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Corporate Decision-Making for the Adoption of Cloud Computing: Economic and Organizational Factors

Jacques Bou Abdo

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Prise de décision commerciale pour
l'adoption du cloud computing:
facteurs économiques et
organisationnels
*Corporate Decision-Making for the Adoption
of Cloud Computing: Economic and
Organizational Factors*

Thèse de doctorat de l'Université Paris-Saclay

École doctorale n°630, Droit Economie Management (DEM)

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Above all, I am thankful for God's grace.

Ad maiorem Dei gloriam

Titre: Prise de décision commerciale pour l'adoption du cloud computing: facteurs économiques et organisationnels

Mots clés: Modèles économiques, Cloud Computing, Filtrage collaboratif, Solutions d'aide à la décision, Technologies de rupture, Réseaux mobiles, Économie de réseau, Systèmes de recommandation, Adoption de la technologie, 5G et au-delà

Résumé: L'admission des technologies disruptives est une décision assez cruciale et délicate qui affecte la survie et la continuité des entreprises, startups et multinationales. Cette décision est considérée par de nombreux chercheurs et décideurs comme étant un jugement que chaque organisation devrait juger et décider. La question qui se pose est la suivante : les organisations, sont-elles vraiment libres de décider d'adopter ou non une technologie spécifique ? En fait, de nombreuses organisations n'ont pas la concession d'imposer leurs besoins aux fournisseurs, leurs services aux clients, ou leurs modèles commerciaux aux concurrents. Dans ce travail, nous étudions, à deux niveaux, la décision des organisations en ce qui concerne l'adoption des technologies de rupture. En premier lieu, nous considérons les forces économiques (forces externes) qui influencent la décision des organisations. Ainsi, nous examinons minutieusement la réponse du marché aux technologies de rupture. En deuxième lieu, nous considérons les forces organisationnelles (forces internes) affectant la décision des organisations, et nous étudions soigneusement les besoins et la préparation des organisations pour une technologie de rupture. Ce travail considère le cloud computing comme la technologie disruptive étudiée et concentre sa contribution sur l'admission du cloud computing par les organisations. Au niveau organisationnel, une solution d'aide à la décision est conçue à l'aide des systèmes de recommandation de filtrage collaboratif. Cette solution vise à aider les décideurs à évaluer leurs besoins organisationnels et à choisir de façon optimale l'ensemble des technologies adaptées aux besoins de leurs organisations. Au niveau économique, les facteurs économiques sont modélisés à l'aide de la modélisation à base d'agents. Nous considérons l'adoption du cloud computing dans les réseaux mobiles 5G comme un cas spécifique d'admission du cloud. Cette spécification est nécessaire pour permettre une modélisation précise des facteurs économiques. Deux scénarios sont envisagés, le premier suppose une concurrence parfaite sur le marché de la 5G, alors que le second assume un marché oligopolistique.

Title: Corporate Decision-Making for the Adoption of Cloud Computing: Economic and Organizational Factors

Keywords: Business models, cloud computing, collaborative filtering, decision support solutions, disruptive technologies, mobile networks, network economics, recommender systems, technology adoption, 5G & Beyond

Abstract: The adoption of disruptive technologies is a very critical decision affecting the survival and continuity of businesses, startups to multinationals. Many researchers and decision makers consider technology adoption as a decision each organization should evaluate and decide upon. But are organizations really free to decide whether to adopt a specific technology or not? Many businesses do not have the privilege to dictate its needs to vendors, its services to customers or its business models to competitors. In this work we study the organization's decision on disruptive technology adoption at two levels. In the first level, we consider the economic forces (external forces) affecting the organization's decision. More thoroughly, we look at the market's response to disruptive technologies. In the second level, we consider the organizational forces (internal forces) affecting the organization's decision. More thoroughly, we look at the organization's needs and readiness for a disruptive technology. This work considers cloud computing as the studied disruptive technology and focuses its contribution on cloud computing adoption. In the organizational level, a Decision Support Solution is designed using collaborative filtering recommender systems to help decision makers evaluate their organizational needs and decide on the optimal technology mix suitable for their organization. In the economic level, the economic factors are modeled using Agent-Based Modeling. We consider cloud computing adoption in the 5G mobile networks as a specific case of cloud adoption. This specification is needed to allow accurate modeling of the economic factors. Two scenarios are considered, the first assumes perfect competition in the 5G market and the second assumes an oligopolistic market.



Contents

Introduction	1
Background on Cloud Computing	3
Chapter Abstracts	11
1 Methodology	13
1.1 Introduction	13
1.2 Research Project	23
1.2.1 Project-related previous contributions	23
1.2.2 CBOD Objectives and Tasks	23
1.2.3 Objectives	25
1.3 General discussion	26
1.4 Epistemology	30
2 Decision Support Solution for Cloud Computing Adoption	39
2.1 Introduction	40
2.2 Background	41
2.2.1 Decision support solution	41
2.2.2 Legacy technology adoption models	47
2.3 Related Work	49
2.4 Design Constraint	53
2.5 Design	55
2.5.1 Determinants	55
2.5.2 DSS objectives	57
2.5.3 Components	57
2.5.4 Design	58

2.5.5	Auto-learning and Self-correcting	61
2.5.6	Fine-tuning algorithm	62
2.5.7	Data quality	62
2.6	Collected Data	65
2.7	Evaluation	68
2.8	Summary	68
	Appendix - A: Active Learning Questions	69
	Appendix - B: Accuracy metrics for recommender systems	72
3	The Network Economics of Cloud Computing	77
3.1	Introduction	78
3.2	Literature Review	80
3.2.1	Traditional EPC vs. vEPC	80
3.2.2	EPCaaS and Multi-tenancy	82
3.2.3	Pricing scheme	84
3.3	Proposed Approach and Evaluation	93
3.3.1	Expected scenario	93
3.3.2	Proposed approach and metrics	94
3.3.3	Metrics	100
3.3.4	Evaluation	100
3.4	Conclusion and Future Challenges	103
	Appendix	104
4	The Oligopoly of Cloud Computing	131
4.1	Introduction	131
4.2	Research Background	132
4.2.1	Dynamics of oligopoly	133
4.2.2	Game theory	136
4.3	Research Framework	137
4.4	Literature Review	138
4.5	Oligopoly of Cloud Computing	140
4.5.1	Oligopoly of Cloud Computing: elastic demand use case	141
4.5.2	Oligopoly of Cloud Computing: inelastic demand use case	145

4.6 Conclusion and Future Work	146
Appendix	149
5 General Discussion	167
5.1 Introduction	167
5.2 Impact on Literature	169
5.3 Impact on Managerial Practices	171
5.4 Future Research Design	173
5.4.1 Simulation using system dynamics	173
5.4.2 Optimizing the recommender system	173
5.4.3 Investment and time series	174
5.4.4 Oligopoly models	174
6 Conclusion	175
6.1 Contributions	178
6.1.1 Generic and vendor-neutral decision support solution for cloud computing adoption	178
6.1.2 Modeling 5G networks under perfect competition conditions	178
6.1.3 Modeling 5G networks under oligopolistic conditions	179
6.2 Limitations	179
6.2.1 Cold-Start problem	179
6.2.2 Recommender system	180
6.2.3 Parameter fine-tuning	180
References	181

List of Figures

0.1	Cloud stack (Well-known layers).	8
0.2	Mobile Cloud computing (MCC).	11
1.1	Cloud adoption literature.	15
1.2	Focus Areas.	19
1.3	Objectives.	26
1.4	Systematic analysis of cloud adoption approaches.	27
1.5	Systematic analysis of blockchain adoption approaches.	29
1.6	Cloud adoption approaches vs. Cloud adoption risk.	30
1.7	Relationships of science and technology with truth and utility.	33
1.8	The epistemological orientations used in management research (inspired from [1]).	35
2.1	Decision-Making Process.	42
2.2	Conceptual Overview of the Architecture of DSS.	44
2.3	Technology Adoption Model.	48
2.4	Technology – Organization – Environment Framework.	49
2.5	DeLone and McLean IS Success Model.	50
2.6	The proposed DSS' message flow diagram.	59
2.7	Flowchart of the processing operation i.e. to select the closest 3 technologies.	60
2.8	Fine-tuning algorithm flowchart.	63
2.9	Distribution of respondents by position.	65
2.10	Distribution of respondents by market sector.	66
2.11	Distribution of respondents by company size.	66
2.12	Distribution of respondents by company age.	67
2.13	Technology mixes selected by respondents.	67

2.14 Evaluation of the recommendation's accuracy Using Predictive Accuracy Metrics - MAE	68
3.1 Scenario.	94
3.2 Outcome 1: All legacy mobile operators driven out of business with the final user cost exceeding the initial cost.	102
3.3 Outcome 2: All legacy mobile operators driven out of business with the final user cost less than the initial cost.	125
3.4 Outcome 3: Co-existence between legacy and cloud-based mobile operators. Some of the legacy and cloud-based operators left the market.	126
3.5 Outcome 4: Cloud-based mobile operators join the market and leave later because of competition from the legacy mobile operators.	127
3.6 Simulator's Main View.	128
3.7 First Sample Round.	128
3.8 Fifth Sample Round.	129
3.9 Twentieth Sample Round.	129
4.1 Oligopolistic equilibrium with legacy operators out of business (cloud-based operators have the same operational cost which is lower than that of legacy operators for the considered number of clients).	146
4.2 Oligopolistic equilibrium with cloud-based operators out of business (cloud-based operators have the same operational cost which is higher than that of legacy operators for the considered number of clients).	147
4.3 Oligopolistic equilibrium ending up in monopoly.	148

List of Tables

0.1	Advantages and disadvantages of cloud computing.	5
1.1	Previous contributions to CBOD objectives and tasks	25
1.2	Blockchain selection schemes	28
2.1	Chapter 2 contributions to CBOD objectives and tasks	69
2.3	Confusion Matrix Used in Recommender Systems	74
2.2	Details of the Predictive Accuracy Metrics	75
2.4	Details of the Classification Accuracy Metrics Used in this Study	76
3.1	Related Works	88
3.2	Chapter 3 contributions to CBOD objectives and tasks	104
4.1	Chapter 4 contributions to CBOD objectives and tasks	149
6.1	Chapter 5 contributions to CBOD objectives and tasks	177

Introduction

Technology is a driving force for current businesses and is among the key decisions and investments directly supervised by the senior executives. Correct decisions help businesses thrive while wrong ones can dramatically limit an organization's competitiveness and possibly lead it to bankruptcy. The history is full of companies that gambled on technologies that were proven to be a big success and others that took decisions we currently consider as very short-sighted.

Large organizations are searching the industry for technologies developed by startups and small companies that can complement their arsenal of services and technologies. Those startups and small companies receive generous offers for acquisition in the hope that their technologies offer market superiority for the buyer. Venture capitals, incubators, and angel investors are also on the hunt for promising technologies, ideas, or services that will become disruptive.

Selecting winner technologies is a tedious task, contains many ambiguities and variables, and is relatively not very accurate. The literature does not propose any successful formula and the decision relies on organizational learning. Epistemologically, the organization cannot know a winner technology ahead of time but can use existing evidence, predictions, statistics, surveys, and other techniques to justify its belief in the correctness of its decision. Dodgeball is an example of a service acquired by Google and then completely discontinued after 4 years.

The majority of emerging technologies will have slight impact and marginal market penetration, and will not mature into becoming a mainstream technology. Business

executives, in contrary to legislators, have to assess all emerging technologies, thus spending their limited resources on failing technologies, and this sometimes leads them to overlook real disruptive technologies and thus risk becoming late adopters. Although late adoption eliminates many of emerging technologies' intrinsic risks but also eliminates a considerable portion of the profit margin.

