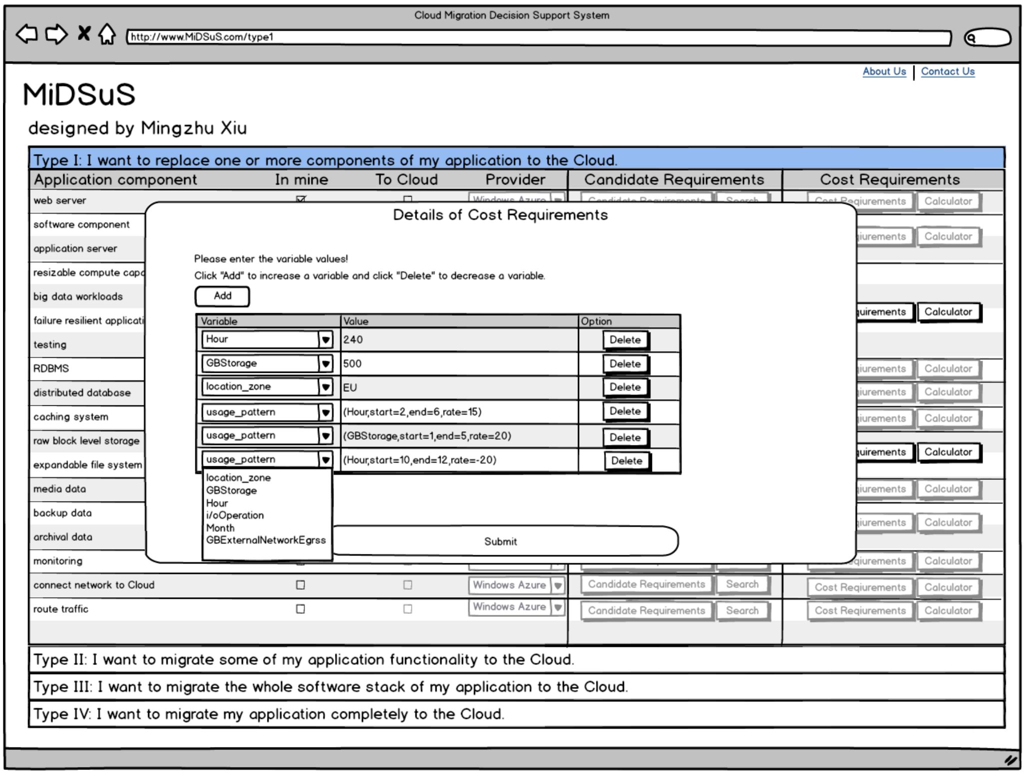


Select configurations which I attempt to use and these configuration will be calculated in the next step.

Select	Configuration
☑	n1-highmem-8-d
☑	n1-standard-8
☑	30GB(Windows)
□	Double Extra Large Light Utilization Second Generation Standard On-Demand Instances
□	Double Extra Large Heavy Utilization Second Generation Standard On-Demand Instances
☑	Double Extra Large Second Generation Standard On-Demand Instances
□	Eight Extra Large Light Utilization Cluster Compute Instances
☑	double extra large
☑	Quadruple Extra Large High-Memory On-Demand Instances
□	Quadruple Extra Large Light Utilization High-Memory On-Demand Instances
□	Quadruple Extra Large Medium Utilization High-I/O On-Demand Instances
☑	n1-highmem-8
□	Eight Extra Large Medium Utilization High-Storage On-Demand Instances
□	Eight Extra Large Light Utilization High-Memory Cluster On-Demand Instances
□	Eight Extra Large Light Utilization High-Storage On-Demand Instances
□	Quadruple Extra Large Light Utilization High-I/O On-Demand Instances
☑	extra large
□	Eight Extra Large Cluster Compute Instances
□	Eight Extra Large High-Memory Cluster On-Demand Instances
□	30GB(Windows+SQL Standard)
□	Eight Extra Large Heavy Utilization High-Memory Cluster On-Demand Instances
□	Eight Extra Large Medium Utilization High-Memory Cluster On-Demand Instances
□	30GB(Windows+SQL Web)
□	Eight Extra Large Heavy Utilization High-Storage On-Demand Instances
□	Quadruple Extra Large Heavy Utilization High-I/O On-Demand Instances
□	Eight Extra Large High-Storage On-Demand Instances
□	Quadruple Extra Large High-I/O On-Demand Instances
□	Eight Extra Large Medium Utilization Cluster Compute Instances
□	n1-standard-8-d
□	Quadruple Extra Large Heavy Utilization High-Memory On-Demand Instances
□	Quadruple Extra Large Medium Utilization High-Memory On-Demand Instances
□	Double Extra Large Medium Utilization Second Generation Standard On-Demand Instances
□	Eight Extra Large Heavy Utilization Cluster Compute Instances

Figure 3.8: Result of Candidate Search Details of Type I

for user to answer the fifth question. Namely, he should select some offerings from all the candidate offerings in Figure 3.8. At the same time, the last four questions will be settled in Figure 3.9. Some evaluate variables' values are entered. In this example, the basic value of Hour variable is 240 hours, the basic value of storage is 500 GB. If there are also some other variables which are necessary during the cost formula calculation, some default values should be defined in such situation. The specific values will be talked in implementation chapter. In the dynamic rate situation, the Hour variable is increased by 15% between the second month and the 6th month and decreased by −20% between the 10th month and the 12th month; the storage variable is increased by 20% between the first month and the 5th month. So far all the questions are already answered. Now



Cloud Migration Decision Support System

http://www.MiDSuS.com/type1

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Type I: I want to replace one or more components of my application to the Cloud.

Application component	In mine	To Cloud	Provider	Candidate Requirements	Cost Requirements
web server	☑	☐	Windows Azure	Candidate Requirements Search	Cost Reqiurements Calculator
software component					
application server					
resizable compute capa					
big data workloads					
failure resilient applicati					
testing					
RDBMS					
distributed database					
caching system					
raw block level storage					
expandable file system					
media data					
backup data					
archival data					
monitoring					
connect network to Cloud	☐	☐	Windows Azure	Candidate Requirements Search	Cost Reqiurements Calculator
route traffic	☐	☐	Windows Azure	Candidate Requirements Search	Cost Reqiurements Calculator

Details of Cost Requirements

Please enter the variable values!

Click "Add" to increase a variable and click "Delete" to decrease a variable.

Add

Variable	Value	Option
Hour	240	Delete
GBStorage	500	Delete
location_zone	EU	Delete
usage_pattern	(Hour,start=2,end=6,rate=15)	Delete
usage_pattern	(GBStorage,start=1,end=5,rate=20)	Delete
usage_pattern	(Hour,start=10,end=12,rate=-20)	Delete

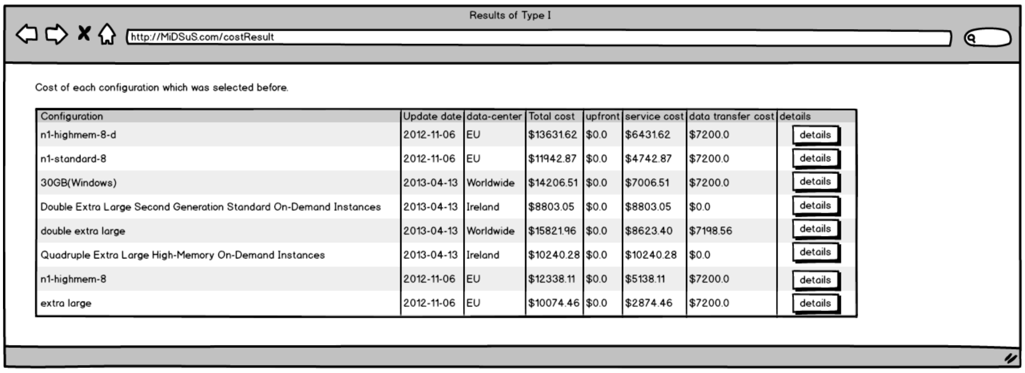
Type II: I want to migrate some of my application functionality to the Cloud.

Type III: I want to migrate the whole software stack of my application to the Cloud.

Type IV: I want to migrate my application completely to the Cloud.

Figure 3.9: Cost Requirements Details of Type I

it's time to calculate the costs. All these results are showed in Figure 3.10. Use the details button, a trend of each offering's cost is displayed on the same page. There also some other functions can be done, like sorts all the information by update date, data center or cost. With this Ranking result user can directly see which one is the best one.



Results of Type I

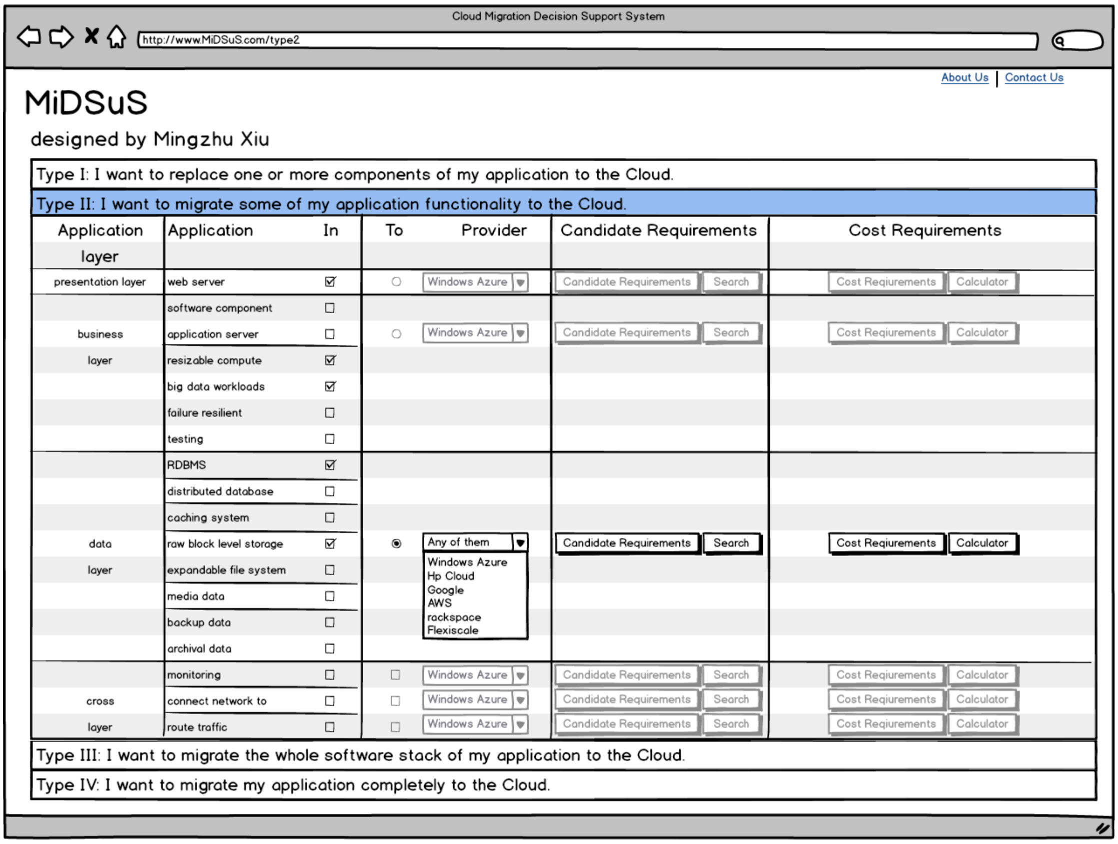
http://MiDSuS.com/costResult

Cost of each configuration which was selected before.

Configuration	Update date	data-center	Total cost	upfront	service cost	data transfer cost	details
n1-highmem-8-d	2012-11-06	EU	$13631.62	$0.0	$6431.62	$7200.0	details
n1-standard-8	2012-11-06	EU	$11942.87	$0.0	$4742.87	$7200.0	details
30GB(Windows)	2013-04-13	Worldwide	$14206.51	$0.0	$7006.51	$7200.0	details
Double Extra Large Second Generation Standard On-Demand Instances	2013-04-13	Ireland	$8803.05	$0.0	$8803.05	$0.0	details
double extra large	2013-04-13	Worldwide	$15821.96	$0.0	$8623.40	$7198.56	details
Quadruple Extra Large High-Memory On-Demand Instances	2013-04-13	Ireland	$10240.28	$0.0	$10240.28	$0.0	details
n1-highmem-8	2012-11-06	EU	$12338.11	$0.0	$5138.11	$7200.0	details
extra large	2012-11-06	EU	$10074.46	$0.0	$2874.46	$7200.0	details

Figure 3.10: Results of Type I

The other example is about migrating to the Cloud with Type II. In Figure 3.11, all application components are classified into three layers. We focus only on a three layer application architecture in this work. These three layers are presentation layer, business layer and data layer [18]. Among these defined components in this work there is also a cross layer. All application components which is defined in Figure 3.6 is generalized in different layer in Figure 3.11. The implementation of Type II is similar as what was introduced in Migration Type I. But in one layer there may be more than one service type. In this example, the data layer is chosen to migrate to the Cloud. In this layer this application contains RDBMS component and raw block level storage. It means the SQL database service type and block storage service type are ready to migrate.



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Type I: I want to replace one or more components of my application to the Cloud.

Type II: I want to migrate some of my application functionality to the Cloud.

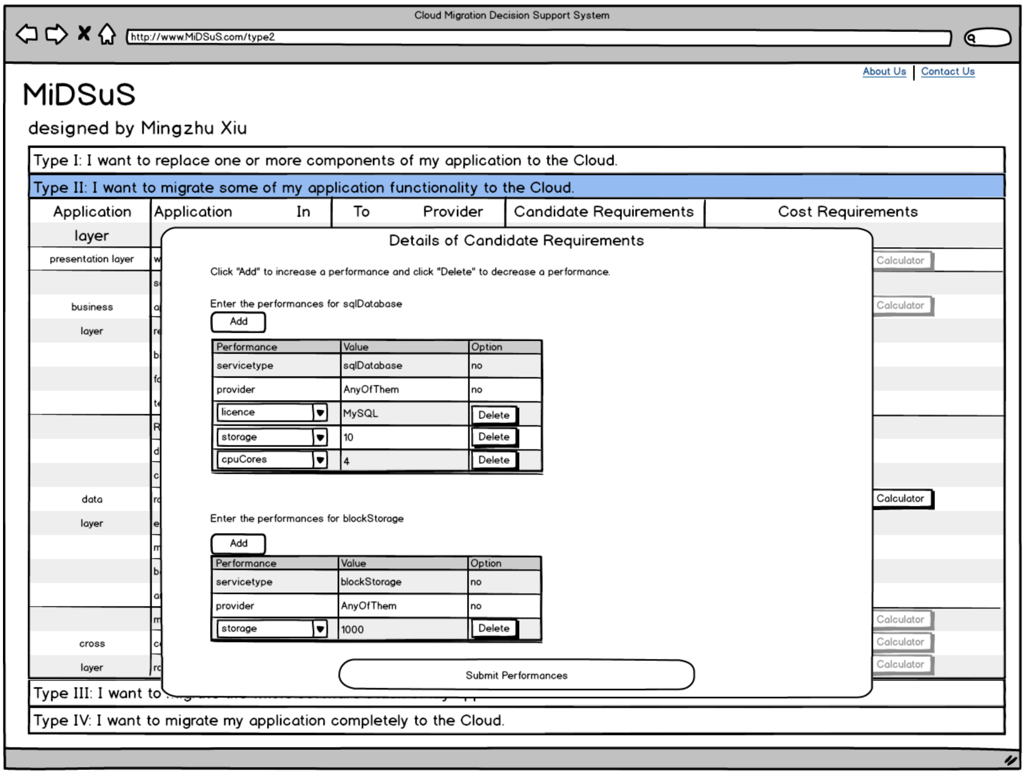
Application layer	Application	In	To	Provider	Candidate Requirements	Cost Requirements
presentation layer	web server	☑	○	Windows Azure ▼	Candidate Requirements Search	Cost Reqiurements Calculator
	software component	□				
business	application server	□	○	Windows Azure ▼	Candidate Requirements Search	Cost Reqiurements Calculator
layer	resizable compute	☑				
	big data workloads	☑				
	failure resilient	□				
	testing	□				
	RDBMS	☑				
	distributed database	□				
	caching system	□				
data	raw block level storage	☑	●	Any of them ▼ Windows Azure Hp Cloud Google AWS rackspace Flexiscale	Candidate Requirements Search	Cost Reqiurements Calculator
layer	expandable file system	□				
	media data	□				
	backup data	□				
	archival data	□				
	monitoring	□	□	Windows Azure ▼	Candidate Requirements Search	Cost Reqiurements Calculator
cross	connect network to	□	□	Windows Azure ▼	Candidate Requirements Search	Cost Reqiurements Calculator
layer	route traffic	□	□	Windows Azure ▼	Candidate Requirements Search	Cost Reqiurements Calculator

Type III: I want to migrate the whole software stack of my application to the Cloud.

Type IV: I want to migrate my application completely to the Cloud.

Figure 3.11: Details of Type II

In Figure 3.12, the performances of both service types are entered. On SQL database side, user needs a Cloud offering which has 4 virtual cores with 10 GB of local instance storage and MySQL. On block storage side, user has only one requirement that instance storage is at least 1000 GB.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Type I: I want to replace one or more components of my application to the Cloud.

Type II: I want to migrate some of my application functionality to the Cloud.

Application layer	Application	In	To	Provider	Candidate Requirements	Cost Requirements
presentation layer						Calculator
business layer						Calculator
data layer						Calculator
cross layer						Calculator Calculator Calculator

Details of Candidate Requirements

Click "Add" to increase a performance and click "Delete" to decrease a performance.