Cloud computing is a typical disruptive technology that divides the market as adopter vs. non-adopter and the adopters themselves are divided by the type of cloud selected. The meaningful division, due to cloud computing, is success vs. failure. Selecting whether or not to adopt cloud computing is just a meaningless question if not associated with its impact on the organization's success. An organization's success depends on internal and external factors, thus the decision to adopt a certain technology is not trivial and does not rely on the organization's internal state, but rather on the market's future opportunities and dynamics.

The literature addressed organizational cloud computing adoption using two different and distinct approaches. The first approach considered the internal factors preparing an organization to adopt cloud computing and determining which type is most convenient. The second approach considered the external factors that set the market price and service standard. In this thesis, we covered both approaches to provide a more complete answer. This work has been applied to cloud computing but can be extended to other emerging and disruptive technologies such as blockchain.

Blockchain is the technology supporting many applications in financial, healthcare, and IoT sectors, but the most famous among all is the bitcoin. Unknown participants can agree on the state of the blockchain using a consensus algorithm. The agreed upon state is the generated block which contains the submitted transactions. **"Blockchain companies' funding grew by 10 times from 2013 till 2016"**[2]. This growth in funding will dramatically accelerate the speed of blockchain application development. Blockchain is an appealing technology that attracted a lot of interest from fans, investors, activists, businesses, and academics. It enables mutually distrusted entities to conduct a variety of transactions without relying on a central authority, while also providing integrity-protected data storage. With all this hype surrounding blockchain, it is not always convenient to adopt it, technically and economically [2].

We will start this work by introducing cloud computing as the case study technology used throughout the manuscript.

Background on Cloud Computing

Nowadays, business owners are faced with building and managing complex Information Technology (IT) infrastructures. They are supposed to be able to install a variety of software and applications, and configure, and upgrade them. However, IT resources may become obsolete over time. Therefore, cloud computing (CC) becomes an attractive paradigm for business owners since it allows them to deal with complex IT infrastructures by using outsourced cloud computing platforms. In cloud computing, Information Technologies (ITs) capabilities are moved away from personal computers and mobile devices towards a remote cloud. Its main concept is to allow users and businesses to increase and release rapidly their computing and storage resources, in real-time, without the need to investigate new infrastructure, or train new personnel, or buy a new software.

Many definitions for cloud computing can be found in literature, each trying to give a complete and specific explanation of what this technology is all about. We start by surveying these definitions and then give our own based on the lessons learned. Cloud computing is:

- "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction." [3].
- "a parallel and distributed computing system consisting of a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on Service-Level Agreements (SLA) established through negotiation between the service provider and consumers." [4], [5].
- "a large pool of easily usable and accessible virtualized resources (such as hardware,

development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized Service Level Agreements." [5], [6].

- "hardware-based service offering compute, network, and storage capacity where: Hardware management is highly abstracted from the buyer, buyers incur infrastructure costs as variable OPEX, and infrastructure capacity is highly elastic." [5], [7].

Cloud computing can be better described by two complementary definitions, one conveying the user's perspective, and the other conveying the provider's perspective. So, we define Cloud computing to be:

- "Online, infinite-like, easily provisioned and pay-as-you-go resource pool that are bound by SLAs." [8]
- "Pool of resource under the management of a centralized entity that is capable of dynamically provisioning it." [8]

The last component to define is the "Cloud Manager". It provides higher-level functionalities such as authentication [9]. It also includes the federation manager [10], which performs the following abstracted operations:

- Selecting a foreign cloud provider and performing the abstraction procedures needed for having the foreign IdP (Identity Provider) trusted by the client's IdP which is necessary for establishing a secure connection.
- Transferring the Virtual Machines and extending the hypervisor.

The adoption of CC has a lot of benefits. The user can offload her job (computation, storage, etc.) to the Cloud to decrease the utilization at his local devices and to get additional functionalities he doesn't have locally. CC allows businesses to avoid up-front infrastructure investment. It provides customers with limitless computing resources that

are available on demand, removing the need for resource provisioning planning. It also enables businesses to start small and scale up their hardware resources just as their demands grow. Users can pay for computing resources on a short-term basis (hourly processing, daily storage) and release them as needed with CC. There are no upfront costs, and software upgrades are automated. Because Cloud customers do not have to acquire hardware or license software, the expense and complexity of owning and operating computers and networks is minimized. All the information and applications on the Cloud are mobile accessible and they can be accessed remotely.

TABLE 0.1 – Advantages and disadvantages of cloud computing.

Advantages	Disadvantages
Thin clients	Always online
Compatibility	High-speed connection
Lower IT costs	Limited features
Fewer maintenance	Data confidentiality
Software patching	Data availability
Computation/Storage on-demand	
Easier Collaboration	
Access to Documents	

The advantages and disadvantages of CC as described in [11] are summarized in Table 0.1.

Deployment models

The Cloud infrastructure supports four deployment models: public, private, hybrid, and Community [12], [13].

- **Public:** It is the dominant Cloud model. It is provided for the use by the general public. The Cloud service provider *"is the owner of the Cloud and anyone can access its services through web interfaces"*[14]. Thus, Cloud customers have no control over the location of the Cloud. The most common uses of Public Clouds are for application development and testing, file-sharing, web applications, email service, etc. The Public Cloud is adopted by many popular Cloud providers. One can cite IBM, Amazon EC2, Microsoft Azure, and Google App Engine. The Public Cloud has the advantage to be flexible, reliable, highly scalable, allows easy access to data, and

cost-effective. ***"However, it is less secured: among all the Cloud deployment models, the Public Cloud poses the major security issues [15], [16]"[14].***

- **Private:** The private Cloud, also called "Internal Cloud", is a Cloud model provided for the use within a single organization. It is owned and managed either by the organization itself or by the Cloud Service Provider, or by some combination of both of them. Within this Cloud infrastructure, only authorized users within the organization have access to the Cloud resources and applications. This provides the organization with a high control level over its data and resources. The Private Cloud infrastructure is suitable for the business societies that have high-security requirements, and dynamic and critical management demands. The Private Cloud is the best Cloud model to deal with the security and privacy issues of the organizations adopting Cloud technology. ***"Unlike the Public Cloud, the Private Cloud is highly secured and it is control-oriented. It has more control over its resources as these later can only be accessed within the organization boundaries."[14].*** Despite all its benefits, the Private Cloud model is less scalable than the Public Cloud, and it is very expensive to be maintained and managed [17], [18].
- **Hybrid:** It is a mix of several distinct Cloud infrastructures. It is a single architecture that combines different interconnected public, private, and community Clouds. ***"In fact, Clouds must be used in conjunction with each other. For instance, an organization may use a Public Cloud to perform non-critical tasks, whereas crucial tasks such as data processing and storage are carried out in a Private Cloud. A Hybrid Cloud has the advantage of being flexible, scalable, cost-effective, and more secure than the Public Cloud [17], [18]."***[14]
- **Community:** ***"A Cloud of type community is a collaborative and shared Cloud computing system. It is provided for the use by a particular group of Cloud consumers belonging to several organizations that have common concerns, such as banks, commercial enterprises, universities, police departments, etc. It is owned and managed by one or more organizations belonging to the community, or by the Cloud Service Provider, or by some combination of both of them. The access to the data and resources within the Community Cloud is restricted to the users belonging to the community [17],[18]."***[14]

Service models

"The Cloud architecture stack is composed of main layers such as SaaS (Software as a Service), PaaS (Platform as a Service), and IaaS (Infrastructure as a Service) [19], as shown in Figure 0.1, and additional supporting layers, such as PasS [20]"[21] and HuaaS [19].

- **Software as a Service (SaaS):** is a web-based application interface where the end-users have the capability to access applications and software hosted on the Cloud premises. These applications are provided to end-users via the Internet, and are accessible via a web interface. The provided software and applications are installed, maintained, and upgraded remotely by the Cloud Service Provider on its own data center. This allows the end-users to get rid of buying software licenses, and installing, controlling, and upgrading the software on their computers. Google Docs, Microsoft Office 365 and Salesforce.com are some of the well-known SaaS providers.
- **Platform as a Service (PaaS):** is a platform on which software and applications can be directly developed and hosted. PaaS provides libraries allowing its users to develop better applications faster. Unlike SaaS where the Cloud users have at their disposal "ready to use" software, PaaS provides the users with opportunities to design, develop, test, and deploy their own software, thus, providing them the ability to control their software lifecycle. Examples of PaaS providers include Google AppEngine and Windows Azure.
- **Infrastructure as a Service (IaaS):** IaaS is the Cloud stack's lowest layer responsible for on-demand provisioning of servers [5]. *"It consists of providing the Cloud users several computing, storage, and network resources using which the users can deploy their code and run their own applications"*[14]. IBM, Amazon Web Services, S3 (Secure Storage Service), and HP Public Cloud are examples of IaaS providers. VRS (Virtual Resource Set) and PRS (Physical Resource Set) [5] are two services offered at this layer. The first is hardware dependent and creates, for the second, an abstraction layer. The second is hardware-independent and its role is to track the running applications. Hypervisor, one of the VRS technologies, is a widely used technology. both layers are shown in Figure 0.1.

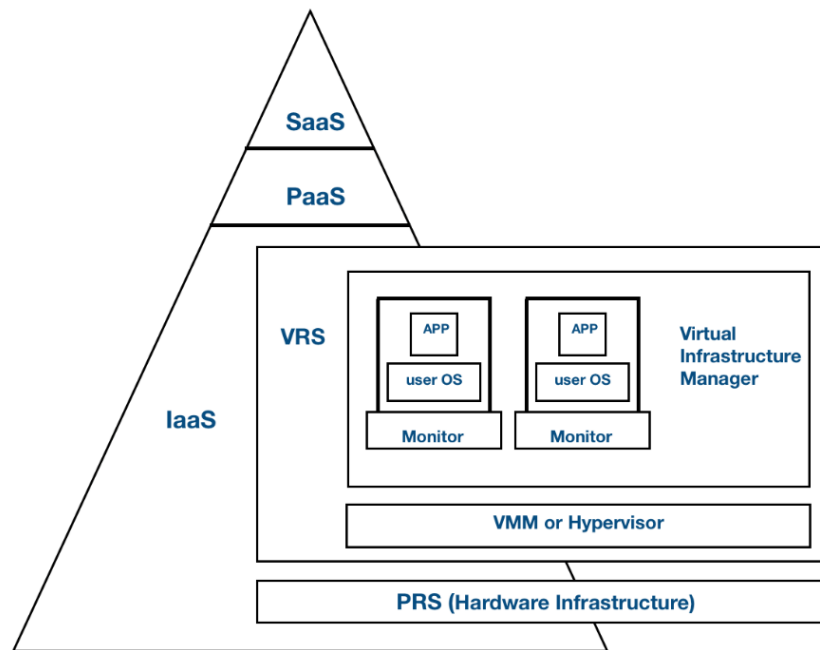


FIGURE 0.1 – Cloud stack (Well-known layers).

Issues

Cloud computing adopters experience the following issues in variable extents.

- Data availability:** One of the main issues in Cloud computing environments is data availability. It is a critical Cloud requirement that needs to be achieved to meet the users' needs. Thus, different techniques have to be applied by the Cloud Service Provider in order to ensure that data is available and easy and quickly accessible by the end-users, even with the increasing number of Cloud users, or in the case of network failure. Data availability can be guaranteed by implementing data storage redundancy, data security policies, and network optimization.
- Data security:** Cloud computing saves time and money, but trusting the system is a top priority. Data security is one of the most significant roadblocks in Cloud computing. As a result, data security in Cloud computing is a major concern. It is vital to preserve and secure the security of the data kept in the Cloud in order to assure the Cloud's dependability and the users' confidence in this environment. The deployment model, as well as the data protection and prevention mechanisms deployed, determine the level of trust in a Cloud context. In a public cloud deployment, data access control is delegated to the infrastructure owner, who is responsible for defining a security

policy. The integrity, anonymity, and confidentiality of data on the Cloud are all aspects of data security. The goal of data integrity preservation is to prevent illegal data deletion, alteration, or fabrication. Database restrictions and transactions are used in conjunction with a database management system to accomplish this. When users' private data is kept in the Cloud, the security of such data becomes critical in order to boost the Cloud's dependability. Authentication and access control measures, data encryption, and data storage distribution can all help to ensure data confidentiality.

- **Costing model:** The cost dimension is based on several factors. It is defined according to the service provided, the rental period of the service, the quality of the service, the cost of maintenance, the age of the resources, and the investment cost of the service provider [22].
- **Lock-in:** It is one of the principal constraints of the Cloud environment. It concerns the cost of services mobility between different Clouds. Some businesses are hesitant to use Cloud computing because it is difficult to extract and move data and services from one Cloud to another. When using Cloud services, this risk should be taken into account.
- **Platform control:** Businesses are generally wary of the Cloud environment. In fact, unlike the Cloud providers who can concept and change their platforms when and how they want and without the consent of the customers, companies are unable to change the technology of their platforms when they need it. Besides, the conception of Cloud platforms does not depend on business-specific IT and business practices, which will limit the appeal of Cloud computing.
- **Business domain:** This criterion refers to companies adopting the Cloud computing solution. It is the strategy used by the company to manage its resources and to offer the market the best services and products that its competitors. A good business model of an enterprise is supposed to define the customers, their needs and appreciated services, as well as the strategy to be adopted to earn money while offering the customers the services and products at appropriate costs [23].

- **Disaster recovery:** Cloud disaster recovery is an important feature of the Cloud computing systems. It allows to backup and to restore the data of the users in disaster cases. It consists of storing several electronic copies of the users' data stored in the Cloud.

Latest Applications

Cloud computing refers to a set of services delivered via the internet. Cloud computing's primary technology is the centralization of computer processing, services, and specialized applications. In Mobile Cloud computing (MCC), thin mobile devices can request cloud services through the mobile network. Virtually any service that can be developed on the mobile device can be extended to the cloud. As shown in Figure 0.2, MCC is the combination of Cloud computing and Mobile Computing.

Huerta-Canepa and Lee [24] define Mobile Cloud as a group of mobile devices in close proximity that are all interested in processing the same data. In this instance, the processing costs (battery power and CPU cycles) will be shared among the participating devices, allowing the mobile Cloud to achieve its objectives. Mobile Cloud is divisive because we want a single architecture to be sufficient for all mobile apps while also reducing power consumption in mobile devices and, most crucially, being inexpensive. There was no architecture in the literature that could meet the aforementioned criteria, and none of them were standardized.

Mobile Cloud computing has been understood differently by the research community and this explains the deep difference in defining this technology and designing its architectures. To give a generalized definition that includes all points of view and architectures, it should be abstract and doesn't specify detailed features. For this reason, we define mobile Cloud computing as: "A technology which allows the user to access Cloud services through mobile devices".

MCC provides a lot of benefits. It allows compute and data storage to be moved from mobile devices to the cloud. It overcomes mobile devices' constraints, particularly their processing power and data storage capacity. MCC also allows you to increase the battery life of your mobile device by transferring the computation-intensive application

to the cloud. Finally, it enables the delivery of e-payment services.

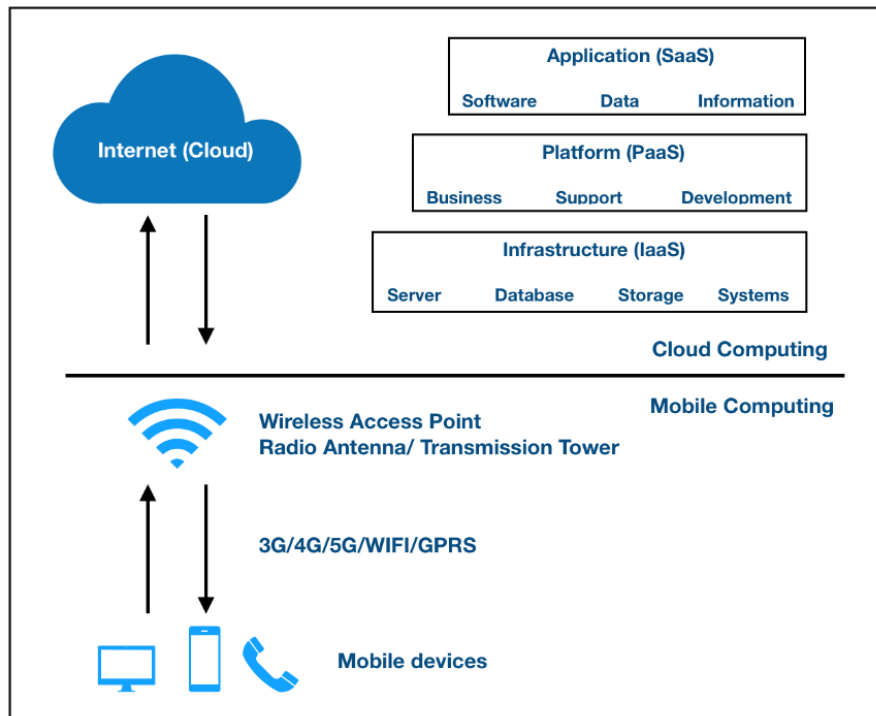


FIGURE 0.2 – Mobile Cloud computing (MCC).

Chapter Abstracts

• Chapter 1 - Methodology

This chapter identifies the research gap addressed in this work. A systematic survey is performed, and the literature is critically analyzed. The research objectives are clearly stated and articulated in alignment with the funding research project. Finally, the epistemological orientation for this work is specified and argued in comparison with the available epistemological orientations.

• Chapter 2 - Decision Support Solution for Cloud Computing Adoption

"Selecting the technologies suitable for an organization is a very critical and difficult task especially in the absence of historical data. Organizations have to outsource expensive cloud experts to design their technology mix and help them set their strategy. Vendors' experts can help organizations but with the expense of less network optimization and more vendor

lock-in. This chapter presents a generic and vendor-neutral decision support solution that aids decision-makers in setting their strategy towards cloud computing. The novelty of this proposed solution is based on its decision algorithm that uses the Collaborative Filtering Recommender System to enhance its accuracy in selecting the suitable/recommended technologies for each user." [25]

- **Chapter 3 - The Network Economics of Cloud Computing**

The literature around cloud computing adoption hasn't considered the variable effects of the market factors and this made researchers propose a relationship between organizational factors and suitable cloud technologies. In this chapter, we showed the effect of market factors on the suitability of cloud computing and proved that direct relationships between organizational factors and suitable cloud technologies are not very accurate. This reinforced our contribution in Chapter 2 by using recommender systems to match between organizational needs and cloud technologies. We used agent-based modeling to simulate the market and predict the interaction between players and finally predicting the emergent market behavior.

- **Chapter 4 - The Oligopoly of Cloud Computing**

In this chapter, we evaluated the market behavior under oligopolistic conditions. Two cases were considered the elastic and inelastic demands for cloud services. For the first case, the market stability was modeled mathematically where legacy mobile operators have a limited capacity inherited from the nature of their infrastructures, while cloud-based mobile operators are free from this constraint. The market behavior of the second case was modeled using Agent-Based-Modeling.

- **Chapter 5 - General Discussion**

In this chapter, our contributions are transversally discussed and put into a broader context of scientific literature and managerial practice development. In this chapter, we also positioned our orientation for future work.

- **Chapter 6 - Conclusions**

In this chapter, we concluded this work and specified its contributions and limitations.

Chapter 1

Methodology

Contents

1.1 Introduction	13
1.2 Research Project	23
1.2.1 Project-related previous contributions	23
1.2.2 CBOD Objectives and Tasks	23
1.2.3 Objectives	25
1.3 General discussion	26
1.4 Epistemology	30

1.1 Introduction

Cloud computing can be represented by a three-layer business model framework [26] where each layer is related to one of its core services which are Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). More advanced and complex business models evolved to respond to the new features of cloud computing such as cloud federation [27]. Such business models could be evaluated as a chain of transactions each based on one of the layers of cloud’s business model framework mentioned above. In

the case of broker-based [21] or peer-based federation, new and more complex business models are needed [28] [29], [30].

Cloud computing, like all disruptive and legacy technologies, is susceptible to failures and downtime thus considering adopting it involves risk [31], sophisticated contracts [32] and complex decision-making process [33]. Naldi [34] evaluated customer losses due to cloud outages and proposed a loss model for customers using the cloud. Mastroeni and Naldi [31] then calculated the price of insurance premiums covering cloud outages. They also calculated the refund to equate customer's value-at-risk, insurance premium and Naldi's loss model. The insurance premium is recalculated in [35] to include new outage models and QoS metrics. An important requirement for enforcing the insurance policy is a trusted and agreed upon outage measuring mechanism. It has been claimed by Naldi [36] that the statistical accuracy of the measurement mechanisms included in cloud monitoring systems, "is often neglected. Such measurements may therefore be useless in SLA-related disputes between cloud providers and customers" [36]. Adiani and Naldi [37] and Naldi [38] proposed a procedure to identify the failures actually due to the cloud itself and provide a correct cloud availability measure.

Adopting cloud computing, and other disruptive technologies, is a core decision that should be taken at the highest corporate levels because it can lead to unexpected losses if not bankruptcy. The severity of the decision's consequences and the value-at-risk motivated researchers to help decision-makers select the suitable technology. The literature is divided into two distinct methodologies for deciding on the adoption of cloud computing. The first methodology relies on questionnaires sent to experts and decision-makers to extract a set of determinants for cloud computing adoption. The literature has lately shown weaknesses in this methodology such as in [39] [40] [41]. The second methodology relies on modeling the market dynamics and predicting the success of the adoption. The second methodology is becoming the dominant in recent years as shown in Figure 1.1.