Enter the performances for sqlDatabase

Add

Performance	Value	Option
servicetype	sqlDatabase	no
provider	AnyOfThem	no
licence ▾	MySQL	Delete
storage ▾	10	Delete
cpuCores ▾	4	Delete

Enter the performances for blockStorage

Add

Performance	Value	Option
servicetype	blockStorage	no
provider	AnyOfThem	no
storage ▾	1000	Delete

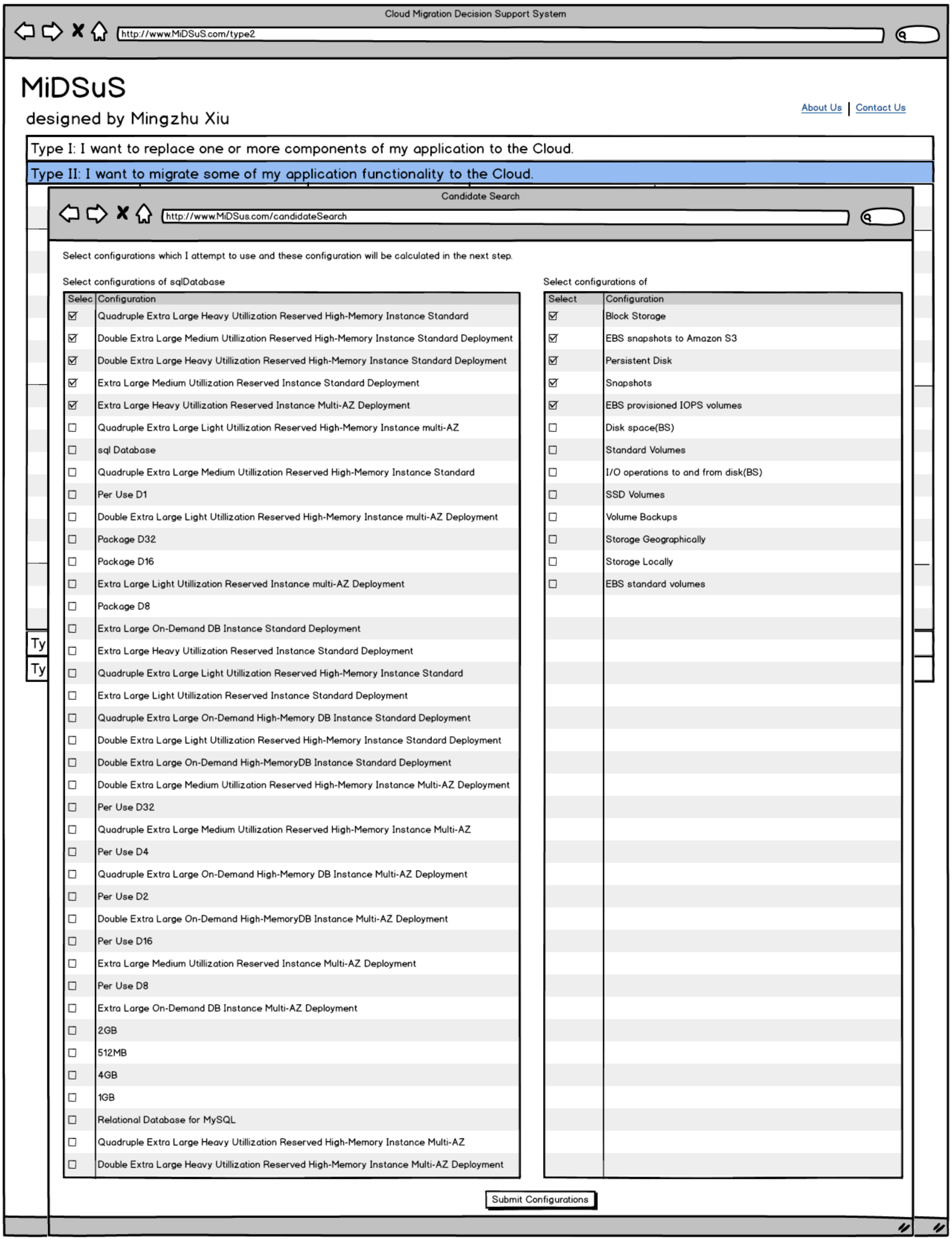
Submit Performances

Type III: I want to

Type IV: I want to migrate my application completely to the Cloud.

Figure 3.12: Candidate Requirements Details of Type II

As a result, in Figure 3.13 there are two set of configurations. The one on the left of this figure is about the SQL database service type and the other one which is on the right side is about the block storage service type. The first five configurations are chosen in order to make a cost comparison.



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Ty
Ty
Submit Configurations

Type I: I want to replace one or more components of my application to the Cloud.

Type II: I want to migrate some of my application functionality to the Cloud.

Select configurations which I attempt to use and these configuration will be calculated in the next step.

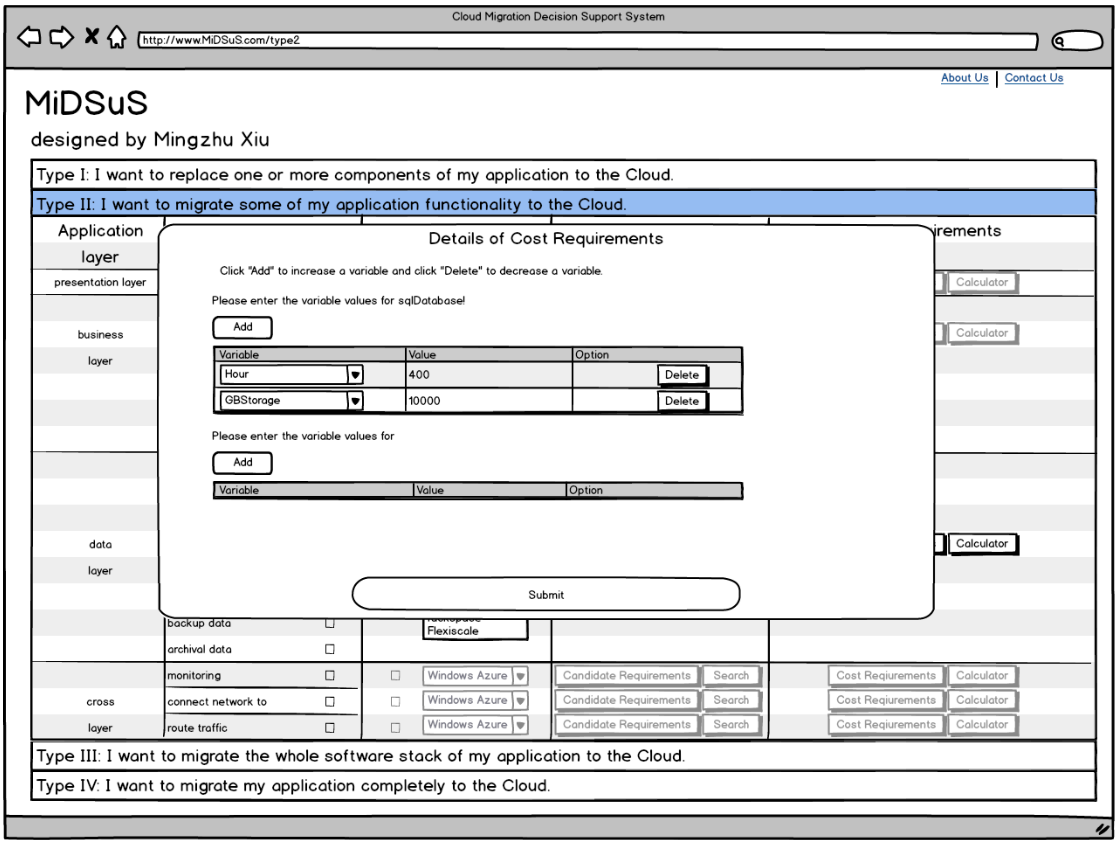
Select configurations of sqlDatabase

Selec	Configuration
☑	Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard
☑	Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment
☑	Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment
☑	Extra Large Medium Utillization Reserved Instance Standard Deployment
☑	Extra Large Heavy Utillization Reserved Instance Multi-AZ Deployment
□	Quadruple Extra Large Light Utillization Reserved High-Memory Instance multi-AZ
□	sql Database
□	Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Standard
□	Per Use D1
□	Double Extra Large Light Utillization Reserved High-Memory Instance multi-AZ Deployment
□	Package D32
□	Package D16
□	Extra Large Light Utillization Reserved Instance multi-AZ Deployment
□	Package D8
□	Extra Large On-Demand DB Instance Standard Deployment
□	Extra Large Heavy Utillization Reserved Instance Standard Deployment
□	Quadruple Extra Large Light Utillization Reserved High-Memory Instance Standard
□	Extra Large Light Utillization Reserved Instance Standard Deployment
□	Quadruple Extra Large On-Demand High-Memory DB Instance Standard Deployment
□	Double Extra Large Light Utillization Reserved High-Memory Instance Standard Deployment
□	Double Extra Large On-Demand High-MemoryDB Instance Standard Deployment
□	Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment
□	Per Use D32
□	Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ
□	Per Use D4
□	Quadruple Extra Large On-Demand High-Memory DB Instance Multi-AZ Deployment
□	Per Use D2
□	Double Extra Large On-Demand High-MemoryDB Instance Multi-AZ Deployment
□	Per Use D16
□	Extra Large Medium Utillization Reserved Instance Multi-AZ Deployment
□	Per Use D8
□	Extra Large On-Demand DB Instance Multi-AZ Deployment
□	2GB
□	512MB
□	4GB
□	1GB
□	Relational Database for MySQL
□	Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Multi-AZ
□	Double Extra Large Heavy Utillization Reserved High-Memory Instance Multi-AZ Deployment

Select configurations of

Select	Configuration
☑	Block Storage
☑	EBS snapshots to Amazon S3
☑	Persistent Disk
☑	Snapshots
☑	EBS provisioned IOPS volumes
□	Disk space(BS)
□	Standard Volumes
□	I/O operations to and from disk(BS)
□	SSD Volumes
□	Volume Backups
□	Storage Geographically
□	Storage Locally
□	EBS standard volumes

Figure 3.13: Result of Candidate Search Details of Type II



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Type I: I want to replace one or more components of my application to the Cloud.

Type II: I want to migrate some of my application functionality to the Cloud.

Details of Cost Requirements

Click "Add" to increase a variable and click "Delete" to decrease a variable.

Please enter the variable values for sqlDatabase!

Add

Variable	Value	Option
Hour	400	Delete
GBStorage	10000	Delete

Please enter the variable values for

Add

Variable	Value	Option

Submit

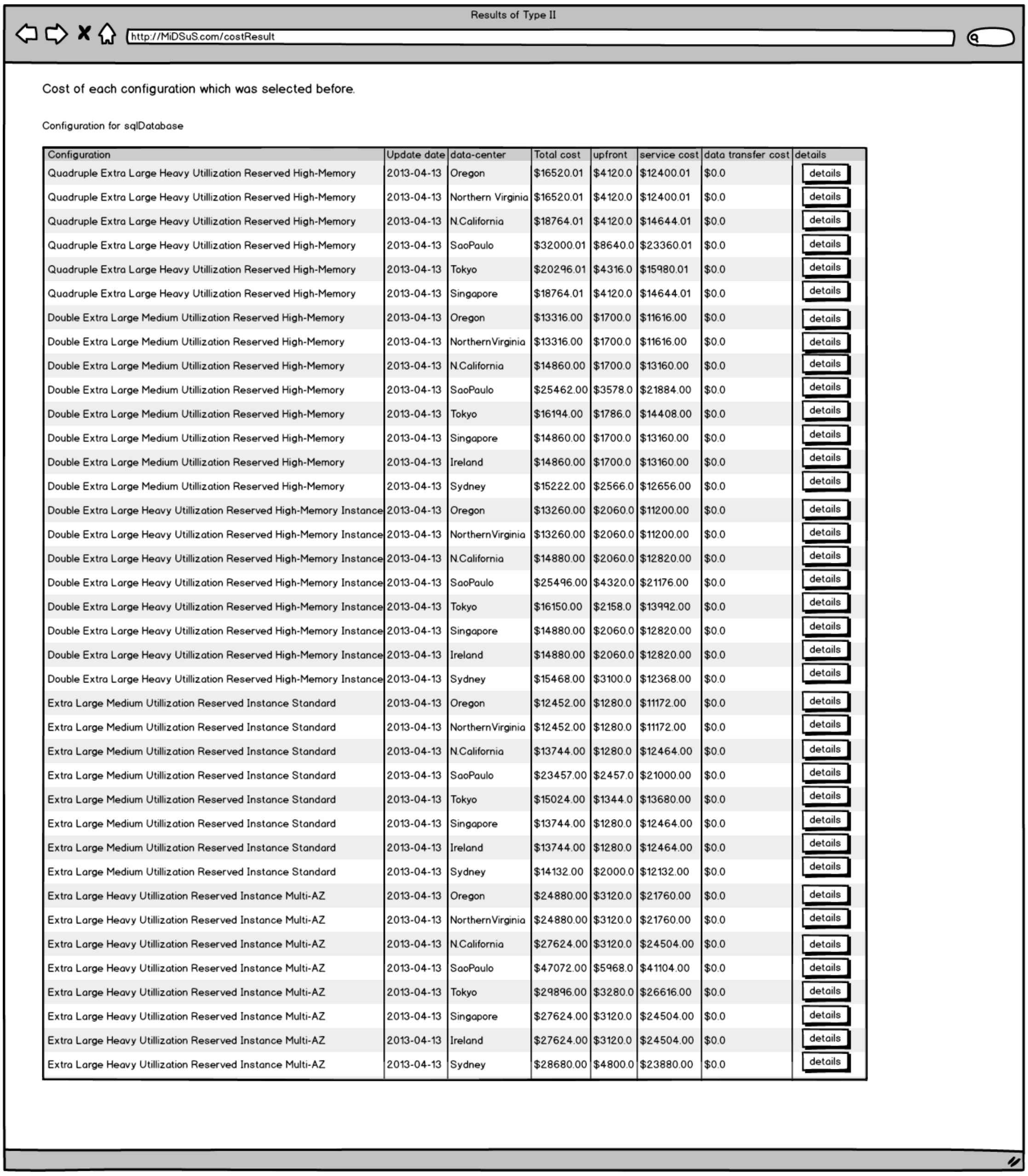
Application layer						
	backup data □		Flexiscale			
	archival data □					
	monitoring □	□	Windows Azure	Candidate Requirements Search	Cost Requirements	Calculator
cross	connect network to □	□	Windows Azure	Candidate Requirements Search	Cost Requirements	Calculator
layer	route traffic □	□	Windows Azure	Candidate Requirements Search	Cost Requirements	Calculator

Type III: I want to migrate the whole software stack of my application to the Cloud.

Type IV: I want to migrate my application completely to the Cloud.

Figure 3.14: Cost Requirements Details of Type II

The initial value are entered in Figure 3.14. In this example, user only entered two values for the SQL database, no value for the block storage. It means he cares only about the cost comparison of SQL database's configurations. The usage variable has a value of 400 hours and storage variable has a value of 10000 GB. After setting the evaluate variables' values the cost calculations of each selected configuration are shown in Figure 3.15. It is a long list whose same configuration has different cost with different data center. User can click details button to get more information about one configuration's cost in months and also the necessary variables' values of this cost calculation.



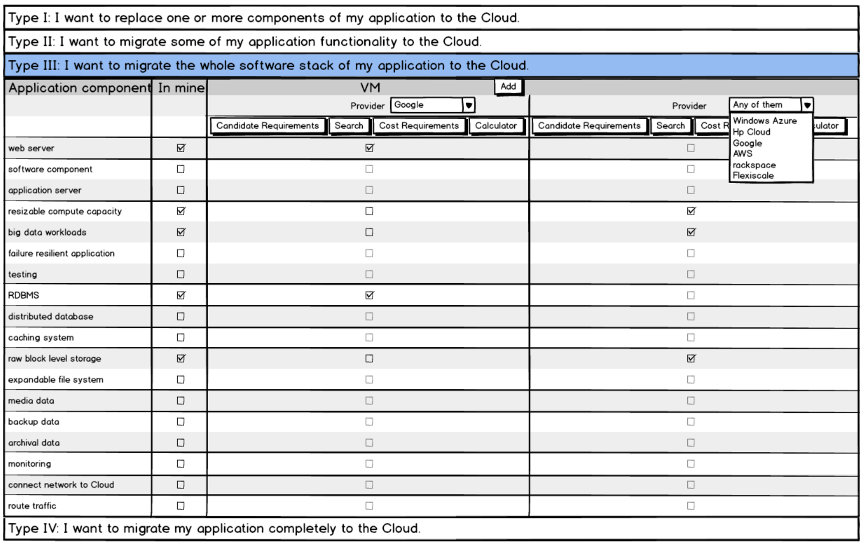
Cost of each configuration which was selected before.

Configuration for sqlDatabase

Configuration	Update date	data-center	Total cost	upfront	service cost	data transfer cost	details
Quadruple Extra Large Heavy Utillization Reserved High-Memory	2013-04-13	Oregon	$16520.01	$4120.0	$12400.01	$0.0	details
Quadruple Extra Large Heavy Utillization Reserved High-Memory	2013-04-13	Northern Virginia	$16520.01	$4120.0	$12400.01	$0.0	details
Quadruple Extra Large Heavy Utillization Reserved High-Memory	2013-04-13	N.California	$18764.01	$4120.0	$14644.01	$0.0	details
Quadruple Extra Large Heavy Utillization Reserved High-Memory	2013-04-13	SaoPaulo	$32000.01	$8640.0	$23360.01	$0.0	details
Quadruple Extra Large Heavy Utillization Reserved High-Memory	2013-04-13	Tokyo	$20296.01	$4316.0	$15980.01	$0.0	details
Quadruple Extra Large Heavy Utillization Reserved High-Memory	2013-04-13	Singapore	$18764.01	$4120.0	$14644.01	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	Oregon	$13316.00	$1700.0	$11616.00	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	NorthernVirginia	$13316.00	$1700.0	$11616.00	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	N.California	$14860.00	$1700.0	$13160.00	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	SaoPaulo	$25462.00	$3578.0	$21884.00	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	Tokyo	$16194.00	$1786.0	$14408.00	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	Singapore	$14860.00	$1700.0	$13160.00	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	Ireland	$14860.00	$1700.0	$13160.00	$0.0	details
Double Extra Large Medium Utillization Reserved High-Memory	2013-04-13	Sydney	$15222.00	$2566.0	$12656.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	Oregon	$13260.00	$2060.0	$11200.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	NorthernVirginia	$13260.00	$2060.0	$11200.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	N.California	$14880.00	$2060.0	$12820.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	SaoPaulo	$25496.00	$4320.0	$21176.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	Tokyo	$16150.00	$2158.0	$13992.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	Singapore	$14880.00	$2060.0	$12820.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	Ireland	$14880.00	$2060.0	$12820.00	$0.0	details
Double Extra Large Heavy Utillization Reserved High-Memory Instance	2013-04-13	Sydney	$15468.00	$3100.0	$12368.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	Oregon	$12452.00	$1280.0	$11172.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	NorthernVirginia	$12452.00	$1280.0	$11172.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	N.California	$13744.00	$1280.0	$12464.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	SaoPaulo	$23457.00	$2457.0	$21000.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	Tokyo	$15024.00	$1344.0	$13680.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	Singapore	$13744.00	$1280.0	$12464.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	Ireland	$13744.00	$1280.0	$12464.00	$0.0	details
Extra Large Medium Utillization Reserved Instance Standard	2013-04-13	Sydney	$14132.00	$2000.0	$12132.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	Oregon	$24880.00	$3120.0	$21760.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	NorthernVirginia	$24880.00	$3120.0	$21760.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	N.California	$27624.00	$3120.0	$24504.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	SaoPaulo	$47072.00	$5968.0	$41104.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	Tokyo	$29896.00	$3280.0	$26616.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	Singapore	$27624.00	$3120.0	$24504.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	Ireland	$27624.00	$3120.0	$24504.00	$0.0	details
Extra Large Heavy Utillization Reserved Instance Multi-AZ	2013-04-13	Sydney	$28680.00	$4800.0	$23880.00	$0.0	details

Figure 3.15: Results of Type II

The starting UI pages for Type II, Type III and Type IV are shown in Figure 3.11, Figure 3.16 and Figure 3.17. For these three types only the main tables are given. The details steps for requirements collection and results calculation are similar as Type I. With the help of Figure 3.7 and Figure 3.9 the candidate requirements and cost requirements are determined as these initial conditions for the APIs. In addition with the requirements from the type table all the requirements collections are finished like what is represented in use case Figure 3.2. As discussed in Section 2.1, the most fundamental difference among these 4 types is either a migration between the application components or a migration of a whole application layer. In other word, whether there is a functionality relationship between each components is what distinguishes each migration type. Migration Type



Type I: I want to replace one or more components of my application to the Cloud.

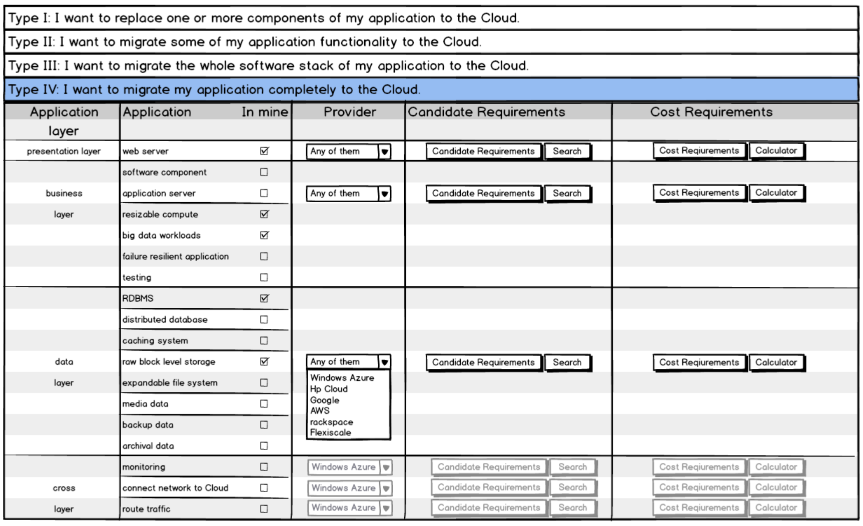
Type II: I want to migrate some of my application functionality to the Cloud.

Type III: I want to migrate the whole software stack of my application to the Cloud.

Application component	In mine	VM Add	
		Provider Google ▾	Provider Any of them ▾ (Windows Azure, Hp Cloud, Google, AWS, rackspace, Flexiscale)
		Candidate Requirements · Search · Cost Requirements · Calculator	Candidate Requirements · Search · Cost R… ulator
web server	☑	☑	□
software component	□	□	□
application server	□	□	□
resizable compute capacity	☑	□	☑
big data workloads	☑	□	☑
failure resilient application	□	□	□
testing	□	□	□
RDBMS	☑	☑	□
distributed database	□	□	□
caching system	□	□	□
raw block level storage	☑	□	☑
expandable file system	□	□	□
media data	□	□	□
backup data	□	□	□
archival data	□	□	□
monitoring	□	□	□
connect network to Cloud	□	□	□
route traffic	□	□	□

Type IV: I want to migrate my application completely to the Cloud.

Figure 3.16: Details of Type III



Type I: I want to replace one or more components of my application to the Cloud.

Type II: I want to migrate some of my application functionality to the Cloud.

Type III: I want to migrate the whole software stack of my application to the Cloud.

Type IV: I want to migrate my application completely to the Cloud.

Application layer	Application	In mine	Provider	Candidate Requirements	Cost Requirements
presentation layer	web server	☑	Any of them ▾	Candidate Requirements · Search	Cost Reqiurements · Calculator
	software component	□			
business	application server	□	Any of them ▾	Candidate Requirements · Search	Cost Reqiurements · Calculator
layer	resizable compute	☑			
	big data workloads	☑			
	failure resilient application	□			
	testing	□			
	RDBMS	☑			
	distributed database	□			
	caching system	□			
data	raw block level storage	☑	Any of them ▾	Candidate Requirements · Search	Cost Reqiurements · Calculator
layer	expandable file system	□	Windows Azure Hp Cloud Google AWS rackspace Flexiscale		
	media data	□			
	backup data	□			
	archival data	□			
	monitoring	□	Windows Azure ▾	Candidate Requirements · Search	Cost Reqiurements · Calculator
cross	connect network to Cloud	□	Windows Azure ▾	Candidate Requirements · Search	Cost Reqiurements · Calculator
layer	route traffic	□	Windows Azure ▾	Candidate Requirements · Search	Cost Reqiurements · Calculator

Figure 3.17: Details of Type IV

III is a specific classification of Type I. Both of them collect application descriptions from different components. In Figure 3.6 and Figure 3.16, it can be seen that some application components are defined. There are several components for each service type. These definitions are collected and summarized from the Cloud services providers. Migration Type III is a complete migration type of Type I. But there is only one offering can be chosen to complete Migration Type III that is VMs offering.

Type IV is a special classification of Type II. They all collect requirements from different layer. In this work as mentioned above, an application is structured as a three-layered application. The components between each layer are collected in cross-layer. In Type IV, it can choose any offering which user wants except the VMs offering, because it is already included in Type III. It should be careful that Type IV is also a complete migration type. It means with Type III and Type IV application can be migrated to the Cloud completely. Actually, in today's market, there is not so many applications which are migrates with Type IV, because using this migration type there are very higher risks and much more troubles than other particular migration types. Generally speaking, people prefer to choose Type III rather than Type IV, when they have to consider a complete migration situation. Type III is the most frequent choice. It is easy to understand and operate with the application. In Appendix A.1 there is only a little size use case of Cloud migration, but Type III has a large proportion. Compare with Type IV, only one use case is given.

3.6 Summary

In this chapter, a concrete structure of this work is explained. From the available information, a set of requirements are identified as a direction to build this new system. The specification is abstracted from these requirements and illustrated as a Use Case diagram. According to these foundations, we choose to use some web services to complete the data handler part of the new system instead of the previous functions in MDSS, because it is easy to re-use in future works. As a basic support part a database named Cloud providers knowledge base is built which is expanded from the database of MDSS. This new database includes all the available costs of one offering and a more refined service types. It contains as many data centers of each provider as possible in order to help user to have a better knowledge of each offering. Actually, all these preparations are done as the foundation for a decision support system. The further system completes the migration tasks completely. It helps user from the migration type on until the costs of each selected candidate offerings are calculated. All of this searching and calculating are based on those web APIs envisioned in the previous step.

4 Implementation

In this chapter, the implantations of the system designed in the previous section is presented. Two systems are actually built in this work. One is called Nefolog, it composed by database and a set of web restful services. The other is called MiDSuS, it is the decision support system which realized the tasks of migration decision. MiDSuS uses the RESTful APIs which are offered by Nefolog to implement a web application.

4.1 Cloud Provider Knowledge Base of Nefolog System

As in MDSS, the Cloud Provider Knowledge Base was implemented as a relational database on the basis of the Entity-Relation diagram shown in Figure 3.5.

However, in MDSS, Microsoft SQL Server was used, a non-open source solution with strict licensing requirements. In order to get more scalability and save development and licensing costs, it decided to realize the database with an open source software solution. The PostgreSQL RDBMS[1] solution was chosen for this purpose.

PostgreSQL is released under the PostgreSQL license and is free. It is developed by the PostgreSQL Global Development Group. This database system is very similar to the other database systems because it implements data queries by using SQL language, too. These data are linked through the foreign key together and exist as a series of tables. The PostgreSQL main advantage relative to other competitors is its programmability.

Figure 4.1 presents the data model of the new system. This database consists of 16 entities. In the *provider* entity, the numbers of providers is increased from 2 to 6. Except from Windows Azure and Google, it also includes Amazon Web Services, HP Cloud, Rackspace and Flexiscale. So the number of offerings is increased from 18 to 51 and these offerings contain 520 configurations with 472 performances. It's almost 4 times as large as before. The 5 previously available service types are separated into 12 types. A comparison of the two service types tables is shown in Table 4.1. This more fine-granular classification for the service type allows users to find an appropriate Cloud service much more directly and quickly.

For the identification of matching offerings, the general idea is similar to MDSS. Through the performancemapping entity the user knows which performance he should submit if the service type is already chosen. The performancemapping entity is a collection of the performances which are not null and separated by the service types. It means the system can compare each configuration according to the performances between users require and the provider provides.

[1] `http://www.postgresql.org/`

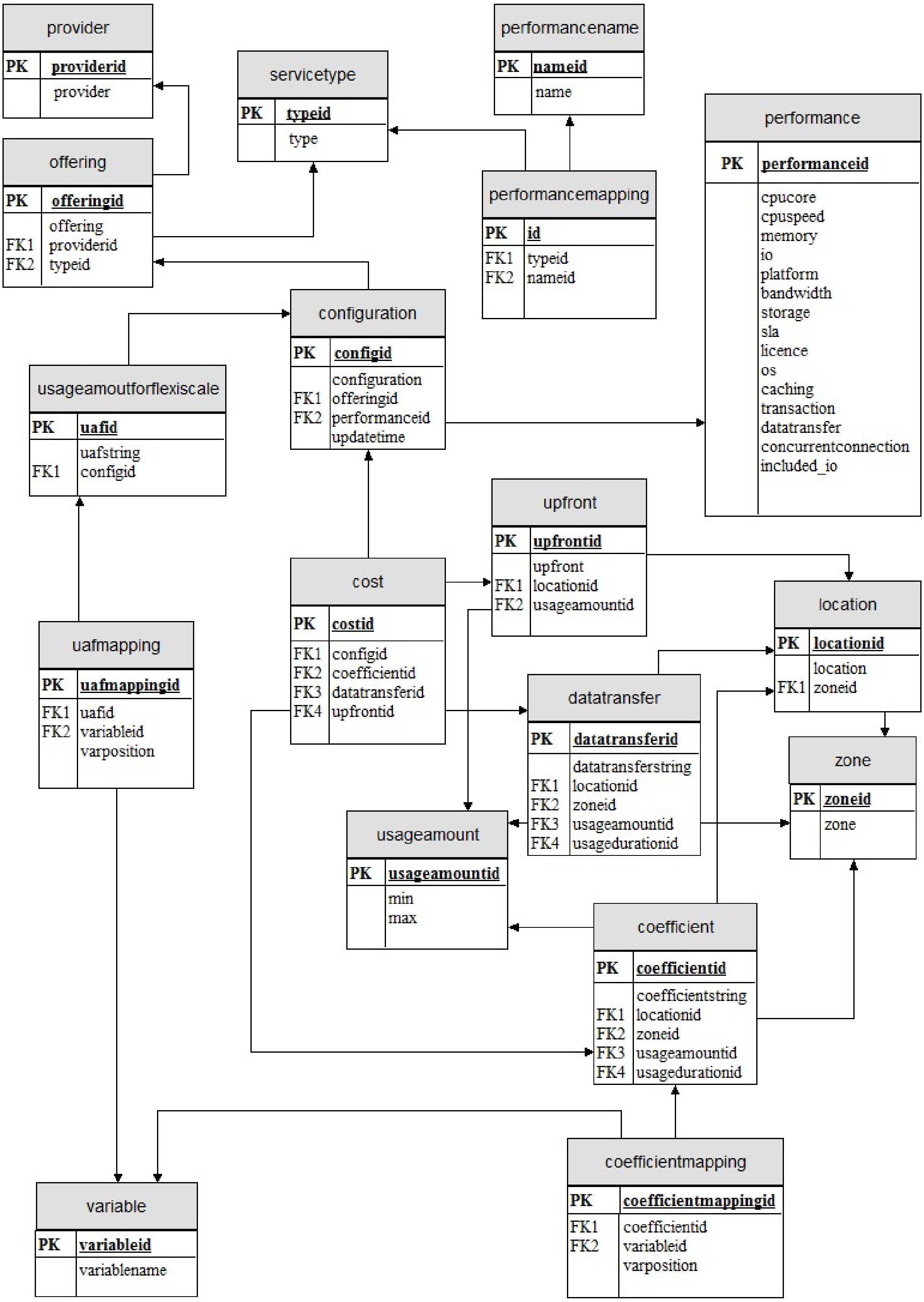


Figure 4.1: Data model

Table 4.1: Overview of Service Types between MDSS and new System

Service Types from MDSS	**New Service Types**
Application	Application
	Web Site
Data	-
Storage	SQL Database
	NoSQL Database
	Block Storage
	Object Storage
	Archival Storage
	Caching
Infrastructure	Infrastructure
Software	-
-	Monitoring
-	Network
-	DNS

On the cost calculator side, different parameters (location, zone or amount of usage) can lead to a number of different costs for the same factors (upfront, data transfer or coefficient) which was separated from the final cost. There are 15 geographical areas included and they belong to 7 zones. The 3 factors are seen as 3 coefficients of the final cost. Users need to submit the usage time and the GB of data transfer in order to achieve the cost calculation. The final cost table has a total of 21856 combinations with 3686 upfront costs, 185 costs of data transfer and 4733 prices of configurations. There is also a problem which must be advertent before the programming of web services starts. Usually it is possible that there are more than one parameter for one cost calculator formula. Some formulas are separated by different usage amount. It means that the parameter which is decided the formula should be indicated and set in the first position in order to make the formula filter much easier. The special provider Flexiscale has 18 configurations and they are priced on units. It means the system supplies the cost of this provider's service through the amount of units. There are 11 prices of buying units. It has a one-to-one relationship with the Configuration entity.

4.2 Services of Nefolog System Implementation

The new system is a restful web services system and is named Nefolog. An open-source software Java EE has been chosen to build it instead of Microsoft Visual Studio 2010. Restlet Framework is selected to achieve these RESTful APIs.

Table 4.2: Overview of Languages and Frameworks to Support Restful Web Services System

Framework	**Language**
Jersey	Java
Restlet	Java
Django	Python
Spring	Java
Konstrukt	PHP
Recess	PHP
Rails	Ruby

There are some many program languages and corresponding frameworks that can build up a restful web services system. From the Table 4.2 some of the available framework are presented.

In fact Python with Django is a simple way, because Python is easy to learn even for a beginner and the framework of a restful web services system on Django is uncomplicated. But finally Python was not chosen. It is a problem about trend and popularity. A restful web services in Java is so common in the market and examples are everywhere. It does not mean that Python is not a trend or not popular, but more people learn Java as a first language of OOP. In other words, Java is more familiar to people than Python. On PHP side, there are so many different kinds of PHP versions and for different version the syntax is different. It is hard for others to continue this work later or even could bring them some new unnecessary troubles. When program language is determined, the next problem is about suitable framework. Restlet is probably the first REST framework and is available in market from 2005. Comparing with Jersey and Spring Restlet is a lightweight framework and provides some low-level REST support. All of them support both server side and client side. There is no conclusive evidence that Restlet is better or Jersey is better. Restlet was therefore chosen for the implementation as a matter of personal preference.

There are many tutorials in [19] on how to build RESTful API. There are 2 types of REST resources, collection resource and instance resource. By definition, a collection resource is always a plural form of a word and means a data collection; an instance resource is a singular form of a word and means one from of this collection. We can use a Restlet component as a container of Restlet applications or Servlet engine.

In this work, all the resources identified by URIs and have 2 representations such as XML data and JSON data. The Restlet applications are developed under separate URI paths. Servlet engine which is considered as a component to contain all these applications and provides the server HTTP connector is chosen to finish this work, because we hope to use this project finally under no base URI path, it means finally a package of this Servlet project will be done as a WAR file. With this WAR file this project will run in any other environments by rebuilding the provider knowledge base from a database backup file.