In the first methodology, researchers tried to identify all the determinants that affect cloud's business models in order to design a realistic model for a viable process. Including all the determinants in a business model is not a guarantee for success. Youssef et al. [42] relied on questionnaire to measure organizations' willingness to adopt cloud

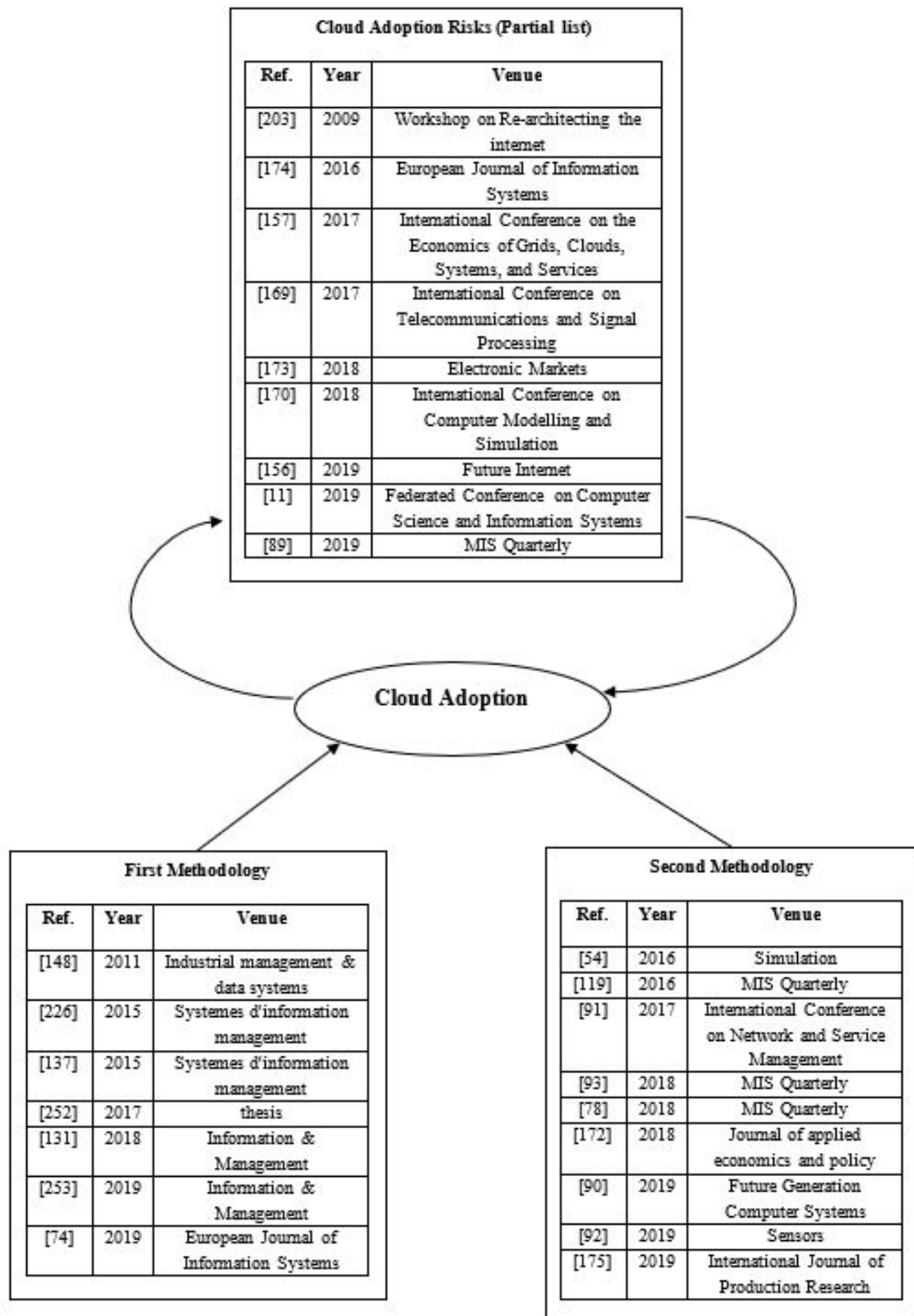


FIGURE 1.1 – Cloud adoption literature.

computing. They based their research on two strands, the first exploring the determinants for cloud computing adoption. The second strand focuses on the special role of technological

absorptive capacity in IT adoption, where cloud computing is found to increase the propensity in emerging countries to innovate and to adopt newer innovations at lower cost. Tran and Bertin [43] proposed an original theoretical typology of the relationships between Information System (IS) and their stakeholders. They focused on the relational modalities between the IT department, the business departments, software editors and online service providers. Four models were proposed which are: IS as product, service, access, and platform. Lang et al. [44] determined the criteria for selecting cloud service providers using a Delphi study. This study relied on 16 professionals to rank QoS importance to companies with different characteristics. Zhang and Ravishankar [45] studied the vendor capabilities in the cloud environment. They found that the five important capabilities provided by Alibaba, china's major IaaS provider, are cloud platform development, cloud platform deployment, IaaS imitation, IaaS commercialization, and IaaS improvement. They also expected that these capabilities are central to the adoption of cloud computing. Leroux and Pupion [46] also relied on 61 CIOs from the French market to design synthetic model for the adoption of cloud computing by local authorities. Fahmideh et al. [47] proposed a generic cloud migration process model which uses a metamodeling approach. They relied on domain experts to evaluate and refine their model. Khalil et al. [48] found that even if companies want to adopt cloud computing, they cannot have successful adoption unless they achieve improved communication between their IT and business departments. Improved communication can be considered as a requirement for successful adoption as confirmed by Fautrero et al. [49].

Biases influence the experts' recommendations (especially if they are affiliated with vendors), decision-makers' answers (it has been shown by [39] that decision-makers change their perception to cloud computing adoption in phases where it can fluctuate between adoption and not over a period of time) and corporate officials' perception to the used adoption model or determinants [41]. Bayerl et al. [39] established the notion of Technology Adoption States (TAS) to characterize the rationale for collective adoption choices and to give a framework for explaining their dynamics through time. They also shown that the collective adoption is affected by team triggered events.

Chan and Ma [41] highlighted the biased decisions of CEOs concerning IT-based strategies. They showed that CEOs with fixed salaries have less tendency to migrate

to cloud and use green IT services while CEOs with shares have higher tendency to adopt cloud computing. Chang et al. [32] stated that cloud adoption increases bilateral dependence and will elevate the risk of post-contractual opportunistic behavior. The decision to migrate or not is not always meaningful. Sabherwal et al. [40] showed that effect of the interaction between Strategic IT Alignment (SITA) and IT Investment (ITI) can be negative under some environments. They also showed that in stable, simple, and munificent environments, SITA reflects a rigidity that reduces the positive effect of ITI on firm performance. So even if the right decision has been chosen, internal and external factors participate in the success of the adoption. Saunders and Brynjolfsson [50] found that in average 90% of a company's market value is related to the IT's intangible assets such as purchased and internally developed software, other internal IT services, IT consulting, and IT-related training. Retana et al. [51] studied the impact of basic support vs. full support on service usage by cloud users. It was found out that users who have or had full support tend to rely more on cloud services than customers who didn't experience the features of the full service. Wunderlich and Veit [52] studied the end users' imperfect decision making when deciding on the adoption of sustainable technologies. Trenz et al. [53] studied the social factors end users rely on when considering the adoption of cloud computing especially when the relation with the cloud providers is uncertain. Relying on all those concerns, the second methodology is becoming dominant since 2017.

The second methodology considers that strategies and clients' business models, suppliers and competitors' processes are very important in deciding the success of the user's strategy. For this reason, simulating the interaction between business models is important to fine tune the designed model and decrease failure risk by preventing any miscalculated behavior. Various modeling techniques are available to study the interaction between processes and to predict the success rate under each environment.

Naldi and Mastroeni [33] calculated the fees to migrate to the cloud. They then utilized cash flow metrics to create decision criteria. It is important to highlight the fact that their proposed decisions are independent from competitors' decisions and only relied on price, failure and utilization predictions. Such decision method is typical to the second methodology. Naldi and Mastroeni [33] also calculated the risk resulting from wrong decisions. Sen et al. [54] applied a similar logic for providing a model to help decision

makers decide whether to utilize shared or separate networks. Like [33], they relied on organization's internal costs and predicted prices to decide on the network type to be used. Guerin et al. [55] developed a framework that helps decision makers evaluate the benefits of convergence and deciding between shared and dedicated infrastructures. Their proposal uses two operational metrics, gross profit margin and return on capacity when considering reprovisioning resulting from excess demand. Naldi et al. [56] showed that as the number of repositories in the cloud rises, the net advantage of investing in security diminishes until it becomes unprofitable. As a result, unless the cloud provider promises a better return on security investment, the cloud solution has a smaller net benefit than a centralized solution. Gupta et al. [57] motivated researchers to use economic experiments in information systems and presented its advantages. Aligned with this proposal Guo and Ma [58] developed "an analytical model to study the competitive pricing strategies of an incumbent perpetual software vendor in the presence of SaaS competitor" [58]. Multiple strategies are being considered for the software vendor. They discovered that vendor competition does not always result in better consumer surplus, and in certain cases, it might even result in a socially unproductive outcome. Cocco et al. [59] simulated the competition between traditional and on-demand software vendors. Their model can be used as a tool to "forecast future market trends, or to plan business policies concerning investment and pricing. Firms should calibrate this model depending on their past business trends" [59].

Nan et al. [60] mathematically modelled the optimal pricing strategies of a cloud service provider in an incumbent entrant setting under user upgrade cost and switching cost. They found that in equilibrium the market structure is not unique, and this is very important since it proves that the organizational factors are not enough for deciding on the adoption of cloud computing. Feng et al. [61] investigated the competition between a new entrant and an incumbent in a SaaS market and derived the optimal market entry strategy for the new entrant. Naldi et al. [62] evaluated the effects of new entrants on existing players using the Hirschman-Herndahl Index (HHI). Song et al. [63] studied the market dynamics between two competing pricing strategies in contrast to the traditional fixed-fee perpetual licensing strategy. They used Agent-Based Modelling (ABM) to study the interaction between pricing strategies. Postmus et al. [64] used mathematical modeling to compare pay-per-use and fixed-fee licensing. Mastroeni et al. [65] applied ABM on scale-

free networks to study user side decisions. Ketter et al. [66] used multiagent competitive gaming platforms to study dynamic electricity trading. They gave preliminary empirical evidence for the efficacy of competitive gaming platforms. Guijarro et al. [67] studied the mathematical equilibrium in a market for data-based services. They were able to calculate the Nash equilibrium when certain market conditions are available. Guijarro et al. [68] [69] studied the mathematical equilibrium for a Multi-Sided Platform Sensor-Based Services in the Internet of Things. They deduced that an increase in any market side will benefit all the users across the other sides. Bhattacharya et al. [70] used game theory to compare different selling strategies under monopolistic and competitive environments. Feng et al. [71] used system dynamics (SD) to model the adoption of the electric vehicles compared to internal combustion engine vehicles.

Understanding the adoption of cloud computing requires exposure to multiple focus areas and theories. I was able to identify two supporting focus areas in addition to the methodologies discussed above. The focus areas are shown in figure 1.2.

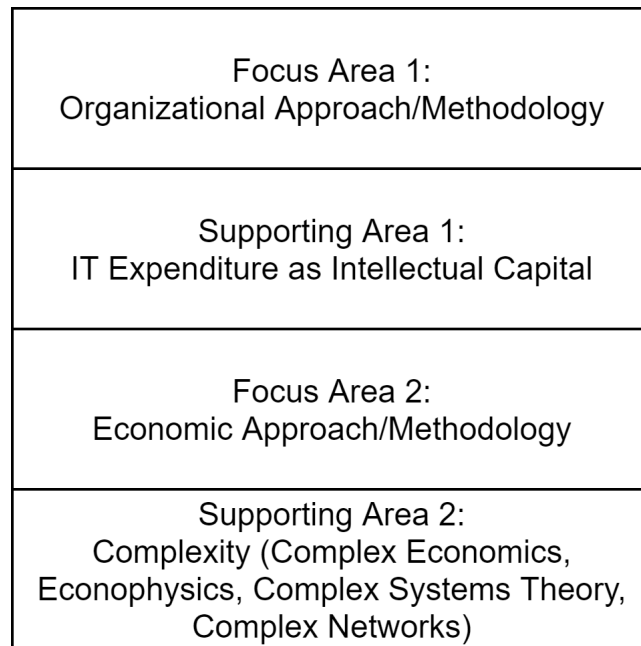


FIGURE 1.2 – Focus Areas.