Each resource is built up by two classes, a *ServerResource* class and a class which is used to implement the representations. A *Representation* instance is used to for both XML representation and JSON representation. Class *DomRepresentation* is a *XMLRepresentation* class, so our XML representation is bases on a DOM document. Class *JsonRepresentation* is a *WriteRepresentation* class, so this JSON representation is based on a JSON document. Then an *Application* class is created. With the help of a *Restlet* class a *Router* object is initialized to create some *attach* instances and assigns each *attach* to a *ServerResource* class.

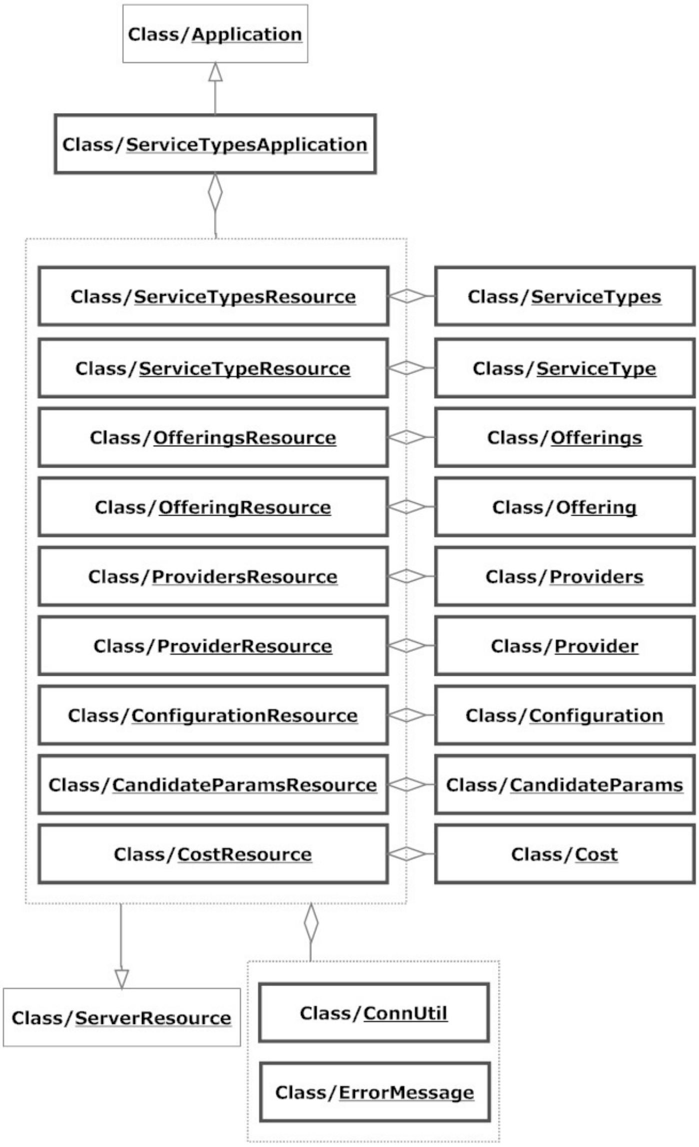


Figure 4.2: UML Classes Diagram of Nefolog

In Figure 4.2, the UML classes diagram is given to have an overview of the whole Nefolog system. As last paragraph mentioned, each resource is implemented by two classes. The classes which inherit their specifications from class *ServerResource* are connected by *Router* objects in the class which inherit from class *Application*. The operations between database and services are done by the class *ConnUtil* and called in classes which extend from *ServerResource*. In addition, there is a class called *ErrorMessage* which is used to warn the user when an error occurred. For example, the configuration id is not in the offering which user typed in the URI.

Table 4.3: Resource URIs supported by Nefolog

URI (...=*http://localhost:8080/nefolog*)	**XML/JSON Content**
.../serviceTypes	service types
	URI of each service type
.../serviceTypes/{serviceTypeName}s	offerings of the service type
	URI of each offering
	provider of the offering
	URI of the provider
.../providers	providers
	URI of each provider
.../providers/{providerName}	offerings of the provider
	URI of each offering
	service type of the offering
	URI of the service type
.../offerings	offerings
	URI of each offering
	provider of the offering
	URI of the provider
	service type of the offering
	URI of the service type
.../offerings/{offeringName}	configurations
	URI of each configuration

.../offerings/{offeringName}
/configuration_{configId}
	necessary performances

	default value of each performance

All the supported by the Nefolog system URIs are listed in Table 4.3 and Table 4.4. The system name nefolog is used as root directory. All these services are hosted on Tomcat and PostgreSQL. Each URI has a mapping to 2 representations. The contents of these representations are the same. The outline of each URI's XML/JSON contents can be seen in Table 4.3.

4.3 Decision Support Services of Nefolog System

In Table 4.4 the decision support services are given. The usability of these two services is according to the query part of the URI. Different result will be showed as XML or JSON with different query part. The consumer could first get initial information about how one service is processed and which parameters should be known before running this service.

Table 4.4: Decision Support Services URIs supported by Nefolog

URI (...=$http://localhost:8080/nefolog$)	**XML/JSON Content**
$.../candidateSearch$	performances
$.../candidateSearch?all$	service types
	URI of each service type
	offerings of the service type
	URI of the offering
	necessary performances of the offering
	maximum value of the performance among all the configurations
$.../candidateSearch?\{query\}$	configurations
	URI of each configuration
$.../costCalculator$	variables
$.../costCalculator?configid = \{id\}$	necessary variables of the configuration
$.../costCalculator?\{query\}$	update time of the configuration
	initial condition
	total cost of each geographical area
	upfront cost
	total service cost
	service cost per month
	total data transfer cost
	data transfer cost per month

4.3.1 Candidate Search Web Service

As what was discussed in Section 3.4.1 and according to the Algorithm 1 two classes are created to achieve it, class *CandidateParams* and class *CandidateParamsResource*.

CandidateParams is used to finish the representations part. In this work two representations are needed. *CandidateParamsResource* is used to solve such problems which should connect to the database and interact with URI. *CandidateParamsResource* class is a *ServerResource* class. The method *candidateSearch*() in Listing 4.2 is a concrete solution.

First of all, we should have a parameter called *inputPerformance_map*. It contains all the requirements from consumer. After that, we should have comparison values which can get from knowledge base. The database SQL query expression is in Listing 4.1. A parameter *configIDWithPerformanceList* in *CandidateParams* class is set to summarize all the necessary data from database in a list according to a configuration id. This list has to be set in a special sequence. Because of the character of *Map* class we can compare these requirements with the help of a sequence of *keys* list. These *keys* list has a name *perform*. *perform* is set at the beginning of Listing 4.2. Obviously, it is a special sequence for indexes of a list.

The comparison process is uncomplicated. We reject all the data which are smaller than the required values and collect the remaining data as the result of this service.

Listing 4.1: SQL Query Expression for Candidate Search Service

```
String sql="";
if(this.inputPerformance_map.get("servicetype")!=null){
  sql=" and servicetype.type=’"+this.inputPerformance_map.get("servicetype")+"’";
  if(this.inputPerformance_map.get("provider")!=null){
    sql=sql+" and provider.provider=’"+this.inputPerformance_map.get("provider")+"’";
    if(this.inputPerformance_map.get("offering")!=null){
      sql=sql+" and offering.offering=’"+this.inputPerformance_map.get("offering")+"’";
    }
  }
  else{
    if(this.inputPerformance_map.get("offering")!=null){
      sql=sql+" and offering.offering=’"+this.inputPerformance_map.get("offering")+"’";
    }
  }
}
else{
  if(this.inputPerformance_map.get("provider")!=null){
    sql=sql+" and provider.provider=’"+this.inputPerformance_map.get("provider")+"’";
    if(this.inputPerformance_map.get("offering")!=null){
      sql=sql+" and offering.offering=’"+this.inputPerformance_map.get("offering")+"’";
    }
  }
  else{
    if(this.inputPerformance_map.get("offering")!=null){
      sql=sql+" and offering.offering=’"+this.inputPerformance_map.get("offering")+"’";
    }
  }
}
```

```
sql="select configuration.configid, performance.* , configuration.configuration,offering.offering, provider.provider from servicetype, offering, performance, configuration, provider where servicetype.typeid=offering.typeid and offering.providerid=provider.providerid and offering.offeringid=configuration.offeringid and configuration.performanceid=performance.performanceid"+sql;
```

Listing 4.2: Candidate Search

```
public Map<String,String> candidateSearch() throws SQLException{
  Map<String,String> result_map=new HashMap<String,String>();
  for(int i=3;i<this.all_query_list.size();i++){
    result.setPerformance(this.all_query_list.get(i));
  }
  Connection conn=ConnUtil.getConn();
  conn.setAutoCommit(false);
//*****************Listing 4.1******************//
    Statement stmt=null;
    ResultSet rs=null;
  stmt=conn.createStatement();
  rs=stmt.executeQuery(sql);
  while(rs.next()){
    List<String> temp=new LinkedList<String>();
    String configid=rs.getString(1);
    if(rs.getString(2)!=null){
      temp.add(rs.getString(3));
      temp.add(rs.getString(4));
      temp.add(rs.getString(5));
      temp.add(rs.getString(6));
      temp.add(rs.getString(7));
      temp.add(rs.getString(8));
      temp.add(rs.getString(9));
      temp.add(rs.getString(10));
      temp.add(rs.getString(11));
      temp.add(rs.getString(12));
      temp.add(rs.getString(13));
      temp.add(rs.getString(14));
      temp.add(rs.getString(15));
      temp.add(rs.getString(16));
      temp.add(rs.getString(17));
      temp.add(rs.getString(18));
    }
    result.setConfigName(configid,rs.getString(19));
    result.setOfferingName(configid, rs.getString(20));
    result.setProviderName(configid,rs.getString(21));
    result.setConfigIDWithPerformanceList(configid, temp);
  }
  conn.commit();
  conn.close();
    Set<Entry<String, List<String>>> set_configIDWithPerformanceList=result.getConfigIDWithPerformanceList().entrySet();
    Iterator<Entry<String, List<String>>> it_configIDWithPerformanceList=set_configIDWithPerformanceList.iterator();
    while(it_configIDWithPerformanceList.hasNext()){
      Entry<String, List<String>> entry_configIDWithPerformanceList=it_configIDWithPerformanceList.next();
      List<String> performanceList=new LinkedList<String>();
      performanceList=entry_configIDWithPerformanceList.getValue();
```

```
   Iterator<String> it_list=performanceList.iterator();
   Iterator<String> it_perform=result.getPerformance().iterator();
   while(it_list.hasNext() && it_perform.hasNext()){
    String text_list=it_list.next();//value of one parameter
    String text_perform=it_perform.next();// the parameter
    if(this.inputPerformance_map.get(text_perform)!=null){
    if(text_perform.equals("os") || text_perform.equals("io") || text_perform.equals("licence")){
     if(text_list!=null){
      if(text_perform.equals("io")){//there are 4 values of io performance, low, moderate, high and very high.
       if(this.inputPerformance_map.get(text_perform).equals("very high")){
        if(!text_list.equals(this.inputPerformance_map.get(text_perform))){
         it_configIDWithPerformanceList.remove();
         break;
        }
       }else if(this.inputPerformance_map.get(text_perform).equals("high")){
        if(text_list.equals("low") || text_list.equals("moderate")){
         it_configIDWithPerformanceList.remove();
         break;
        }
       }else if(this.inputPerformance_map.get(text_perform).equals("moderate")){
        if(text_list.equals("low")){
         it_configIDWithPerformanceList.remove();
         break;
        }
       }
      }else if(!text_list.equals(this.inputPerformance_map.get(text_perform))){
       it_configIDWithPerformanceList.remove();
       break;
      }
     }
    }
    else if(text_list!=null){
     if(Double.valueOf(text_list)<Double.valueOf(this.inputPerformance_map.get(text_perform))){
      it_configIDWithPerformanceList.remove();
      break;
     }
    }
   }
  }
 }
 Iterator<String> it=result.getConfigIDWithPerformanceList().keySet().iterator();
 while(it.hasNext()){
   String id=it.next();
   result_map.put(id,result.getConfigName().get(id));
 }
  return result_map;
}
```

4.3.2 Cost Calculator Web Service

The cost calculator service works with the help of configuration id. Classes *CostResource* and *Cost* are created to realize this cost calculation task.

After doing the SQL database query search, some necessary data are obtained. As what was discussed in Section 3.4.2, the amount range is not considered as a restriction. The one restriction is a configuration id and the other restriction is a geographical area id, if consumer requires the data-center.

Before starting to calculate, the initial values of all the necessary variables are given. If not, some default values should be complemented as a part of initial conditions. The default value of "Hour" is 500; the default value of "month" is 10; the other default values are 5000, e.g. "GB", "GBExternalNetworkEgress" etc. These default values are not depending on each configuration, because a comparison should be made in the same initial condition, otherwise the comparison between each cost result makes no sense. The concrete process can be seen in Listing 4.3. All information about the initial variables is inserted in a *Map* instance called *varsList_additional*. Its *key* is implemented by a list which contains the value of this variable and a *Boolean* parameter. This *Boolean* parameter represents whether this value is from consumer or from the system. Although the consumer does not know the default value for each variable, with the help of this *Boolean* parameter all the initial conditions will be shown at the returned data. In that case, the consumer will know clearly how the result can be calculated.

Listing 4.3: Default initial Values

```java
Iterator<String> i_var_list=this.varsList.iterator();
while(i_var_list.hasNext()){
    String insert_string=i_var_list.next();
    List<String> insert_list=new LinkedList<String>();
    if(this.query_vars.get(insert_string)==null){
        if(insert_string.equals("Hour")){
            this.query_vars.put(insert_string, "500");
            insert_list.add("500");
        }
        else if(insert_string.equals("Month")){
            this.month=10;
            this.query_vars.put(insert_string, "10");
            insert_list.add("10");
        }
        else{
            this.query_vars.put(insert_string, "5000");
            insert_list.add("5000");
        }
        insert_list.add("false");
    }
    else{
        insert_list.add(this.query_vars.get(insert_string));
        insert_list.add("true");
    }
    this.varsList_additional.put(insert_string, insert_list);
}
```

There are two *Boolean* parameters, *IsAmazon* and *IsFlexiscale*. They are used to divide this method into 3 directions. One is that the provider is AWS; another one is that the provider is Flexiscale and the last one is that the provider is not AWS or Flexiscale. For each direction, the program idea is the same. One direction will also split into 2 branches. They are static unit-price and dynamic unit-price. For the dynamic unit-price, how to identify a cost formula with different usage amount range is very important. One unit-price situation can also be separated into 2 rates, static rate and dynamic rate. A *Boolean* parameter *doMonthsCost* is used to implement this partition of rate. For the dynamic rate, how to calculate the change rate for each month and each variable is very complicated and should be treated carefully. All the possible situations should be considered. E.g. a variable is changed not from 1th month on but later; there is a change time overlapping for two variables; a variable is changed with different rate in different times, etc. A dynamic unit-price situation with a dynamic rate is a very complicated situation. For each changed value a range check must be done. A *for* loop is used to find a new limit range. If the trend of this variable is increased, the loop will continue in normal sequence. If the trend is decreased, this loop will continue in reverse order. The following parameters are created for this situation. First one is a *HashMap* instance *pattern_map*. It is used to map each variable as *key* to its values for each month in a list *varvalue_month* as *value*. Second one is *coststring_list*. Its use is to collect cost formulas for each month. The last one is *data_dataid*. It contains all the data transfer id for each month. The implementation of this situation is in Listing 4.4.

Listing 4.4: Dynamic Rate Situation

```java
if(Integer.valueOf(e_list.get(0).get(0))!=1){
    for(int index=1;index<Integer.valueOf(e_list.get(0).get(0));index++){
        varvalue_month.add(temp_cost);
        coststring_list.add(costString);
        data_dataid.add(data_ids);
    }
}
else{
    varvalue_month.add(temp_cost);
    coststring_list.add(costString);
    data_dataid.add(data_ids);
    step=1;
}
for(int index=Integer.valueOf(e_list.get(0).get(0))+step;index<=Integer.
     valueOf(e_list.get(0).get(1));index++){
    double rate=Double.valueOf(e_list.get(0).get(2));
    temp_cost=temp_cost*(1+(rate/100));
    if(e_pattern.getKey().equals("Hour")){
        if(temp_cost>730){
            temp_cost=730;
        }
    }
    if(e_pattern.getKey().equals(compare_var)){
        if(!(temp_cost<=max && temp_cost>=min)){
            if(rate>=0){
        for(int start=varsList_index;start<varsList.size();start++){
          min=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(
              start))).get(4));
          max=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(
              start))).get(5));
          if(temp_cost<=max && temp_cost>=min){
            coefficientid=varsList.get(start);
            data_ids=this.coeff_datatransferList.get(coefficientid);
            costString=coeff_map.get(String.valueOf(varsList.get(start))).get(0);
            varsList_index=start;
            break;
          }
        }
      }else{
        for(int start=varsList_index;start>=0;start--){
          min=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(start))).get(4));
          max=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(start))).get(5));
          if(temp_cost<=max && temp_cost>=min){
            coefficientid=varsList.get(start);
            data_ids=this.coeff_datatransferList.get(coefficientid);
            costString=coeff_map.get(String.valueOf(varsList.get(start))).get(0);
            varsList_index=start;
            break;
          }
        }
      }
        }
    }
    varvalue_month.add(temp_cost);
    coststring_list.add(costString);
    data_dataid.add(data_ids);
}
for(int i=1;i<e_list.size();i++){
    if(Integer.valueOf(e_list.get(i).get(0))-Integer.valueOf(e_list.get(i-1).get(1))!=1){
        for(int index=Integer.valueOf(e_list.get(i-1).get(1))+1;index<Integer.valueOf(e_list.get(i).get(0));index++){
            varvalue_month.add(temp_cost);
            coststring_list.add(costString);
            data_dataid.add(data_ids);
        }
        for(int index=Integer.valueOf(e_list.get(i).get(0));index<=Integer.valueOf(e_list.get(i).get(1));index++){
            double rate=Double.valueOf(e_list.get(i).get(2));
            temp_cost=temp_cost*(1+(rate/100));
            if(e_pattern.getKey().equals("Hour")){
                if(temp_cost>730){
                    temp_cost=730;
                }
            }
            if(e_pattern.getKey().equals(compare_var)){
                if(!(temp_cost<=max && temp_cost>=min)){
                    if(rate>=0){
            for(int start=varsList_index;start<varsList.size();start++){
              min=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(start))).get(4));
              max=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(start))).get(5));
              if(temp_cost<=max && temp_cost>=min){
                coefficientid=varsList.get(start);
                data_ids=this.coeff_datatransferList.get(coefficientid);
                costString=coeff_map.get(String.valueOf(varsList.get(
                    start))).get(0);
                varsList_index=start;
                break;
              }
            }
          }else{
            for(int start=varsList_index;start>=0;start--){
              min=Double.valueOf(coeff_map.get(String.valueOf(varsList.
                  get(start))).get(4));
              max=Double.valueOf(coeff_map.get(String.valueOf(varsList.
                  get(start))).get(5));
              if(temp_cost<=max && temp_cost>=min){
                coefficientid=varsList.get(start);
                data_ids=this.coeff_datatransferList.get(coefficientid);
                costString=coeff_map.get(String.valueOf(varsList.get(
                    start))).get(0);
                varsList_index=start;
                break;
              }
            }
          }
                }
            }
            varvalue_month.add(temp_cost);
            coststring_list.add(costString);
            data_dataid.add(data_ids);
        }
    }
    else{
        for(int index=Integer.valueOf(e_list.get(i).get(0));index<=
            Integer.valueOf(e_list.get(i).get(1));index++){
            double rate=Double.valueOf(e_list.get(i).get(2));
            temp_cost=temp_cost*(1+(rate/100));
            if(e_pattern.getKey().equals("Hour")){
                if(temp_cost>730){
                    temp_cost=730;
                }
            }
            if(e_pattern.getKey().equals(compare_var)){
                if(!(temp_cost<=max && temp_cost>=min)){
                    if(rate>=0){
            for(int start=varsList_index;start<varsList.size();start++){
              min=Double.valueOf(coeff_map.get(String.valueOf(varsList.
                  get(start))).get(4));
              max=Double.valueOf(coeff_map.get(String.valueOf(varsList.
                  get(start))).get(5));
              if(temp_cost<=max && temp_cost>=min){
                coefficientid=varsList.get(start);
                data_ids=this.coeff_datatransferList.get(coefficientid);
                costString=coeff_map.get(String.valueOf(varsList.get(
                    start))).get(0);
                varsList_index=start;
                break;
              }
```

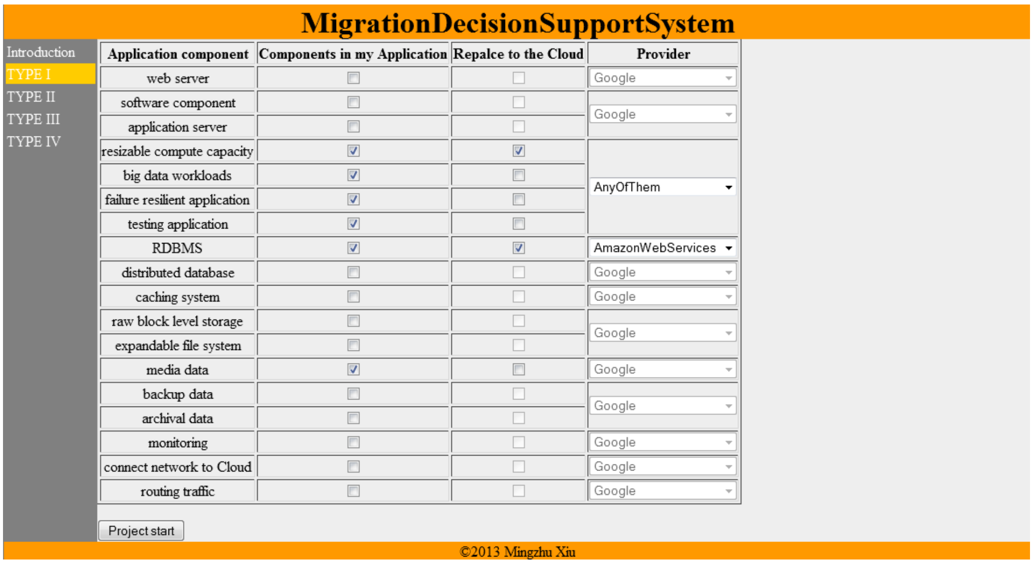
```
      }
     }else{
      for(int start=varsList_index;start>=0;start--){
       min=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(start))).get(4));
       max=Double.valueOf(coeff_map.get(String.valueOf(varsList.get(start))).get(5));
       if(temp_cost<=max && temp_cost>=min){
        coefficientid=varsList.get(start);
        data_ids=this.coeff_datatransferList.get(coefficientid);
        costString=coeff_map.get(String.valueOf(varsList.get(start))).get(0);
        varsList_index=start;
        break;
       }
      }
     }
        }
      }
      varvalue_month.add(temp_cost);
      coststring_list.add(costString);
      data_dataid.add(data_ids);
    }
  }
}
if(Integer.valueOf(e_list.get(e_list.size()-1).get(1))<month){
  for(int index=Integer.valueOf(e_list.get(e_list.size()-1).get(1))+1;index<=month;index++){
    varvalue_month.add(temp_cost);
    coststring_list.add(costString);
    data_dataid.add(data_ids);
  }
}
```

4.4 Decision Support System MiDSuS

This decision support system named MiDSuS is built up by a web application interface with RESTful APIs which were already done in Nefolog system. The web application interface supports a friendly interaction between users and system.

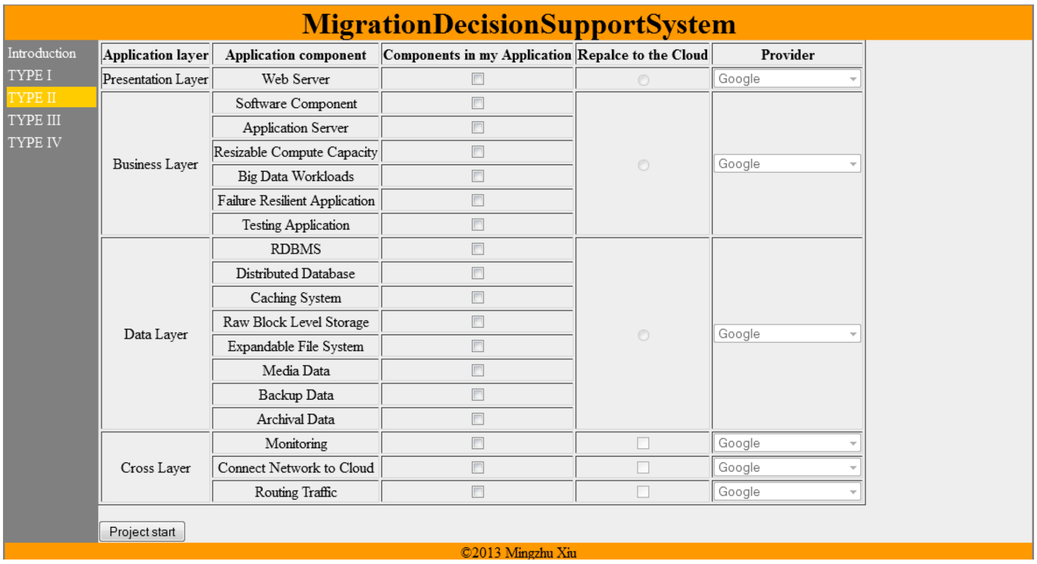
This frontend interface is developed in JSP environment and used JS, CSS, JAVA and HTML together. The main page contains 5 subpages, one introduction subpage and 4 migration types' projects subpages. In each Migration Type, there are 4 inner subpagers to achieve actually 4 steps to find the final offerings. These 4 steps are the first step collection of candidate offerings' requirements, the second step search candidate offerings, the third step collection of cost calculation's requirements and the last step calculation of each configuration's cost.

As discussed in Section 3.5, the decision process starts from the selection of migration types. Figure 4.3 and Figure 4.4 show the user interfaces of first two types. In these two figures it can be seen that either service types or application layers are divided by some application components.



Application component	Components in my Application	Repalce to the Cloud	Provider
web server	□	□	Google
software component	□	□	Google
application server	□	□	
resizable compute capacity	☑	☑	AnyOfThem
big data workloads	☑	□	
failure resilient application	☑	□	
testing application	☑	□	
RDBMS	☑	☑	AmazonWebServices
distributed database	□	□	Google
caching system	□	□	Google
raw block level storage	□	□	Google
expandable file system	□	□	
media data	☑	□	Google
backup data	□	□	Google
archival data	□	□	
monitoring	□	□	Google
connect network to Cloud	□	□	Google
routing traffic	□	□	Google

Figure 4.3: User Interface of MiDSuS: Type I



Application layer	Application component	Components in my Application	Repalce to the Cloud	Provider
Presentation Layer	Web Server	□	○	Google
Business Layer	Software Component	□	○	Google
	Application Server	□		
	Resizable Compute Capacity	□		
	Big Data Workloads	□		
	Failure Resilient Application	□		
	Testing Application	□		
Data Layer	RDBMS	□	○	Google
	Distributed Database	□		
	Caching System	□		
	Raw Block Level Storage	□		
	Expandable File System	□		
	Media Data	□		
	Backup Data	□		
	Archival Data	□		
Cross Layer	Monitoring	□	□	Google
	Connect Network to Cloud	□	□	Google
	Routing Traffic	□	□	Google

Figure 4.4: User Interface of MiDSuS: Type II

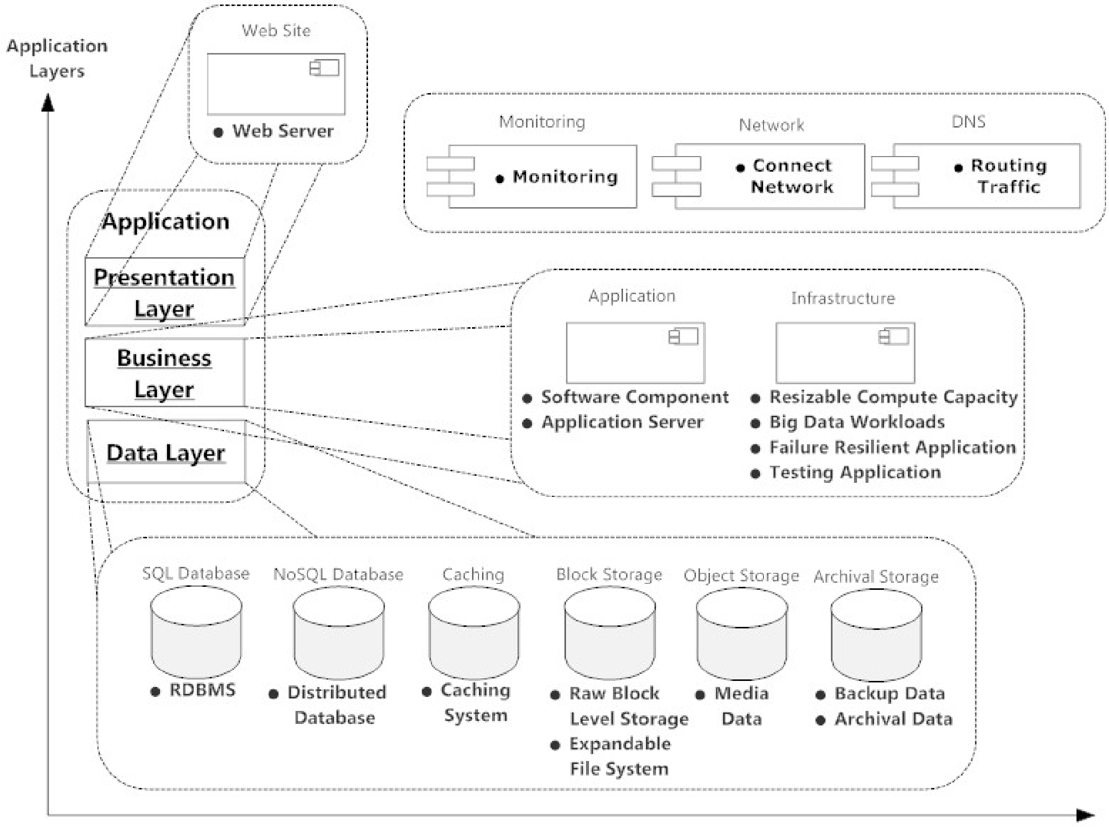


Figure 4.5: Subdivision of MiDSuS

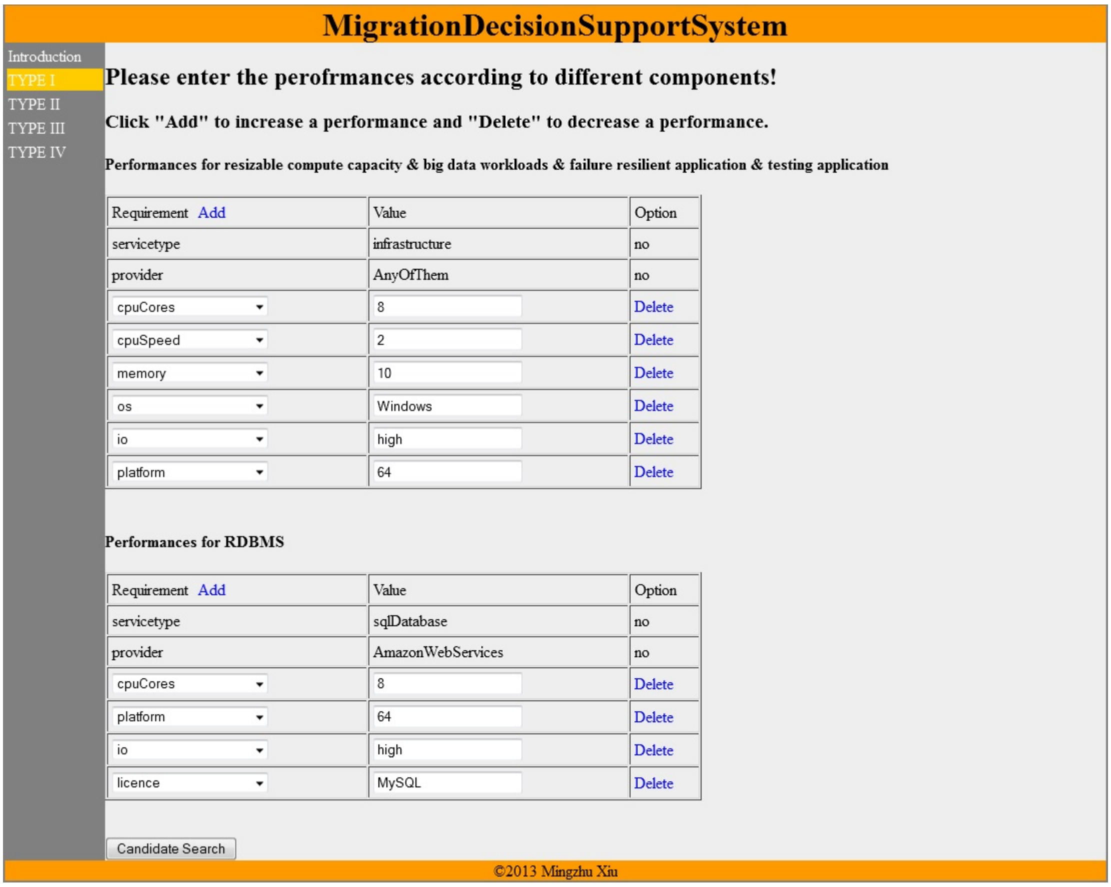
Figure 4.5 explains the mappings between application components and service types, application components and application layer. In this figure, one application is divided into 3 layers. In each layer, there is at least one mapped service type. Besides these 3 layers, there is also a cross layer. This layer contains the service types which support networking between layers and monitoring of components across layers. In each service type, at least one application component is defined. It helps users more easily to find the mapping between their migrated components and service types. Some of these application components are defined by the Cloud services providers. Some are from the applications use case in Appendix A.1. All the defined application components in Figure 4.5 are listed with their provenances in Table 4.5. Actually, if the migrated components or application layers are identified, it means the service types are identified.

Table 4.5: Provenances of each Application Component in MiDSuS

Application Component	**Reference**
Web Server	gumi [20] Holiday Extras [21]
Software Component	Logistics & Project Management [8] Astronomic Data Processing [8] Essex County Council [22]
Application Server	Payroll Processing [8] Ice.com [23]
Resizable Compute Capacity	HP Cloud Compute [24]
Big Data Workload	”Big” data processing [25] HP Cloud Compute [24]
Failure Resilient Application	AWS EC2 [26]
Testing Application	Application testing [25]
RDBMS	-
Distributed Database	AWS DynamoDB [27]
Caching System	-
Raw Block Level Storage	HP Cloud Block Storage [28] AWS EBS [29]
Expandable File System	HP Cloud Block Storage [28]
Media Data	Windows Azure Blob Storage [30]
Backup Data	AWS Glacier [31]
Archival Data	AWS Glacier [31]

In order to have a better idea about inner 4 steps in each migration type, the selection process of Type I is chosen to explain as an example. In Figure 4.3 whose tasks are to select an appropriate migration type and the desired provider, the migrated application components are resizable compute capacity which belongs to infrastructure service type and RDBMS which belongs to SQL database service type. At the same time user chooses AWS provider for RDBMS component.