Focus areas 1 and 2 are discussed above and will be explored thoroughly in the remaining of this thesis. In supporting area 1, the literature argues that the organizational approach is not enough to justify IT investment, but rather financial analytics should be supportive of sometimes speculative investments. Housel and Nelson [72] proposed using complexity and information theory with knowledge valuation analysis to measure

corporate knowledge and thus assign revenue streams to IT which provides an accounting and financial justification for potential investment in cloud computing. Cintron et al. [73] simulated and measured the knowledge value added by core IT processes. Such simulation is critical in predicting the financial feasibility of the potential adoption. Additionally, in uncertain conditions, real option analysis [74] provides a rigorous framework that helps in valuating investments. This framework can be extended to consider investments related to cloud adoption. In [75] the authors showed that the adoption of single innovation does not concur impact or economic performance. Even multiple adoptions may not guarantee impact. Economic performance is achieved through "innovative combinations" and is very specific and case dependent. Extending this discussion from environmental innovation into disruptive technologies has profound impact as it shows that organizational approach's recipe model falls short to deal with "innovative combinations" and case dependency. In the same context, Cecere et al. [76] discussed the lock-in and lock-out factors that prevent an organization from adopting eco-innovations. This work, if extended or generalized, can explain the possibility of being locked out from adopting a technology even if the organization wants. This literature body, called supporting area 1, does not focus on technology adoption, but is critical in understanding the theoretical basis for the first methodology.

In supporting area 2, we can rely on complexity/complex systems theory to understand the emergent rules that govern the market dynamics and consequently technology adoption. I will quote Brian Arthur's groundbreaking work that was summarized in [77]. Economics, the understanding of market dynamics, is a complex system since the

"recursive loop that makes the economy a complex system [77]"

and thus, the theoretical foundations of complexity should be applied to understand these dynamics. This sub-field has been named complexity economics [78]. The strategic decision of technology adoption is neither solely dependent of internal factors, nor a game theory decision between multiple actors, but a loop of tactics and dynamic game theory decisions. Arthur defined this concept clearly

"Companies in a novel market may have different technologies, different motivations and different resources, and they may not know who their competitors will be or, indeed,

how they will think. They are subject to what economists call fundamental uncertainty... About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know. As a result, the decision problem faced by agents is not logically defined and, so, it cannot have a logical solution. It follows that rational behaviour is not well- defined. Therefore, there is no 'optimal' set of moves, no optimal behaviour [77]."

Agent-Based Modelling and mathematical modelling are the natural methods for understanding the complex nature of markets and its emerging nature. Arthur defined this concept clearly

"it was computation more than anything else that allowed economic theorists to venture beyond the standard neoclassical assumptions — for instance, to allow complicated inductive reasoning and compute its consequences. If we turn these new possibilities into a theoretical framework, we get complexity economics, or something like it. If we turn them into a solution method, we get agent- based computational economics. So there is no well- marked boundary between the two approaches. One could, therefore, regard agent- based computational economics as a key method within the framework of complexity economics; or one could regard complexity economics as a conceptual foundation behind agent- based economic modelling [77]."

Adoption can be looked at as a propagation of change that is guided and dictated by network dynamics. Arthur defined this concept clearly

"The topology of a network matters as to whether connectedness enhances its stability or not. Its density of connections matters, too. When a transmissible event happens somewhere in a sparsely connected network, the change will fairly soon die out for lack of onward transmission; if it happens in a densely connected network, the event will spread and continue to spread for long periods. So, if a network were to slowly increase in its degree of connection, the system will go from few, if any, consequences to many, even to consequences that do not die out. It will undergo a phase change. This property is a familiar hallmark of complexity. Notice that the propagation of events brings time inexorably into systems; without such propagation, time disappears."

Since the market of non-adopters can be represented as a network of nodes, where the links between these nodes represent comparability and decision trends, the stability of this network can be predicted. In other words, the ability of non-adopters to withstand a new trend, cloud computing in our case, and thus maintain their choice of non-adoption has been elegantly represented by Gao et al. [79]. The relationship between nodes has to be mutualistic for [79] to stand, otherwise the variation proposed by Arnoldi et al. [80] has to be applied. Additionally, the competition between adopters and non-adopters has been theoretically modelled by Aguirre et al. [81]. This theoretical work is the building block for any real understanding of the adoption of cloud computing and generally any disruptive technology.

In this work we revisited both methodologies. We found that first methodology's weaknesses can be categorized into:

1. **Implementation weaknesses:** these weaknesses are due to limitations in the determinant's selection, questionnaire distribution and rigidity of the outcomes. For the outcomes to be meaningful, the questionnaire must identify specific environment such as: country, sector, size and others. This makes the number of respondents small enough for any bias to affect the accuracy of the outcome. Inversely, accumulating responses from different countries, sectors or sizes also decreases the accuracy of the outcome.
2. **Conceptual weaknesses:** these weaknesses are due to the nature of the methodology such as: experts' biased recommendations, decision-makers' biased answers and corporate officials' biased perception to the used adoption model or determinants.

The implementation weaknesses will be tackled in Chapter 1. The second methodology is revisited in Chapters 2 and 3.

1.2 Research Project

This work is under the umbrella of the CBOD Project (Cloud-Based Organizational Design – ANR). CBOD is “inscribed in fundamental research, but with applicability in real world settings, aims at developing the management and IS community knowledge on cloud computing, from an organizational and business point of view” [82].

1.2.1 Project-related previous contributions

Previous contribution on the CBOD project includes [83] which found that "perceived usefulness, perceived ease of use, complexity and compatibility are key factors for cloud adoption. It also found that most small cloud providers have more stable and better computing performance than large cloud providers and that the performance of CPU impact price significantly" [82].

1.2.2 CBOD Objectives and Tasks

The CBOD project identified 6 objectives which are [82]:

1. "Make an inventory of cloud-based research and approaches in the domain of managing information systems." [82]
2. "Elaborate a conceptual and analytical holistic framework of cloud computing for organizations. A particular attention will be given at articulating the different dimensions, rather than considering each of them separately." [82]
3. "Elaborate different means to model and simulate cloud-based design in organizations enabling a more active and intelligent exploration of Cloud-based solutions from an organizational and business point of view. The means considered include approaches such agent-based modelling, system dynamics, equation-based modelling,

ontology modelling, and associated tools, with a particular interest to solutions that are very comprehensible (both in exploring and designing the models) (action led by Paris Sud)" [82]

4. "Provide a techno-economic model of cloud technology in relation to their dimensioning, and cost models, so as to inform the selection of the way services are offered and charged to the customers, and for instance to guide the choice of the most effective business models (action led by INRIA)" [82]
5. "Investigate issues related to Cloud Computing solutions adoption by organizations (action led by Telecom ParisTech)" [82]
6. "Build a set of cases and scenario able to reflect the diversity of issues, situation and perspective of Cloud-based information systems (e.g. business models, resistance to change, national specificities and international comparison, etc.), that will be also used to validate the approach." [82]

To do this, the CBOD project specified 6 tasks which are [82]:

1. **"TASK 1: Cloud Computing: the Conceptual and Analytical Foundation**
The goal is to set up the foundation of the project, notably by making an overview of the state of the art of cloud computing from a non-technical perspective, and contribute to the establishment of a common ground amongst the partners." [82]
2. **"TASK 2. Preparing the Initial Model (Inria/Paris-Sud)** It will be aimed at elaborating an economic modeling of cloud computing systems and technologies." [82]
3. **"TASK 3: Business Design (Paris-Sud/TPT)** The objective is the analysis of the different modeling advanced approaches (agent-based, system dynamics, etc.), and in the elaboration of the CBOD modeling toolbox (conceptual and technical)." [82]
4. **"TASK 4: Exploration of organizational appropriation or rejection Cloud Computing solutions (TPT/Paris-Sud)** Addresses the modeling of the adoption of the cloud in the organisations." [82]

5. **"TASK 5: Modeling and simulation of scenariii (all)** It is first aimed at modeling the different non-technical aspects of cloud computing systems using the CBOD toolbox, and notably the economic models and the adoption models developed in Task 2 and Task 4. This task will also assess the different modeling approaches (and more specifically the CBOD toolbox). Finally, we will summarize the findings of the project in relation to the non-technical aspects of cloud computing." [82]
6. **"TASK 6: Management, coordination and dissemination"** [82]

The project-related previous contributions, discussed in section 1.2.1, are reflected in table 1.1.

TABLE 1.1 – Previous contributions to CBOD objectives and tasks

	Status		Status
<i>Objective 1</i>	Done	<i>Task 1</i>	Done
<i>Objective 2</i>	Done	<i>Task 2</i>	Done
<i>Objective 3</i>	Pending	<i>Task 3</i>	Pending
<i>Objective 4</i>	Pending	<i>Task 4</i>	Pending
<i>Objective 5</i>	Pending	<i>Task 5</i>	Pending
<i>Objective 6</i>	Pending	<i>Task 6</i>	Pending

1.2.3 Objectives

In this work, our general aim is completing the remaining tasks and objectives set by CBOD. Studying the organizational impact of cloud computing adoption is a declaration of the new technology’s disruptive nature. Our aim is to help decision makers assess the value of disruptive technology (and cloud computing in particular) on their organizations to be able to draw better conclusions. Our objectives can be categorized into economic and organizational which are:

- **Objective 1 (The economic objective):** is understanding the market’s response to disruptive technologies such as cloud computing. This understanding is critical for predicting future market trends that can be translated into decisions at the organizational level.

- **Objective 2 (The organizational objective):** is providing practitioners and decision makers with tools to help them analyze internal and external factors that influence their technology adoption decisions.

The objectives are presented graphically in Figure 1.3.



FIGURE 1.3 – Objectives.

1.3 General discussion

Although it may seem from the above discussion that the literature is offering two distinct alternative approaches and has favored one over the other, the literature doesn't contain any comparison between the two approaches nor a systematic analysis specifying the relationship between them. The relationship can span from complimentary to alternative, but without systematic analysis it can be ambiguous and possibly subjective. My

observations pushed me to believe that the organizational and economic approaches have the following relationship:

1. The organizational approach precedes the economic approach as the first attempt to understand an emerging technology.
2. The organizational approach provides, on the long run, an inexpensive, simple and readily available hand rule for decision makers when the economic approach is too complicated, too expensive or too slow to be evaluated.

In the Figure 1.4, we plot the number of publications per year for every approach. The x-axis of Figure 1.4 is the publication year, while the y-axis is the number of publications (cumulative).

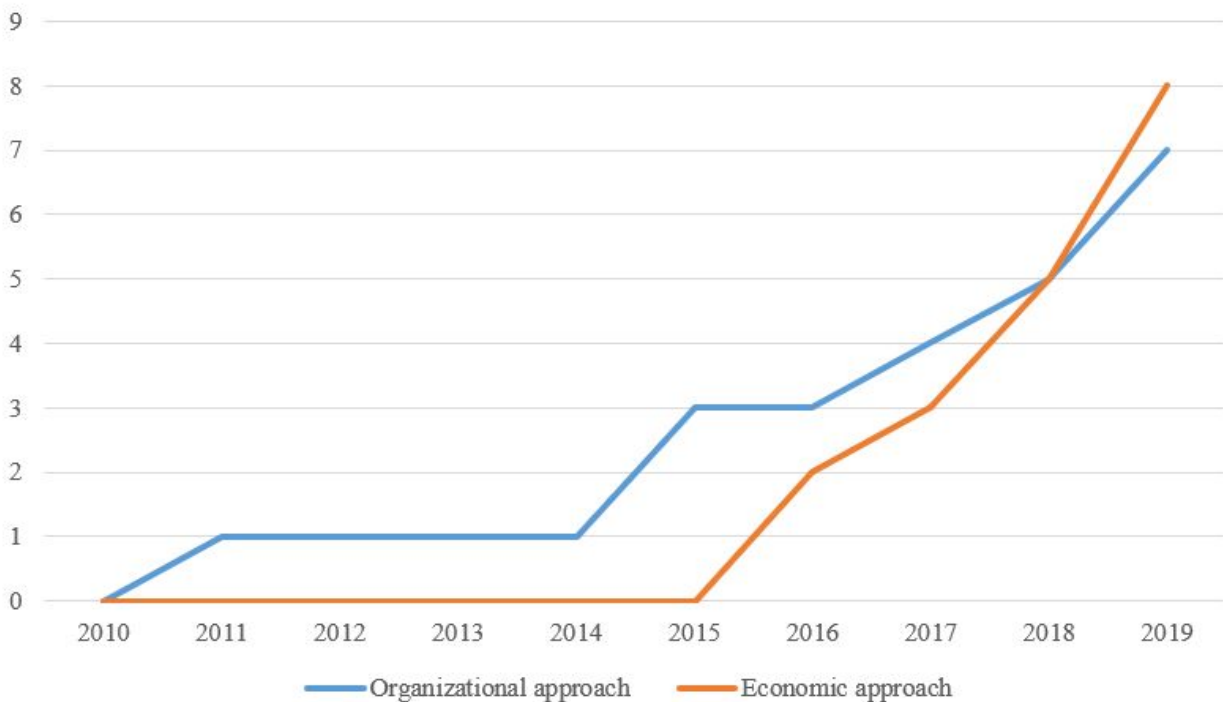


FIGURE 1.4 – Systematic analysis of cloud adoption approaches.