After Figure 4.3, system runs to the first inner page which is called the first step of Type I to collect the user's requirements of offerings' performances in Figure 4.6. Following the selection of previous page, components which are from two service types are ready to be migrated to the Cloud. In addition, user can use "Add" button to increase any performances with certain values while use "Delete" button in the end of each performance row to decrease the performance in this row. In this example, some non-numerical and numerical performances for both service types are entered. Then system goes to the candidate search step.



Please enter the perofrmances according to different components!

Click "Add" to increase a performance and "Delete" to decrease a performance.

Performances for resizable compute capacity & big data workloads & failure resilient application & testing application

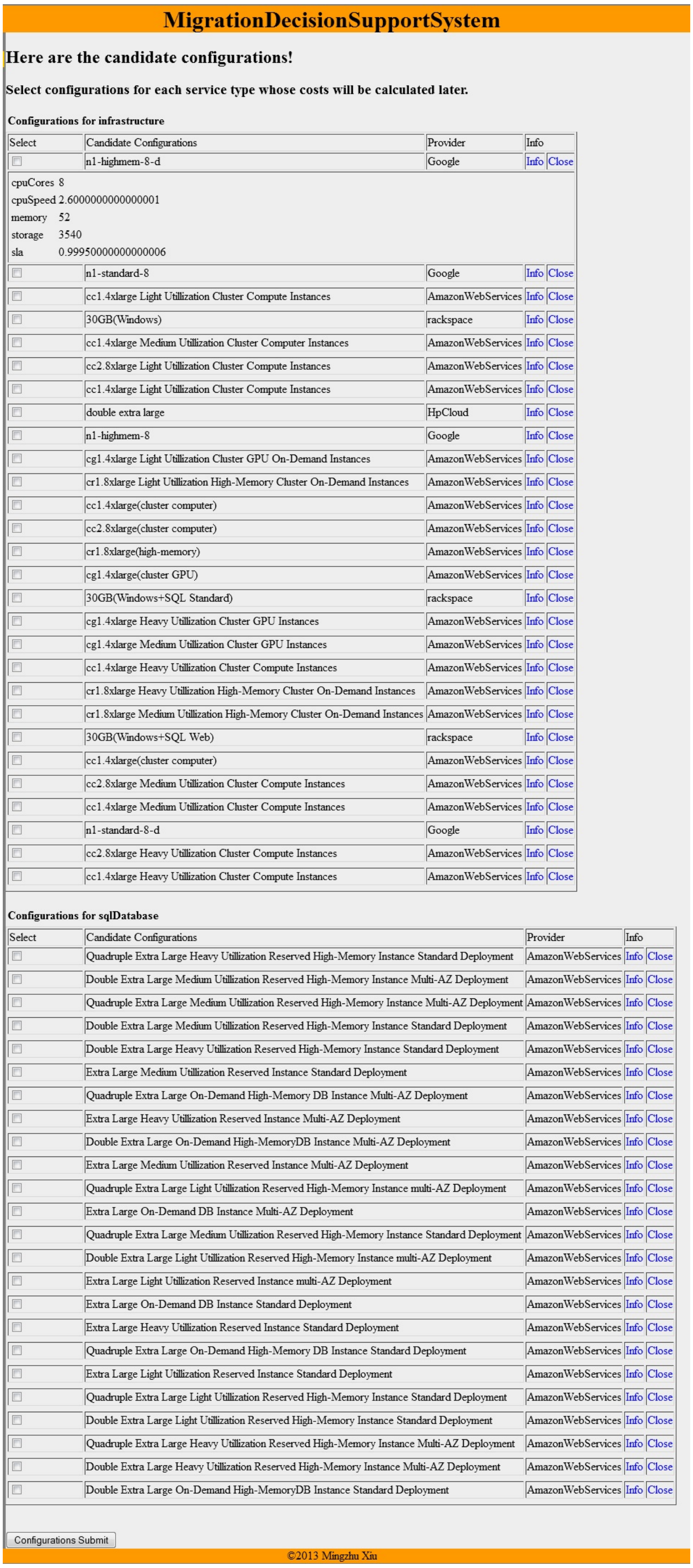
Requirement Add	Value	Option
servicetype	infrastructure	no
provider	AnyOfThem	no
cpuCores	8	Delete
cpuSpeed	2	Delete
memory	10	Delete
os	Windows	Delete
io	high	Delete
platform	64	Delete

Performances for RDBMS

Requirement Add	Value	Option
servicetype	sqlDatabase	no
provider	AmazonWebServices	no
cpuCores	8	Delete
platform	64	Delete
io	high	Delete
licence	MySQL	Delete

Figure 4.6: User Interface: First Step of Type I

In Figure 4.7, the candidate offerings with providers are listed and with the help of "Info" button user can have a complete look of this configuration. In this example, the first candidate configuration of infrastructure service type has 8 CPU cores with 2.6 GHz CPU speed and 52 GB of memory, 3540 GB of local storage instance, and 99.95% SLA. User selects first 5 configurations of each service type to calculate the costs.



MigrationDecisionSupportSystem

Here are the candidate configurations!

Select configurations for each service type whose costs will be calculated later.

Configurations for infrastructure

Select	Candidate Configurations	Provider	Info	
□	n1-highmem-8-d	Google	Info	Close
cpuCores 8 cpuSpeed 2.6000000000000001 memory 52 storage 3540 sla 0.99950000000000006				
□	n1-standard-8	Google	Info	Close
□	cc1.4xlarge Light Utillization Cluster Compute Instances	AmazonWebServices	Info	Close
□	30GB(Windows)	rackspace	Info	Close
□	cc1.4xlarge Medium Utillization Cluster Computer Instances	AmazonWebServices	Info	Close
□	cc2.8xlarge Light Utillization Cluster Compute Instances	AmazonWebServices	Info	Close
□	cc1.4xlarge Light Utillization Cluster Compute Instances	AmazonWebServices	Info	Close
□	double extra large	HpCloud	Info	Close
□	n1-highmem-8	Google	Info	Close
□	cg1.4xlarge Light Utillization Cluster GPU On-Demand Instances	AmazonWebServices	Info	Close
□	cr1.8xlarge Light Utillization High-Memory Cluster On-Demand Instances	AmazonWebServices	Info	Close
□	cc1.4xlarge(cluster computer)	AmazonWebServices	Info	Close
□	cc2.8xlarge(cluster computer)	AmazonWebServices	Info	Close
□	cr1.8xlarge(high-memory)	AmazonWebServices	Info	Close
□	cg1.4xlarge(cluster GPU)	AmazonWebServices	Info	Close
□	30GB(Windows+SQL Standard)	rackspace	Info	Close
□	cg1.4xlarge Heavy Utillization Cluster GPU Instances	AmazonWebServices	Info	Close
□	cg1.4xlarge Medium Utillization Cluster GPU Instances	AmazonWebServices	Info	Close
□	cc1.4xlarge Heavy Utillization Cluster Compute Instances	AmazonWebServices	Info	Close
□	cr1.8xlarge Heavy Utillization High-Memory Cluster On-Demand Instances	AmazonWebServices	Info	Close
□	cr1.8xlarge Medium Utillization High-Memory Cluster On-Demand Instances	AmazonWebServices	Info	Close
□	30GB(Windows+SQL Web)	rackspace	Info	Close
□	cc1.4xlarge(cluster computer)	AmazonWebServices	Info	Close
□	cc2.8xlarge Medium Utillization Cluster Compute Instances	AmazonWebServices	Info	Close
□	cc1.4xlarge Medium Utillization Cluster Compute Instances	AmazonWebServices	Info	Close
□	n1-standard-8-d	Google	Info	Close
□	cc2.8xlarge Heavy Utillization Cluster Compute Instances	AmazonWebServices	Info	Close
□	cc1.4xlarge Heavy Utillization Cluster Compute Instances	AmazonWebServices	Info	Close

Configurations for sqlDatabase

Select	Candidate Configurations	Provider	Info	
□	Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	AmazonWebServices	Info	Close
□	Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	AmazonWebServices	Info	Close
□	Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	AmazonWebServices	Info	Close
□	Extra Large Medium Utillization Reserved Instance Standard Deployment	AmazonWebServices	Info	Close
□	Quadruple Extra Large On-Demand High-Memory DB Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Extra Large Heavy Utillization Reserved Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Double Extra Large On-Demand High-MemoryDB Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Extra Large Medium Utillization Reserved Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Quadruple Extra Large Light Utillization Reserved High-Memory Instance multi-AZ Deployment	AmazonWebServices	Info	Close
□	Extra Large On-Demand DB Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	AmazonWebServices	Info	Close
□	Double Extra Large Light Utillization Reserved High-Memory Instance multi-AZ Deployment	AmazonWebServices	Info	Close
□	Extra Large Light Utillization Reserved Instance multi-AZ Deployment	AmazonWebServices	Info	Close
□	Extra Large On-Demand DB Instance Standard Deployment	AmazonWebServices	Info	Close
□	Extra Large Heavy Utillization Reserved Instance Standard Deployment	AmazonWebServices	Info	Close
□	Quadruple Extra Large On-Demand High-Memory DB Instance Standard Deployment	AmazonWebServices	Info	Close
□	Extra Large Light Utillization Reserved Instance Standard Deployment	AmazonWebServices	Info	Close
□	Quadruple Extra Large Light Utillization Reserved High-Memory Instance Standard Deployment	AmazonWebServices	Info	Close
□	Double Extra Large Light Utillization Reserved High-Memory Instance Standard Deployment	AmazonWebServices	Info	Close
□	Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Double Extra Large Heavy Utillization Reserved High-Memory Instance Multi-AZ Deployment	AmazonWebServices	Info	Close
□	Double Extra Large On-Demand High-MemoryDB Instance Standard Deployment	AmazonWebServices	Info	Close

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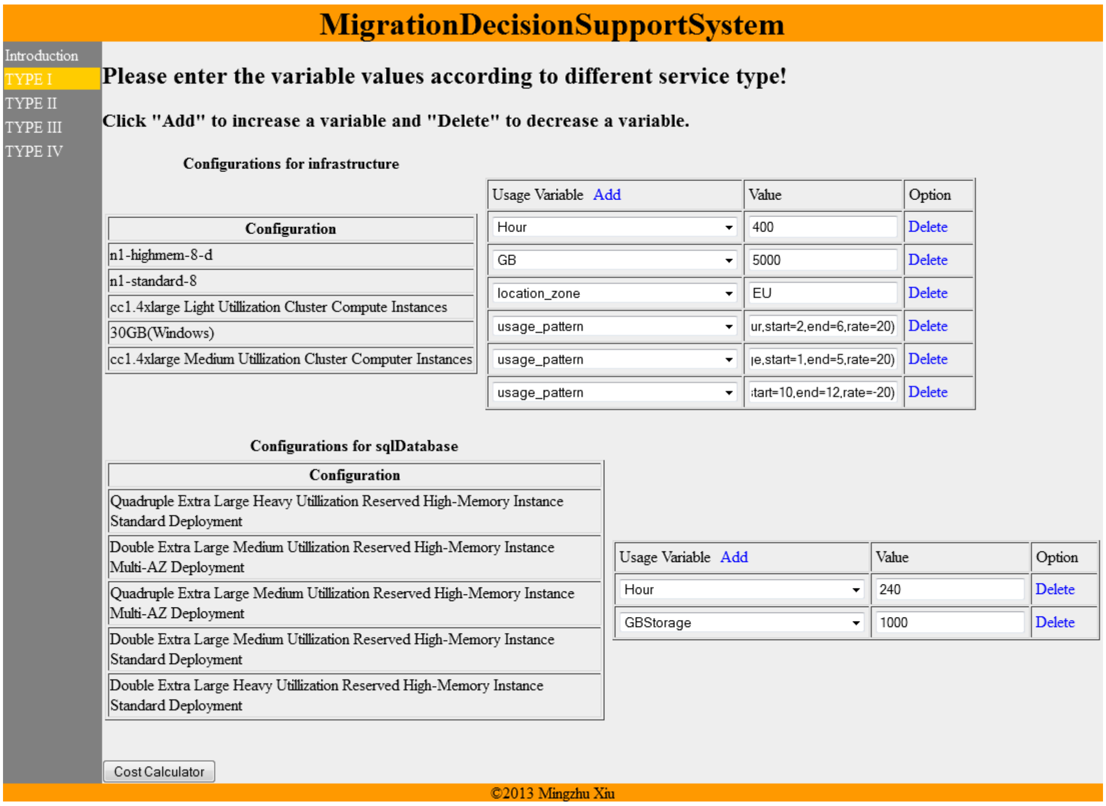
Figure 4.7: User Interface: Second Step of Type I Candidate Search Step



MigrationDecisionSupportSystem

Please enter the variable values according to different service type!

Click "Add" to increase a variable and "Delete" to decrease a variable.

Configurations for infrastructure

Configuration
n1-highmem-8-d
n1-standard-8
cc1.4xlarge Light Utilization Cluster Compute Instances
30GB(Windows)
cc1.4xlarge Medium Utilization Cluster Computer Instances

Usage Variable Add	Value	Option
Hour	400	Delete
GB	5000	Delete
location_zone	EU	Delete
usage_pattern	ur,start=2,end=6,rate=20)	Delete
usage_pattern	ɪe,start=1,end=5,rate=20)	Delete
usage_pattern	;tart=10,end=12,rate=-20)	Delete

Configurations for sqlDatabase

Configuration
Quadruple Extra Large Heavy Utilization Reserved High-Memory Instance Standard Deployment
Double Extra Large Medium Utilization Reserved High-Memory Instance Multi-AZ Deployment
Quadruple Extra Large Medium Utilization Reserved High-Memory Instance Multi-AZ Deployment
Double Extra Large Medium Utilization Reserved High-Memory Instance Standard Deployment
Double Extra Large Heavy Utilization Reserved High-Memory Instance Standard Deployment

Usage Variable Add	Value	Option
Hour	240	Delete
GBStorage	1000	Delete

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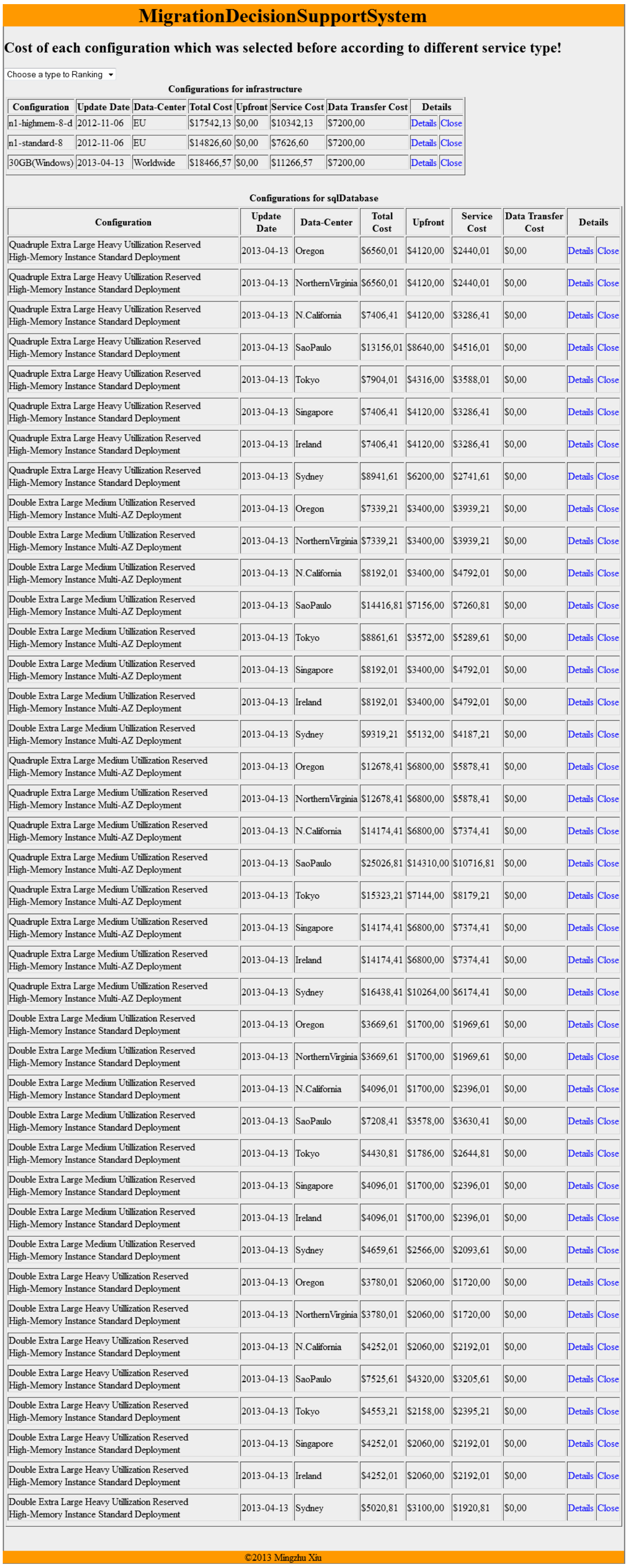
Figure 4.8: User Interface: Third Step of Type I

In Figure 4.8, system starts to collect the requirements of cost calculation. User can also use "Add" button to increase requirement variables with certain values and use "Delete" button to decrease one row. This design idea is similar as the first step design. The usage variables of the tables in Figure 4.8 are generally separated into static rate and dynamic rate. The infrastructure service type has a usage variable called "usage_pattern". This variable means that a variable will be changed during a period time with a certain rate (this rate cannot be zero). This situation is called dynamic rate. The other service type SQL database is no "usage_pattern" variable, so it is in static rate which means rate is equal to zero. In this situation, cost calculator will also calculate each month cost with invariant rate. It is important to say one more time that these necessary usage variables which should be valued in the beginning but here no-values from the user have default values which has already been talked in Section 4.3.2.

After the third step which collects all the necessary information, system comes to the last step in Figure 4.9 which gives the results of this migrated application. Clicking the "Details" button user can see the trend of this configuration in each month, the usage variables in this cost calculation and the features of this offerings. The Figure 4.10 shows the details of the first offering. User can also use the "Ranking" drop down list to choose a parameter to make a ranking. This helps user to have a better look which candidate offering(s) is the most worthy to invest.