As seen in Figure 1.4, the organizational approach precedes the economic approach by 6 years. This observation is consistent across other emerging technologies. Table 1.2 shows the blockchain selection papers and their relative approach.

TABLE 1.2 – Blockchain selection schemes

Ref.	Author	Decision scheme	Publication year	Approach
[84]	Greenspan	Questionnaire	2015	Organizational approach
[85]	Suichies	Flow-chart	2015	
[86]	Nandwani	Flow-chart	2016	
[87]	PWC	Questionnaire	2016	
[88]	Birch et al.	Flow-chart	2016	
[89]	Saiko	Flow-chart	2016	
[90]	IBM	Flow-chart	2016	
[91]	Lewis	Flow-chart	2016	
[92]	Meunier	Questionnaire	2016	
[93]	Quindazzi	Flow-chart	2016	
[94]	Deloitte	Questionnaire	2016	
[95]	Peck	Flow-chart	2017	
[96]	Lixar	Flow-chart	2017	
[97]	Verslype	Flow-chart	2017	
[98]	Lo et al.	Flow-chart	2017	
[99]	Verified ICOs	Flow-chart	2017	
[100]	Lin et al.	Flow-chart	2017	
[101]	Meuller	Flow-chart	2017	
[102]	Henkel	Flow-chart	2017	
[103]	Mauil et al.	Flow-chart	2017	
[104]	Xu et al.	Flow-chart	2017	
[105]	CapGemini	Questionnaire	2017	
[106]	Klein et al.	Questionnaire	2018	
[107]	Pahl et al.	Flow-chart	2018	
[108]	Wessling et al.	N/A	2018	
[109]	World Economic Forum	Flow-chart	2018	
[110]	Wust	Flow-chart	2018	
[111]	Gardner	Flow-chart	2018	
[112]	Gatteschi et al.	Questionnaire	2018	
[113]	Koens et al.	Flow-chart	2018	
[114]	Scriber	Questionnaire	2018	
[115]	Chand	Flow-chart	2020	
[2]	Bou abdo et al.	Neural network	2020	

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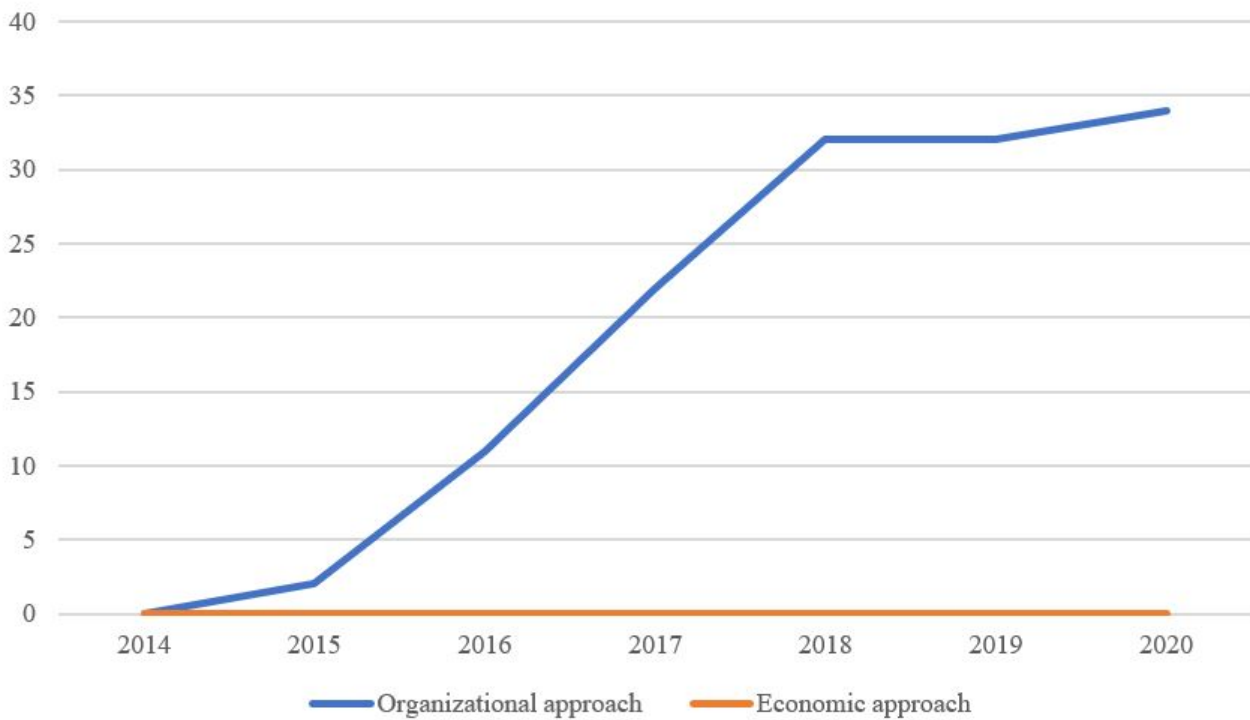


FIGURE 1.5 – Systematic analysis of blockchain adoption approaches.

As can be seen in Figure 1.5, blockchain adoption decision schemes started to be discussed in 2015 following the organizational approach and none has followed the economic approach yet. If all emerging technologies follow the same trend in adoption approaches, we should expect a new blockchain adoption schemes following the economic approach soon.

Plotting the cloud adoption risk publications on the same graph with the two cloud adoption approaches, as shown in Figure 1.6, instantly visualizes the direct correlation between the initiatives to understand cloud adoption risk and initiatives to rely on the economic approach for deciding cloud adoption. The “economic approach” and “cloud adoption risk” have clear positive correlation ($r = 0.88$).

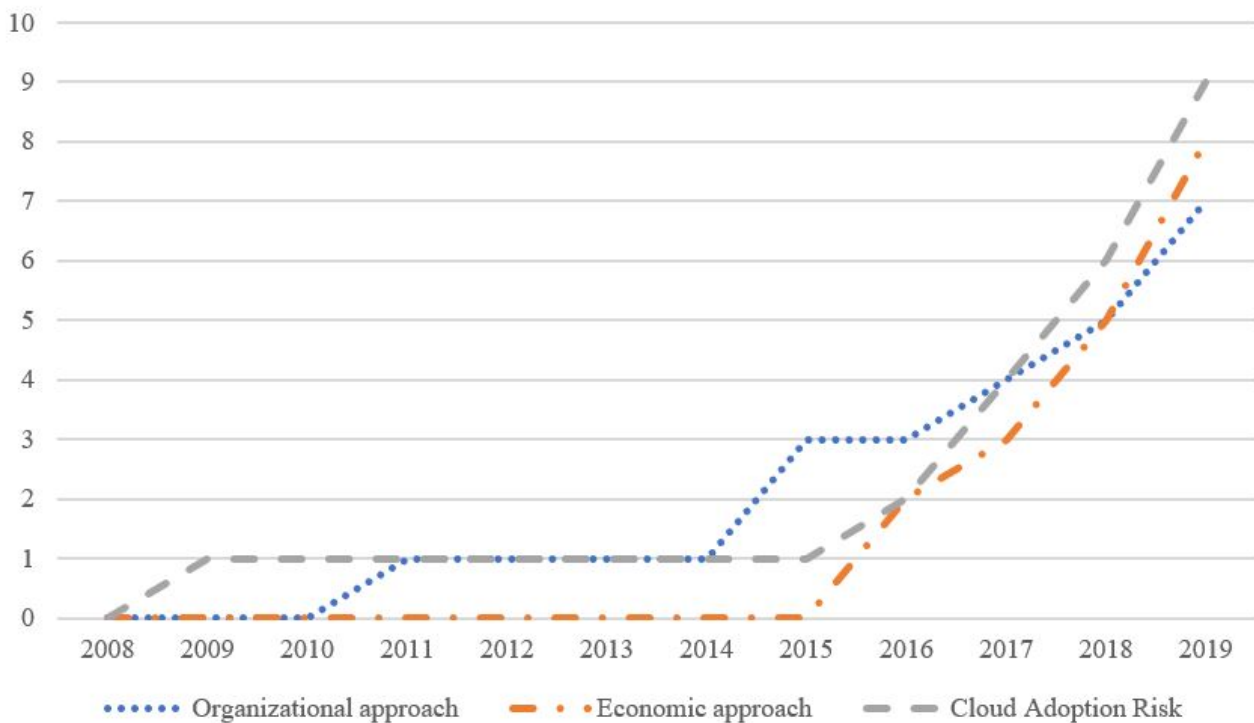


FIGURE 1.6 – Cloud adoption approaches vs. Cloud adoption risk.

1.4 Epistemology

Epistemology is a philosophical branch which aims to study the sources of knowledge. It has been diversely defined in literature with intersections and distinctions in respective definitions. Some of the definitions, found in literature, include:

- “Epistemology is the branch of philosophy that evaluates competing views of the morality, nature, standards, sources, and functions of knowledge” [116].
- “Epistemology is the study of the criteria by which we can know what does and does not constitute warranted, or scientific, knowledge” [1].
- The functional/systematic approach for defining epistemology in contemporary management is “oriented on the creation of integrated systems, verification of truth with the help of objective quantitative methods” [117]. The symbolic/interpretative approach, on the other side, considers epistemology to be built on the assumption of “a constructional and conventional character of the social and organizational reality

[118]. Organizational order does not exist objectively but is being continuously maintained, reconstructed and modified by individuals and groups acting in and around an organization” [117].

The distinctions in epistemology definitions create a diversity in research methods and goals. As specified by Levant and Zimnovitch [119], the goal in management research should be the utility of the theory rather than sheer correctness. We will demonstrate throughout the following how our objective was to search for the best theory regarding our work.

The principle of epistemology in research is the status of knowledge, its formation and elaboration, and the obtained results. The sources of knowledge can be divided into four: The intuitive knowledge based on intuition, the rational knowledge based on trusted information, the empirical reasoning based on demonstrated facts and the Logical knowledge based on logical reasoning. One can use the 4 sources or can refer to some of them. In this thesis, we referred to the rational knowledge when studying our literature review and when discussing the results obtained to build up new ideas and theories. While using questionnaires to extract a set of determinants, we were going throughout empirical reasoning. At the end, our results are the fruits of a logical reasoning ending up in a logical knowledge.

Two of the well-known epistemological orientations are positivism and pragmatism. These two approaches have a different perception of knowledge. In the positivist approach, a theory cannot be considered as true unless it is measured and verified, while in the pragmatist approach, the correctness of a theory is related to its practical interest. The pragmatists define the truth of a theory in terms of its success and utility. Thus, “truth serves practical interests” as specified in [120] and can be measured according to satisfaction. However, Popper separates the notion of utility and truth, thus opposing the pragmatist position which combines value and truth [121] (value and utility are used interchangeably in this section). According to Popper, "falsification is what distinguishes scientific logic from other types of discourse. He considers that scientific knowledge develops according to a ‘verisimilitude’. Thus, there are no statements that can be said to be unquestionably true" [121]. A theory should make postulations that can be approved

or declined experimentally [121]. According to [122], the epistemological issue is not truth but action. Pragmatism is concerned with action and the interplay between knowledge and action. The authors of [123] proposed the experience-based research as a general framework for management research.

Management sciences are part of human sciences [119] hence, a “criteria of utility rather than ‘truth’ should be employed in making judgements on the adequacy of theory” [124]. The stands, from utility and value, used in management research, as specified by Levant and Zimnovitch [119], are as follows: Although an important part of management research falls into dogmatism and sophism, action research provides real perspectives and the hermeneutical-historical approach valuable information. It is what is called Dead ends and prospects. On one hand, the management sciences theory degenerates into dogmatism when it pretends to express the truth and tries to produce universal regulations in order to succeed. If science pretends to apply to utilitarian things, it will deteriorate into dogmatism. On another hand, the application of rhetoric as a technique for management and its teaching is quite common. However, the use of rhetoric as a goal or science will at last lead to a sophism that shifts utility over truth. The connection between sophism and marketing is quite clear. The last situation, raising a technology, which is relative to a context, a point of view, or a preference, to the rank of truth, would be to deny it and destroy its claims to universality. This is sophism. According to [125], they both, ultimately, aim to seduce, convince, and persuade. Our research aims to provide real perspectives and not speculation regarding modeling the factors influencing the adoption of cloud computing and the success of the adoption decision.

The stands from utility and truth can be reformulated into the stands between science and technology. As shown in Figure 1.7, science and technology have four possible relationships with truth and utility. These relations can be described as follows:

- Science is based on empirical content as well as a set of assumptions that can be rejected. Thus, it is related to the concept of truth and not utility, and without any assertion to accomplish it definitively.
- If science pretends to apply to utilitarian things, it will deteriorate into dogmatism.
- Technology is know-how and is linked to what is beneficial. Technology is designed

pragmatically: “the great advantage of a pragmatist’s position residing in the interdependence it establishes between what is true and what is useful” [126]. It is an operative knowledge in a situation.

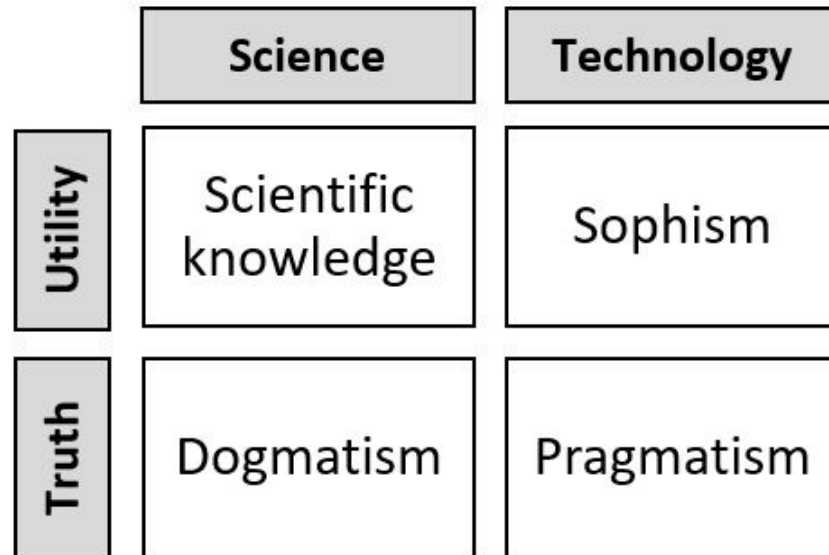


FIGURE 1.7 – Relationships of science and technology with truth and utility.

The epistemological orientations used in management research are:

- **Positivist and Neopositivist Epistemology:** Positivism remains the dominant orientation in management sciences [1], although this dominance is camouflaged “since hardly anyone openly applies a positivist label to their own work”. Logical positivist orientation has the following 4 claims [1]:
 - Observations can be neutral, value-free and objective.
 - All theoretical statements should be subject to empirical testing.
 - All sciences, including social sciences, should follow the natural sciences model.
 - The task of science is to control social and natural events.
- **Conventionalist Epistemology:** Conventionalism is centered around the absence of a theory-neutral observational language. The consequences of this assumption have been clearly stated in [1], [127] as:
 - Scientific statements are the creations of the scientist, thus cannot be falsified using external observations.

- Acceptability of a scientific statement is not based on universally valid criteria or objective standards of evaluation, but rather by the scientist’s subjective understanding of reality which is usually derived from socially sanctioned conventions.
 - The absence of a theory-neutral observational language makes scientific statements objectively uncontrollable.
- Postmodernist Epistemology: It provides a relativist stand and dismisses the rational certainty of positivism [1]. This stand is due to the limitation in our observational methods. It has been clearly stated by De Cock as “The consequence of a postmodern stance is that we are advised to stop attempting to systematically define or impose a logic on events and instead recognize the limitations of all our projects” [128].
 - Pragmatism and Critical Realism: Critical Realism considers that people’s observable behavior is not explicable using empirical methods and requires the casual context of non-empirical structures and their interactions.
 - Critical Theory: Critical Theory is oriented towards power structures and related issues such as "exploitation, asymmetrical power relations, distorted communication, and false consciousness" [1].
 - Constructive Epistemology: Constructive empiricism considers that science aims to provide theories that are empirically adequate [129]. It also considers that scientific knowledge is constructed by scientists, compared to the observed environment, but not discovered from the environment. Constructive empiricism is not limited to one single valid methodology for social science. Dicken reported that Van Fraassen [130] defined constructive empiricism to be the view about:
 - What is to make an epistemic judgement?
 - The obligations of being a rational scientific agent.
 - How best to understand the very philosophical debate concerning the aim of science?

The epistemological orientations used in management research are represented in Figure 1.8. The Y-axis represents the ontological stand of each orientation. The X-axis represents the epistemological stand of each orientation.

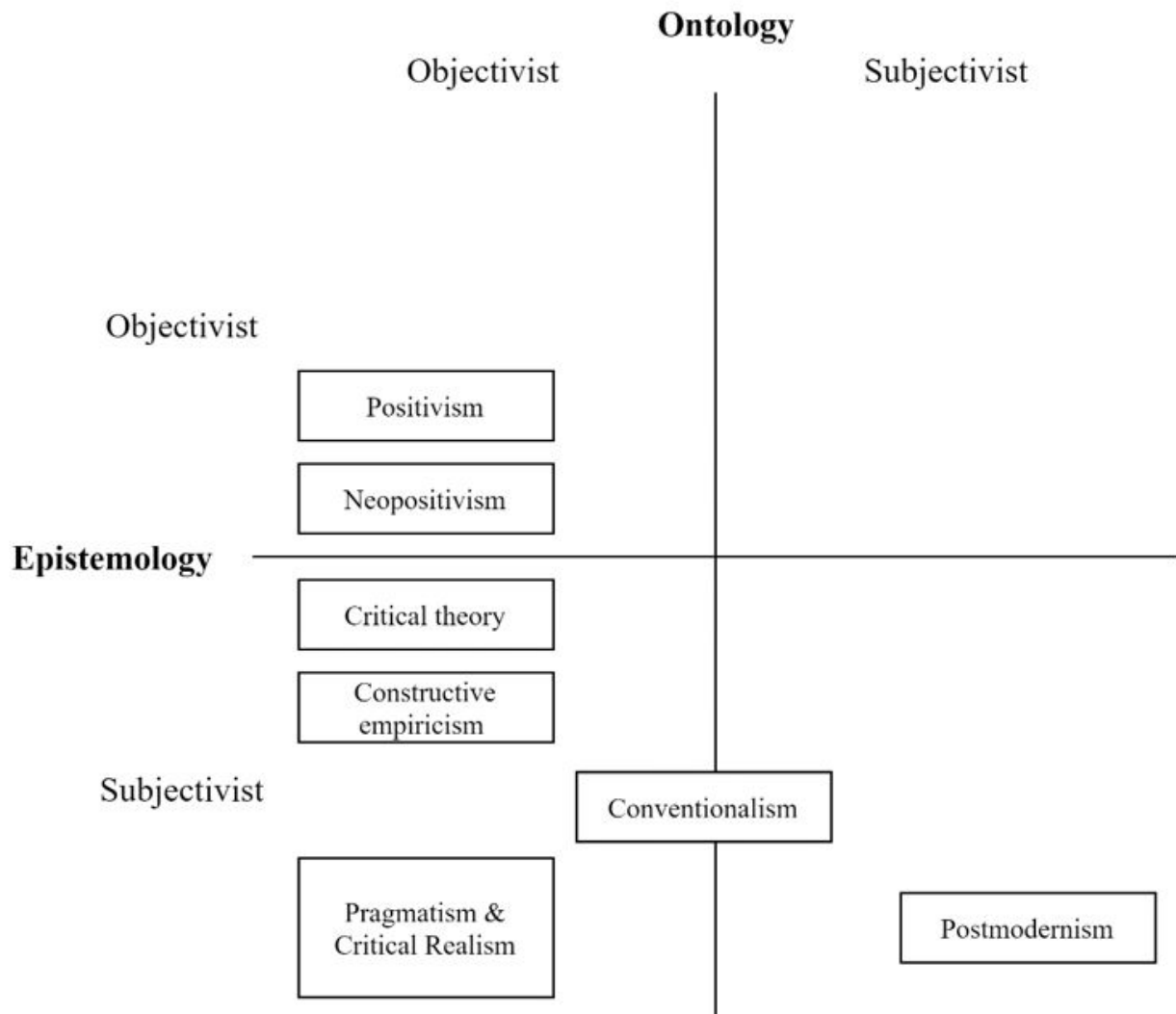


FIGURE 1.8 – The epistemological orientations used in management research (inspired from [1]).

Our research is oriented towards epistemological objectivism since reasoning is the foundation for our work without relying on personal presumptions and beliefs. The first part of this work is oriented towards ontological subjectivism taking the organization as reference. Constructing the decision based on the organizational situation or perspective without relying on our presumptions is critical for escaping biases. The second part of this work is oriented towards ontological objectivism since the foundational assumptions of economics truly believe that the market is the interactions between supplies and clients irrespective of any single individual or organization.

The first part of our research is aligned with the constructivist approach since we have been immersed in observing the environment of our study to know it, model it and to build our results accordingly. Our constructivist approach is based on three principles: the phenomenological hypothesis, i.e. the relation between economic factors and corporate's success, the relation between subject and object, i.e. how the object of knowledge is constructed through comings and goings of analysis and interpretation, and the construction of new truths. Other proposals found in literature using decision trees or rigid recommendations follow ontological subjectivism and epistemological subjectivism orientations and thus fall prone to biases.

Reality is constructed from the work that is done on it, from the observations that emerge from it. Knowledge is the fruit of constructions that are realized progressively, that are not given by themselves, but that are built continuously. This reality is not directly accessible, but it results from interpretations. It cannot be directly deduced according to pre-defined criteria, but it is deduced according to standards of feasibility that must be reviewed on a case-by-case basis.