MigrationDecisionSupportSystem

Cost of each configuration which was selected before according to different service type!

Configurations for infrastructure

Configuration	Update Date	Data-Center	Total Cost	Upfront	Service Cost	Data Transfer Cost	Details	
n1-highmem-8-d	2012-11-06	EU	$17542,13	$0,00	$10342,13	$7200,00	Details	Close
n1-standard-8	2012-11-06	EU	$14826,60	$0,00	$7626,60	$7200,00	Details	Close
30GB(Windows)	2013-04-13	Worldwide	$18466,57	$0,00	$11266,57	$7200,00	Details	Close

Configurations for sqlDatabase

Configuration	Update Date	Data-Center	Total Cost	Upfront	Service Cost	Data Transfer Cost	Details	
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Oregon	$6560,01	$4120,00	$2440,01	$0,00	Details	Close
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	NorthernVirginia	$6560,01	$4120,00	$2440,01	$0,00	Details	Close
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	N.California	$7406,41	$4120,00	$3286,41	$0,00	Details	Close
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	SaoPaulo	$13156,01	$8640,00	$4516,01	$0,00	Details	Close
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Tokyo	$7904,01	$4316,00	$3588,01	$0,00	Details	Close
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Singapore	$7406,41	$4120,00	$3286,41	$0,00	Details	Close
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Ireland	$7406,41	$4120,00	$3286,41	$0,00	Details	Close
Quadruple Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Sydney	$8941,61	$6200,00	$2741,61	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Oregon	$7339,21	$3400,00	$3939,21	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	NorthernVirginia	$7339,21	$3400,00	$3939,21	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	N.California	$8192,01	$3400,00	$4792,01	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	SaoPaulo	$14416,81	$7156,00	$7260,81	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Tokyo	$8861,61	$3572,00	$5289,61	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Singapore	$8192,01	$3400,00	$4792,01	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Ireland	$8192,01	$3400,00	$4792,01	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Sydney	$9319,21	$5132,00	$4187,21	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Oregon	$12678,41	$6800,00	$5878,41	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	NorthernVirginia	$12678,41	$6800,00	$5878,41	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	N.California	$14174,41	$6800,00	$7374,41	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	SaoPaulo	$25026,81	$14310,00	$10716,81	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Tokyo	$15323,21	$7144,00	$8179,21	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Singapore	$14174,41	$6800,00	$7374,41	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Ireland	$14174,41	$6800,00	$7374,41	$0,00	Details	Close
Quadruple Extra Large Medium Utillization Reserved High-Memory Instance Multi-AZ Deployment	2013-04-13	Sydney	$16438,41	$10264,00	$6174,41	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Oregon	$3669,61	$1700,00	$1969,61	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	NorthernVirginia	$3669,61	$1700,00	$1969,61	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	N.California	$4096,01	$1700,00	$2396,01	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	SaoPaulo	$7208,41	$3578,00	$3630,41	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Tokyo	$4430,81	$1786,00	$2644,81	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Singapore	$4096,01	$1700,00	$2396,01	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Ireland	$4096,01	$1700,00	$2396,01	$0,00	Details	Close
Double Extra Large Medium Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Sydney	$4659,61	$2566,00	$2093,61	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Oregon	$3780,01	$2060,00	$1720,00	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	NorthernVirginia	$3780,01	$2060,00	$1720,00	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	N.California	$4252,01	$2060,00	$2192,01	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	SaoPaulo	$7525,61	$4320,00	$3205,61	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Tokyo	$4553,21	$2158,00	$2395,21	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Singapore	$4252,01	$2060,00	$2192,01	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Ireland	$4252,01	$2060,00	$2192,01	$0,00	Details	Close
Double Extra Large Heavy Utillization Reserved High-Memory Instance Standard Deployment	2013-04-13	Sydney	$5020,81	$3100,00	$1920,81	$0,00	Details	Close

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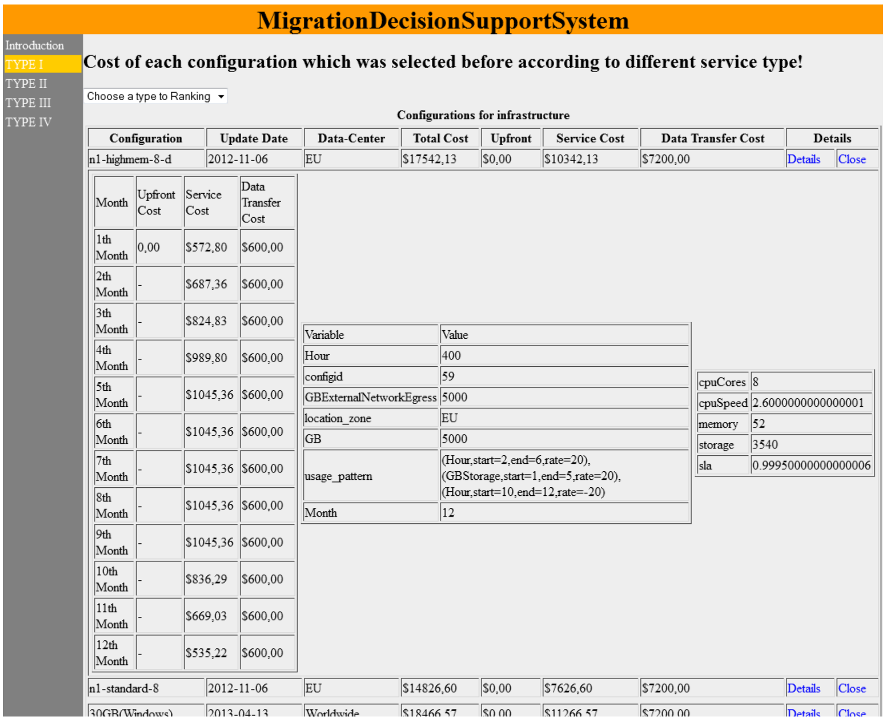
Figure 4.9: User Interface: Fourth Step of Type I



Cost of each configuration which was selected before according to different service type!

Configurations for infrastructure

Configuration	Update Date	Data-Center	Total Cost	Upfront	Service Cost	Data Transfer Cost	Details	
n1-highmem-8-d	2012-11-06	EU	$17542,13	$0,00	$10342,13	$7200,00	Details	Close
n1-standard-8	2012-11-06	EU	$14826,60	$0,00	$7626,60	$7200,00	Details	Close
30GB(Windows)	2013-04-13	Worldwide	$18466,57	$0,00	$11266,57	$7200,00	Details	Close

Month	Upfront Cost	Service Cost	Data Transfer Cost
1th Month	0,00	$572,80	$600,00
2th Month	-	$687,36	$600,00
3th Month	-	$824,83	$600,00
4th Month	-	$989,80	$600,00
5th Month	-	$1045,36	$600,00
6th Month	-	$1045,36	$600,00
7th Month	-	$1045,36	$600,00
8th Month	-	$1045,36	$600,00
9th Month	-	$1045,36	$600,00
10th Month	-	$836,29	$600,00
11th Month	-	$669,03	$600,00
12th Month	-	$535,22	$600,00

Variable	Value
Hour	400
configid	59
GBExternalNetworkEgress	5000
location_zone	EU
GB	5000
usage_pattern	(Hour,start=2,end=6,rate=20), (GBStorage,start=1,end=5,rate=20), (Hour,start=10,end=12,rate=-20)
Month	12

cpuCores	8
cpuSpeed	2.6000000000000001
memory	52
storage	3540
sla	0.99950000000000006

Figure 4.10: User Interface: Fourth Step of Type I with Details

4.5 User Guide

This MiDSuS system works according to user's migrated application, some requirements of the available Cloud offerings' performances and some restrictions of usage variables' values.

4.5.1 Selection of Migration Type

The relationships of each migration type are dispersed in this work, e.g.: definitions of each type are in Section 2.1; identical and different parts of each two types are explained in Section 3.5 and also in the section above. Figure 4.5 show a clear division of an application and with the help of this figure migration types based on application components are like Figure 4.3 while migration types based on application layers are like Figure 4.4.

4.5.2 Requirement Collection of Candidate Offerings

The requirements are collected by a set of performance parameters. All the available parameters are summarized by a drop down list in Figure 4.6. The addition and delete operations are achieved by button to get a dynamic table. The descriptions and units of some commonly used parameters are explained in the following:

- CPU Core: number of virtual cores

- CPU Speed: speed of CPU with GHz
- Memory: size of RAM with GB
- IO: I/O performance with 4 values (very high, high, moderate and low)
- Storage: local disk with GB
- SLA: Service-Level Agreement with a $[0, 1]$ value
- Licence: software licence with 5 values (MySQL, Oracle, SQLServer, SQLWeb and SQLStandard)
- Platform: 32 or 64 -bit
- OS: operating system with 3 values (Linux, Windows and Enterprise Linux)

When entering the non-numerical performance characteristics (IO, Licence, OS), user should be aware that the values are case sensitive. About the no-value performance parameter on both the database side and the user side, it is thought as default that this performance satisfies the requirement.

4.5.3 Selection of Candidate Offerings

According to the requirements in the above section, all the candidate offerings with corresponding provider are listed in a table in Figure 4.7. With the "Info" button user can see a table with all the information about this offering's performances. Furthermore, a set of offerings are selected by the check box to be calculated in next steps. This is the first filter of candidate offerings.

4.5.4 Collection Requirements of Cost Calculator

The cost calculator uses a cost formula with multiple parameters to calculate the cost. These parameters should be provided by user in Figure 4.8. If there is no input value, some default values are set up for all parameters. In Figure 4.8, all the usage variables are summarized in a drop down list and user can use "Add" and "Delete" button to control the number of variables. The default values are talked in Section 4.3.2. If the parameter is "Hour", the default value is 500 hours per month and the input value should not be more than 730 hours per month; if the parameter is "month", the default value is 10 months; All of the other parameters have a same default value of 5000. As said in last section parameter "usage_pattern" is used to set up a dynamic rate situation. The form of this parameter should be treated carefully. This variable should be valued in a form like $(Hour, start = 2, end = 6, rate = -20)$, it means the variable "Hour" will decreased between the second month and the sixth month with a rate value -20%. User can add such "usage_pattern" as many times as he wants.

4.5.5 Checking Results of Cost Calculator and Ranking

Figure 4.9 shows the results page of MiDSuS. It collects results of each offering together in a table and at the end of each row there is a control button called "Details" to see the cost trends in each month, the information about usage variables and a list of performance characteristics of this offering. User can also use Ranking drop down list to check a ranking with update date, data center, total cost, upfront cost, service cost or data transfer cost. With the help of ranking user can know which is the cheapest or which is the newest. These results will support a better comparison for user to make a correct decision.

5 Evaluation

In this chapter, a set of tests is used to validate these web services in Nefolog. Especially for the candidate search service and cost calculator service, the results of them are compared with the results which are calculated by some other available decision support systems. Some use cases in Appendix A.1 are migrated to the Cloud with different migration types in MiDSuS in order to demonstrate that with MiDSuS user can find the best cost for his migration project.

5.1 Nefolog Validation

In Nefolog system, the two decision support services are candidate search service and cost calculator service. The available decision support systems among several Cloud providers with cost calculator are PlanForCloud [9] and Cloudorado [17] which have already been discussed in Section 2.4.

The candidate search service begins with requirements collection. These requirements contain all the available features. There are totally 16 features in Cloud provider knowledge base of Nefolog. However, PlanForCloud and Cloudorado do not support as many features as Nefolog. In PlanForCloud system, only during the selection of server and database user has chances to enter his requirements to control the search results. In addition, Cloudorado system supports only IaaS Cloud service search with 4 features. In order to have a valid comparison between each other, an infrastructure service type with CPU cores and size of RAM is chosen as an example to migrate to the Cloud. The provider data bases of both systems have several same providers. After considering Nefolog system with PlanForCloud and Cloudorado from features of services and the status of data bases perspectives, a set of requirements is set as following:

- $Service\ Type = Infrastructure$
- $CPU\ Core \geq 8$
- $RAM \geq 8GB$
- $Provider = AWS\ or\ Rackspace$

The results of each system are listed in Table 5.1. Comparing the results of Nefolog with PlanForCloud, they present exactly the same search results of provider AWS but the light, medium and heavy utilization reserved instance of AWS EC2 are separated by different offering names in Nefolog while these different reserved instance types are selected in purchase option step in PlanForCloud. In addition, the results of provider Rackspace are almost the same. Both of them have a Cloud offering called 30GB, but

Table 5.1: Comparison of Candidate Offerings Search

Provider	Nefolog	PlanForCloud	Cloudorado
Amazon Web Services	m1.xlarge	m1.xlarge (Standard, light, medium, heavy)	Standard Extra Large
	m1.xlarge light utilization		
	m1.xlarge medium utilization		
	m1.xlarge heavy utilization		
	m2.2xlarge	m2.2xlarge (Standard, light, medium, heavy)	-
	m2.2xlarge light utilization		
	m2.2xlarge medium utilization		
	m2.2xlarge heavy utilization		
	m2.4xlarge	m2.4xlarge (Standard, light, medium, heavy)	-
	m2.4xlarge light utilization		
	m2.4xlarge medium utilization		
	m2.4xlarge heavy utilization		
	m3.xlarge	m3.xlarge (Standard, light, medium, heavy)	Standard Second Generation Extra Large
	m3.xlarge light utilization		
	m3.xlarge medium utilization		
	m3.xlarge heavy utilization		
	m3.2xlarge	m3.2xlarge (Standard, light, medium, heavy)	Standard Second Generation Double Extra Large
	m3.2xlarge light utilization		
	m3.2xlarge medium utilization		
	m3.2xlarge heavy utilization		
	cc1.4xlarge	cc1.4xlarge (Standard, light, medium, heavy)	Cluster Compute Quadruple Extra Large
	cc1.4xlarge light utilization		
	cc1.4xlarge medium utilization		
	cc1.4xlarge heavy utilization		
	cc2.8xlarge	cc2.8xlarge (Standard, light, medium, heavy)	-
	cc2.8xlarge light utilization		
	cc2.8xlarge medium utilization		
	cc2.8xlarge heavy utilization		
	cg1.4xlarge	cg1.4xlarge (Standard, light, medium, heavy)	-
	cg1.4xlarge light utilization		
	cg1.4xlarge medium utilization		
	cg1.4xlarge heavy utilization		
	cr1.8xlarge	cr1.8xlarge (Standard, light, medium, heavy)	-
	cr1.8xlarge light utilization		
	cr1.8xlarge medium utilization		
	cr1.8xlarge heavy utilization		
	hi1.4xlarge	hi1.4xlarge (Standard, light, medium, heavy)	-
	hi1.4xlarge light utilization		
	hi1.4xlarge medium utilization		
	hi1.4xlarge heavy utilization		
	hs1.8xlarge	hs1.8xlarge (Standard, light, medium, heavy)	-
	hs1.8xlarge light utilization		
	hs1.8xlarge medium utilization		
	hs1.8xlarge heavy utilization		
Rackspace	30GB (Windows)	30GB (Windows, Linux) server	30 GB RAM Instance
	30GB (Linux)		
	30GB (Windows+SQL Standard)		
	30GB (Windows+SQL Web)		
	30GB (Enterprise Linux)		

Nefolog includes 5 combinations of different operating systems and licences while PlanForCloud contains only the option of operating systems. Comparing with Cloudorado, the results of Cloudrado do not cover all the Cloud offerings but only some standard offerings. Furthermore, the CUP core calculator is different from the other two systems. As a result of these deficiencies, Cloudorado is not to be considered in the comparison of Nefolog evaluation.

It can be seen from results of comparison with Nefolog and PlanForCloud that the results of candidate offerings search service in Nefolog cover all the results of PlanForCloud and even more. It means this candidate search service supports a sufficient, useful and practical result.

Table 5.2: Static Rate Test Comparing with PlanForCloud

URI:$http://localhost:8080/nefolog/costCalculation?configid=122\&Hour=240\&Month=15$ $\&i/oOperation=5000\&GBStorage=5000\&GBExternalNetworkEgress=50000$	
Provider	Amazon Web Service
Offering	RDS
Configuration	Large Medium Utilization Reserved Instance Multi-AZ Deployment

	Upfront cost once		Service per Month		Data transfer per Month	
Location	Nefolog	PlanForCloud	Nefolog	PlanForCloud	Nefolog	PlanForCloud
Oregon	$2000	$2000	$1052.80	$1052.9	$4800	$4807.08
SaoPaulo	$3780	$3780	$1987.84	$1987.98	$11700	$11704.55
N.California	$2000	$2000	$1167.68	$1167.79	$4800	$4807.08
Tokyo	$2100	$2100	$1278.24	$1278.36	$8330	$8340.12
Singapore	$2000	$2000	$1167.68	$1167.79	$7900	$7909.41
Ireland	$2000	$2000	$1167.68	$1167.79	$4800	$4807.08
NorthernVirginia	$2000	$2000	$1052.80	$1052.9	$4800	$4807.08
Sydney	$2000	$2000	$1167.68	$1167.79	$7900	$7909.41

After that, the cost calculator service should also be evaluated too and compared with PlanForCloud. 3 test cases which were recorded on the end of June 2013 are implemented in order to cover all the situations of cost calculator. The different situation is cause of different rates of usage variable, static rate and dynamic rate.

The results in Table 5.2 which is calculated in the static rate situation are listed with the results of PlanForCloud together. The information in URI means that the configuration id is equals to 122; the usage hour is 240 hours per month; the I/O operation number is 5000; the storage size is 5000GB; the data transfer out from this offering is 50000 GB per month; the total usage time is 15 months. From the database, it can be known that this offering is a relational database service which is provided by AWS and it is a large medium utilization reserved instance multi-AZ deployment. This offering has 8 different locations of data center. Because of the static rate the cost of each month stays the same, so only the upfront cost, service cost and data transfer cost are essential to be compared with different locations. Comparing with upfront cost, both of them have the exactly same result. Comparing with service cost, the maximum difference is $0.14 in SaoPaulo among different locations and the ratio of this difference is about 0.007%. Comparing with data transfer cost, the maximum different is $10.12 in Tokyo and the ratio is about 0.12%. Generally speaking, the difference between two systems is tiny and not over 0.2%. This difference maybe occurs during the identification of different usage amount ranges. To describe this difference clearly, for example in data transfer cost calculation, the cost in Nefolog is a little smaller than in PlanForCloud. It is known from the provider that the data transfer out from RDS offering is free in the first 1 GB. After that, it should be charged. Maybe PlanForCloud does not remove this free part. Therefore PlanForCloud has a little higher price than Nefolog.

Table 5.3: Dynamic Rate Test 1 Comparing with PlanForCloud

URI:$http : //localhost : 8080/nefolog/costCalculation?configid = 467$ $\&GB = 5000\&Month = 5\&usage\_pattern = (GB, start = 1, end = 12, rate = 20),$ $(GBExternalNetworkEgress, start = 1, end = 12, rate = -10)$	
Provider	rackspace
Offering	Cloud Files
Configuration	Cloud Files

Location: worldwide	Upfront cost once		Service per Month		Data transfer per Month	
	Nefolog	PlanForCloud	Nefolog	PlanForCloud	Nefolog	PlanForCloud
1th Month	$0	$0	$460.00	-	$600.00	-
2th Month	-	-	$572.5	$572.74	$540.0	$540.0
3th Month	-	-	$713.13	$713.41	$486.0	$486.0
4th Month	-	-	$888.91	$889.18	$437.4	$437.4
5th Month	-	-	$1108.63	$1108.96	$393.66	$393.72
6th Month	-	-	$1383.29	$1383.55	$354.29	$354.36
7th Month	-	-	$1726.61	$1726.90	$318.86	$318.96
8th Month	-	-	$2155.77	$2156.02	$286.98	$287.048
9th Month	-	-	$2692.21	$2692.51	$258.28	$258.36
10th Month	-	-	$3362.76	$3363.01	$232.45	$232.56
11th Month	-	-	$4200.95	$4201.27	$209.21	$209.28
12th Month	-	-	$5207.65	$5213.92	$188.29	$188.40

In the dynamic rate situation, 2 test cases are implemented to make sure that Nefolog system has also valid results in other providers excepted AWS. Table 5.3 shows the results of provider Rackspace while Table 5.4 shows the results of provider Hp Cloud. The usage patterns in PlanForCloud are fixed. It means that user can choose only the given usage patterns with special variables. Because of this special rule, the usage patterns of the fist test case in Table 5.3 contains the trends of GB and GBExternalNetworkEgress. GB is increased by 20% from the first month to 12th month and GBExternalNetworkEgress is decreased by 10% from the first month to 12th month. The location of Cloud Files' data center is worldwide. The comparisons between two systems are listed by each month. Although the requirement month is 5 months but the total month in usage pattern is 12 months, the final calculated month chooses the longer one. The comparison of upfront cost is similar and the result is that there is no upfront cost of the Cloud Files. The results of service cost are almost the same. The biggest difference is $6.27 in the 12th month and the ratio is about 0.12%. The difference of comparison results of data transfer cost is relatively small. The maximum one is $0.11 in the 9th month and also in the 12th month and the ratio is about 0.058%. Table 5.4 is implemented with the same method like what did in the first test case. This offering called Object Storage is provided by Hp Cloud and also has no upfront cost with a worldwide data center location. The maximum difference of service cost is $0.08 in the 3th month and the 4th month with a ratio of 0.015%. The results of data transfer cost are exactly the same.

Table 5.4: Dynamic Rate Test 2 Comparing with PlanForCloud

URI:$http://localhost:8080/nefolog/costCalculation?configid = 444\&GBStorage = 5000$ $\&Month = 5\&usage\_pattern = (GBStorage, start = 1, end = 12, rate = 10)$	
Provider	Hp Cloud
Offering	Object Storage
Configuration	Object Storage

Location: worldwide	Upfront cost once		Service per Month		Data transfer per Month	
	Nefolog	PlanForCloud	Nefolog	PlanForCloud	Nefolog	PlanForCloud
1th Month	$0	$0	$450.01	-	$599.88	-
2th Month	-	-	$495.01	$495.00	$599.88	$599.88
3th Month	-	-	$544.51	$544.59	$599.88	$599.88
4th Month	-	-	$598.96	$599.04	$599.88	$599.88
5th Month	-	-	$658.85	$658.89	$599.88	$599.88
6th Month	-	-	$724.73	$724.77	$599.88	$599.88
7th Month	-	-	$797.21	$797.22	$599.88	$599.88
8th Month	-	-	$876.93	$876.96	$599.88	$599.88
9th Month	-	-	$964.62	$964.62	$599.88	$599.88
10th Month	-	-	$1061.08	$1061.10	$599.88	$599.88
11th Month	-	-	$1167.19	$1167.21	$599.88	$599.88
12th Month	-	-	$1283.91	$1283.94	$599.88	$599.88

It can be seen from the results that the maximum ratio of difference between Nefolog and PlanForCloud is smaller than 1%. It means that these two systems have an almost similar cost result. Although there could also be some deviations between the cost result which is calculated by the provider itself and the cost results from these two systems, the results of Nefolog can be thought as the closest results as the exact ones.

5.2 MiDSuS Evaluation

The MiDSuS evaluation is realized by estimating the cost of re-migrating an application in Appendix A.1 with different migration types in order to demonstrate that with the help of MiDSuS user can find the best cost of his migration project.

The application payroll processing which has been migrated to the Cloud with Migration Type III already is chosen as a test case here. This application contains one application component and one DBMS and all of them are migrated to the Cloud with 5 VMs. In this test case, Migration Type IV is chosen for this application instead of Type III. The data layer and business layer are migrated to the Cloud. Specifically, the application server and RDBMS are selected to migrate to the Cloud with any of the available providers.

Table 5.5: Same Application with different Migration Types

Migration Types	**Type III**		**Type IV**	
Requirements	For application: CPU cores = 8, RAM = 8 GB, I/O = high, OS = Windows, App = 1000; Hour = 240 hours, Storage = 1000 GB, Month = 1 For DBMS: CPU cores = 8, RAM = 8 GB, I/O = high, Storage = 1000 GB, OS = Windows; Hour = 240 hours, Storage = 1000 GB, Month = 1			
Cloud Offerings	VM for application server	VM for DBMS	application server	RDBMS
Total Cost Range	\$768 - \$14900		\$1196.8 - \$7658.17	
Cost Range	\$153.6 - \$2980.0	\$153.6 - \$2980.0	\$230.4 - \$1620.6	\$275.2 - \$1175.77
Minimum Cost	xlarge by Windows Azure	xlarge by Windows Azure	xlarge by Windows Azure	xlarge on-demand standard deployment by AWS
Maximum Cost	Server8-8 by Flexiscale	Server8-8 by Flexiscale	xlarge search instance by AWS	sql Database by Windows Azure

The results of these two migrations are listed in Table 5.5. There are more than 40 candidate offerings for each migration type. Only the minimum and maximum costs are listed in this table with their offering's names and providers. Because the details of this payroll processing migration are not known, a set of requirements is identified casually but must be kept the same all the time during both of these migration types. The requirements of both candidate offerings search and cost calculator are listed in Table 5.5. Comparing with Type III and Type IV, it can be seen that with the same budget user can choose either VMs services or corresponding Cloud services. Even he chooses a corresponding Cloud offering, the result could not be over budget. In addition, user can also know the total minimum cost of his whole project between different migration types from the table. But it should be not forgotten that with different migration types the risks and any other problems during each migration process are not considered in MiDSuS. All the results are presented from the effective cost's respective that with the help of MiDSuS user can find the most effective cost and minimum cost of the whole project among different offerings combinations easily and directly. Furthermore, if user has a favorite provider or location of data center, MiDSuS is more helpful.

6 Conclusions

6.1 Summary

Some small or medium size enterprises who may have to face a shortage of funds or weak of against the loss during investment focus on Cloud services to reduce the cost and risks. In addition, more and more providers support various Cloud services in order to satisfy more customers' requirements. A migration decision support system which focuses on finding a trade-off between cost evaluation and performances prediction among these different Cloud services is very necessary to help user to find an efficient Cloud service.

First of all, some related works and researches are discussed as foundation in order to get a general understanding of the state of decision support for Cloud migration. There are many factors from both user side and provider side that can influence the final decision. It is clear to see that the decision process consists of many decisions according to comparisons between user's requirements and offerings' information. All these related decision support systems which were mentioned in this work focus on the performances comparisons and effective costs comparisons.

More specifically, this work is based on a foundational system called MDSS which achieved the match offerings selection and cost calculations with an interaction between user and system. The system discussed in this work is aimed to implement these functionalities as web APIs which are exposed as web services. These decision support services which are collected in a system called Nefolog achieve tasks such as candidate offerings search and total cost calculations. Nefolog works in conjunction with a Cloud provider knowledge base. This Cloud provider knowledge base contains more providers and more service types than MDSS. The functions which were already done in MDSS are re-engineered as services in Nefolog. As a result, the offerings matcher function is transplanted to Nefolog with a little change while the costs calculator function is completely rewritten. Each service in Nefolog has two representations, XML and JSON data format with related information.

Furthermore, these APIs can be used in a migration decision support system to achieve the data handler part which was implemented in MDSS. In this work, a migration decision support system called MiDSuS is implemented to support the decision making process. The frontend of MiDSuS is a friendly user interface which is built on JSP with Servlet. The migration project starts from migration type' selection. The migrated application is distributed by different migration types into application components or application layers. After that, the system collects the user's requirements of candidate offerings' search and a web service is used to achieve this search and lists all the candidate offerings with providers and performance information back to user. Next, the system summarized the user's requirements of usage amount of certain variables. With the help of the cost calculator web service, all the results which contains update dates, geographical areas of data center, total costs, upfront costs, service costs, data transfer costs and trends of costs in each month are calculated and summed for each configuration option. A user can use a type of ranking to decide which offering(s) is the appropriate one for him.

To validate the correctness and viability of Nefolog and MiDSuS, the results of Nefolog are compared with costs by PlanForCloud under the same input. To evaluate the MiDSuS, a use case in Appendix A.1 is implemented by different migration types and comparing with each type to demonstrate that with the help of MiDSuS user can find the effective cost for his migration project.

In the meantime, there are also some deficiencies and necessary improvements needed of MiDSuS. All these limitations and improvement suggestions are summarized in the following section and some of them may be useful and helpful for the future work.

6.2 Future Work

Firstly, the MiDSuS system lacks a dedicated knowledge base management system. It is known that technology is developing inconceivably fast. In order to meet customers' needs and survive in the competition, Cloud providers would provide much more favorable service pricing to get more customers from the other providers. For example, some providers launch free try events in a short time, if user selects these providers in that time, the cost will be lower than usually. In this case, the pricings of these Cloud offerings are changed often. If this decision support system is hoped to get a valid and valuable result, all data in database must be updated to the latest.

Secondly, there are various Cloud offerings in the market now that cover almost all service types. In future work, with the growth of database, more and more offerings will be increased into the database, the service types should be refined to get a more detailed management. The meticulous classification of services is essential. It supports more comparability with each offering which belongs to the same service type and provides more choices to user to select.

Thirdly, this system collects 16 performance characteristics for each offering to support a comparison with user's requirements. Actually, there are many other features which can be thought as a performance in this system. These features may not be abstracted directly, for example, trust, risk, etc. In addition, some of these features may play different roles with different users. For example, a user wants to choose a provider and he cares about what degree of risk the offerings have rather than what degree of trust reputation this provider is; but another one may be want to choose a good reputation provider in order to make sure that all his investments and stored data are in a safety statement. An additional design of this system should be considered that user's desires can also influenced the result of the decision and sometimes it may be stronger than the numerical information comparisons. This design should be built on a lot of data collections and case studies which focus on finding a way to represent these abstract features.

Fourthly, it can be considered that the desired performance characteristics as expressed by the user as requirements can also be dynamic [5]. It means that the storage capacities could be increased or decreased in each month. In the candidate offerings' requirements collection step of the further system, a requirement called also usage pattern can be added to expand this requirements collection into a dynamic situation.

Fifthly, MiDSuS system is now searching and calculating without login step. It means that the search results and calculation results of this user cannot be saved in this system. These results are refreshed and deleted after the migrated project is finished. It is better to add a login step in order to help user to compare with all his migrated projects with customized name and select the best one among them.

Finally, in the cost calculation step, MiDSuS suffers in performance time. It depends on the number of configurations. The calculation time for each normal configuration is 2 seconds (this configuration has only one data center) to 5 seconds (this configuration has more than one geographical areas of data center). It means the more configuration user selects the more slowly system runs. A solution is possible that each selected configurations can be assigned with one thread. It means that system could calculate each configuration's cost parallelly. In MDSS, the trend of cost is shown in a diagram with spline. It is more clearly than a list in MiDSuS which contains costs of each month. It can be improved by the further work.

Appendix

A.1 Use Case of Applications on Cloud

Table A.1: Application Migration Use Cases

		Service Type											
Application	**Use Case Documentation**	Application	Web Site	SQL DB	NoSQL DB	Block Storage	Object Storage	Archive Storage	Caching	Infrastructure	Monitoring	Network	DNS
Payroll Processing	[8]			A		A	A	A		Y			
Logistics & Project Management	[8]	Y			Y	A	A	A					
Central Government Services	[8]									A		Y	
Local Government Services	[8]	Y								Y			
Astronomic Data Processing	[8]			Y		Y		Y		A			
Application testing	[25]									Y			
Application contingency	[25]									Y		A	
”Big” data processing	[25]						A			Y			
Abaca	[32]									Y			
Banro	[33]						Y			Y			

Table A.1 – continued from previous page

		Service Type											
Application	**Use Case Documentation**	Application	Web Site	SQL DB	NoSQL DB	Block Storage	Object Storage	Archive Storage	Caching	Infrastructure	Monitoring	Network	DNS
Global Blue	[34]						Y			Y			
gumi	[20]			Y			Y			Y			
HashCube	[35]						Y			Y			
Holiday Extras	[21]			Y									
HostedFTP	[36]					Y	Y			Y			
Hotelogix	[37]			A		Y				Y	Y		
ibay365	[38]						Y			Y			
Ice.com	[23]					Y	Y			Y	Y		
Infostrada Sports Group	[39]					Y	Y			Y	Y		
Data Mining	[40]									Y			
Walsh Group	[41]									Y			
Essex County Council	[22]			Y									
Kaggle	[42]	Y				Y							

Table A.2: Mapping of Application Migration Use Cases to Migration Types

Application	**Initial Topology**	**Migrated Topology**	**Migration Type**
Payroll Processing	1 Application & 1 DBMS	1 Application in 4VMs (concurrent); 1 DBMS in 1 VM	III

Table A.2 – continued from previous page

Application	Initial Topology	Migrated Topology	Migration Type
Logistics & Project Management	a combination of Quickbooks and spreadsheets	1 client-side application; data in GAE datastore	I
Central Government Services	back office systems & front office systems	1 Cloud infrastructure built on a private network	I
Local Government Services	1800 local governments, each has its own servers and IT staff	internal tasks and some data in the private Cloud; other data locally	I
Astronomic Data Processing	AGIS software & DBMS	1 DBMS in 1 VM; AGIS in VMs; Storage in 5 Cloud-based storage volumes	III
Application testing	VM locally	VM in Cloud	I/III
Application contingency	main site	contingency can be processed by cloud infrastructure	I
”Big” data processing	massive amounts of data	parallel processing can be done by the Cloud servers/services which based on tools for big data tasks	I/II
Abaca	servers locally	Amazon EC2 for computing power to solve the requesets for highly-efficient spam filter	I
Banro	ERP & workflow systems & email systems & data warehouse & reporting tools	8 full-time instances ranging from m1.small to m2.2xlarge as an offshore data center solution; Amazon S3 as offsite backups	I
Global Blue	products system	web site and development environments are hosted on Cloud	I

Table A.2 – continued from previous page

Application	Initial Topology	Migrated Topology	Migration Type
gumi	Web server & database server	all services on AWS; local static images store	I/II
HashCube		Website's traffic on Amazon EC2; customer and user information on Amazon S3	I
Holiday Extras	10 quad core blade web servers & 2 1-TB MySQL databases on the back-end	12 web servers; 1 Amazon RDS; a small number of memcached instances; 10 ELBs	I
HostedFTP	web-based file sharing system in several co-location facilities	customer files on S3; website and database on EC2; codebase on EBS	IV
Hotelogix		2 Amazon EC2 instances with Amazon CloudWatch; 1 EBS; local instance store	I/II
ibay365		database, web services and cache on EC2; users' products and images on S3; Elastic Load Balancing	I/II
Ice.com	1 e-commerce system including 1 new web store application & 1 ERP system & 1 CMS & 1 BI platform	e-commerce site & mobile site & ERP & CMS & BI systems & social loyalty program on EC2, backed up on EBS; static HTML & images & backups on S3; CloudWatch to deliver information on the company's servers and data	I/II

Table A.2 – continued from previous page

Application	**Initial Topology**	**Migrated Topology**	**Migration Type**
Infostrada Sports Group		2 EC2 for admin machines & web nodes; EBS for local data storage; S3 for static content; CloudWatch for delivering	I/II
Data Mining	substantial hardware	VM	III
Walsh Group	100 physical servers in Chicago data center & 24 in regional offices & 200 at job sites	150 VMs across 10 data center; server count from 324 to 262	III
Essex County Council	application on Microsoft Excel spreadsheet software	application on SQL Database	I
Kaggle		application code on cloud services; blob storage	I

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I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

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