In the first part of our work, we considered the factors involved in generating accurate decisions without oversimplification or overgeneralization. The factors used are based on a previous contribution of the CBOD project [131]. Similar factors have been grouped by Loukis et al. [132]. The constructed models are not necessarily final, and the included factors are not necessarily complete. Increments can be done to the constructed models to included missed factors that can enhance the model's accuracy. The use of a recommender system and the designed auto-tuning component help enhance the accuracy of the model without manual intervention from our side.

This construction is carried out with the actors concerned, it is not a theoretical construction, but a construction that combines theory and practice in the field of action. It is an articulated approach, based on a learning process between me as a researcher and the experts in the field.

The methods used define the project that allowed the construction of scientific truths or scientific knowledge. According to this constructivist approach, such research is a project in continuous progress. This evolution implies that it is not an elaborated and

definitive reality, but several realities likely to evolve according to the individuals who apprehend it.

Self-Adaptive decision-making systems usually follow the constructivist approach and this can be seen similar research such as in [133] and [134]. In [133] the authors stated that "particularly challenging in unknown and changing complex environments, where providing a complete a priori representation to the system is not possible" [133]. This is also applicable to our research and consequently following a constructivist approach serves our aim the most.

The second part is based on a positivist approach which can be defined by the consideration of knowledge obtained by observation and measurement. It is the study of the social world. This approach is based on an hypothetico-deductive model that verifies and experiments hypotheses set a priori by operations and measures in order to find causal relationships between the elements of the hypothesis. It consists of passing from observable social reality to a generalization considered as a law. These relationships are important since they will be considered as the main base of Management.

In our studies, we started by defining the terms and concepts used in order to establish a clear and valid communication. Then, we established hypotheses defined following the research needs. The second part of the research is based on a quantitative method which was a market simulation in our case. This part has the role to test the hypothesis in order to confirm it.

These results were based on statistical analysis which led to a concentration on facts. The results were validated by rational and logical ways of reasoning in order to be generalized. The results can be formulated in abstract and universal laws which can be stated as "Internal and external factors affect the success of an organization's decision".

Chapter 2

Decision Support Solution for Cloud Computing Adoption

Jacques Bou Abdo, Najma Saidani, Ahmed Bounfour ¹

Contents

2.1	Introduction	40
2.2	Background	41
2.2.1	Decision support solution	41
2.2.2	Legacy technology adoption models	47
2.3	Related Work	49
2.4	Design Constraint	53
2.5	Design	55
2.5.1	Determinants	55
2.5.2	DSS objectives	57
2.5.3	Components	57
2.5.4	Design	58
2.5.5	Auto-learning and Self-correcting	61
2.5.6	Fine-tuning algorithm	62

¹Jacques Bou Abdo, Najma Saidani, Ahmed Bounfour, “Organizations’ Investment in Cloud Computing: Designing a Decision Support Platform”, 14th International Conference on Data Science (ICDATA’18), Las Vegas, July 31, 2018.

2.5.7 Data quality	62
2.6 Collected Data	65
2.7 Evaluation	68
2.8 Summary	68
Appendix - A: Active Learning Questions	69
Appendix - B: Accuracy metrics for recommender systems	72

2.1 Introduction

"The extent to which an organization should utilize cloud computing is a difficult decision to make, especially in the absence of reliable historical data and normatively acceptable decision principles"[25]. Because of competition and rapid technological advancements, the cost of making a bad strategic decision is just too high to be tolerated.

Existing research has focused on defining and ranking the elements that influence adoption decisions, *"as well as the impact of a predetermined set of criteria on the intention to utilize cloud computing services"* [135], [136], [137], [138], [139], [140], [141]. Other suggestions attempted to use traditional economic methods by combining measurable and non-quantifiable components into a single index [142], [143]. The presence of a linear connection between the influencing factors is implicitly assumed by these writers, and this is non-provable. The determinants overlap in influence; thus, any theoretical decision scheme will be very difficult to deduce. On the other hand, inducing an empirical interaction formula as a function of the determinants would be the most convenient taking into consideration the limitation of the available data. As will be discussed later, we debate that non-personalized collaborative filtering recommender systems are best suitable to induce an empirical relationship between the determinants and the available cloud technologies/services.

A previous contribution of the CBOD project [131] resulted in an exhaustive list of determinants that participate in the cloud adoption decision. A similar list of determinants can be seen in [132]. The literature has slightly touched the issue of organizational cloud adoption from a Decision Support Solutions (DSS) perspective. To the best of our knowledge, this work is the first attempt to offer a DSS on cloud computing adoption that is holistic, vendor-neutral, general (not confined to particular cloud services), and non-trivial. The research's ultimate product is a publicly available Web-based DSS tool that decision-makers may utilize to assist them decide on their cloud computing approach.

2.2 Background

2.2.1 Decision support solution

Humans spend the majority of their days in front of screens and devices, connected to the Internet. Whether in their homes, institutions, colleges, hospitals, etc. anywhere and everywhere technology is integrated. They are required to take a multitude of decisions that go from simple daily decisions to life-changing ones. However, with the huge stream of information to which the users are being exposed the problem of information overload arises. The users are receiving a large quantity of data in a short time: they are not being able to convert information to useful knowledge. This affects the decisions negatively to the point of blocking it completely. In order to solve this issue, decision support systems became widespread solution. Decision support systems (DSS) combine computer capabilities and human skills in performing advanced operations such as data analytics, reporting, planning, and modeling. This is not a new field of study, researchers have been focusing on developing solutions for complex decision-making problems since the 1970s [144].

DSS are systems that deal with problems that have semi-structured or unstructured [145] stages. Simon places the problems dealt with DSS on a range from programmed, easy to solve well-structured problems to non-programmed, difficult, and ill-structured

problems [146]. DSS is an incarnation of the concept that computers place an important role in decision-making. They address the requirement of a certain design strategy supporting the cognitive process of human decision.

Three types of DSS exist [144]: active, passive, and cooperative. The active DSS can generate solutions or suggestions. On the other hand, a passive DSS cannot produce such solutions or suggestions, but it is able to support the process of decision-making. A cooperative DSS allows the decision-maker to modify the recommendations that the system provided before being sent back to the system for validation and another round of decision recommendation.

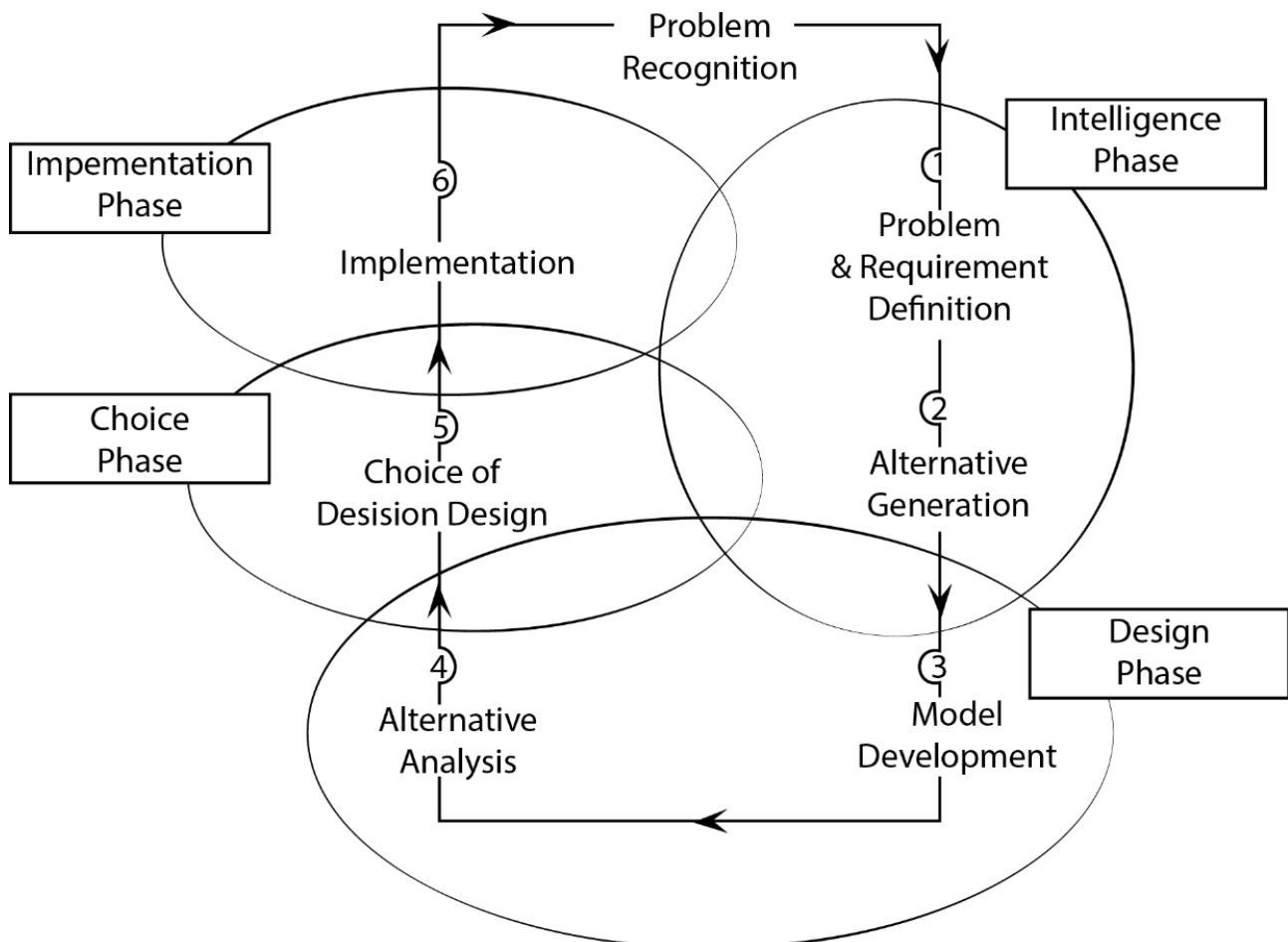


FIGURE 2.1 – Decision-Making Process.

The decision-making process can be summarized in a number of steps as shown in Figure 2.1 [144]:

1. First Step: Problem Requirement Definition Once recognized, the problem needs to

be defined. By definition, a clear statement of the issue is meant: a description of the initial conditions and the desired ones. Afterward, the next part of this step is the determination of the requirements in order to obtain a list of absolute goals and exigencies.

2. **Second Step: Alternative Generation** As the name implies, this stage is in charge of coming up with alternate answers to the uncertainties of decision-making. One of the most important characteristics is that the alternatives must fulfill the previously specified standards. The "Intelligence Phase" is formed when steps one and two are combined. The system is tasked with locating, identifying, and formulating the circumstance or issue. A summary of the present state of the detected issue is provided. As a consequence of this step, a decision statement is issued.
3. **Third Step: Model Development** Once the alternatives are generated and the fitting ones are selected, the model needs to be developed. The aim of the model development is the analysis of the different alternatives. The model that best compares all the alternatives is the one that achieved the selected criteria and goals the soonest.
4. **Fourth Step: Alternative Analysis** After this best model is developed, an alternative analysis is conducted. This analysis concludes the evaluation of alternatives against criteria. Many tools exist and research is still ongoing to find which method is appropriate the most to which type of issues. The aim of these researches is to differentiate between the pros and cons of using a certain method instead of another and to check if changing the method used affected and changes the decision. At the end of this step, the solutions are validated against the problem statement.
5. **Fifth Step: Choice of Decision Design** The choice should be made in a way that the solution best achieves the objectives of the decision process, satisfies the desired state, and meets the requirements
6. **Sixth Step: Implementation** The chosen decision design is implemented. These steps are the flow of the "Choice Phase" model. The developed alternatives to the design phase are here selected. A decision or model is the final product of the process.

A DSS possesses several fundamental components as shown in Figure 2.2. As can

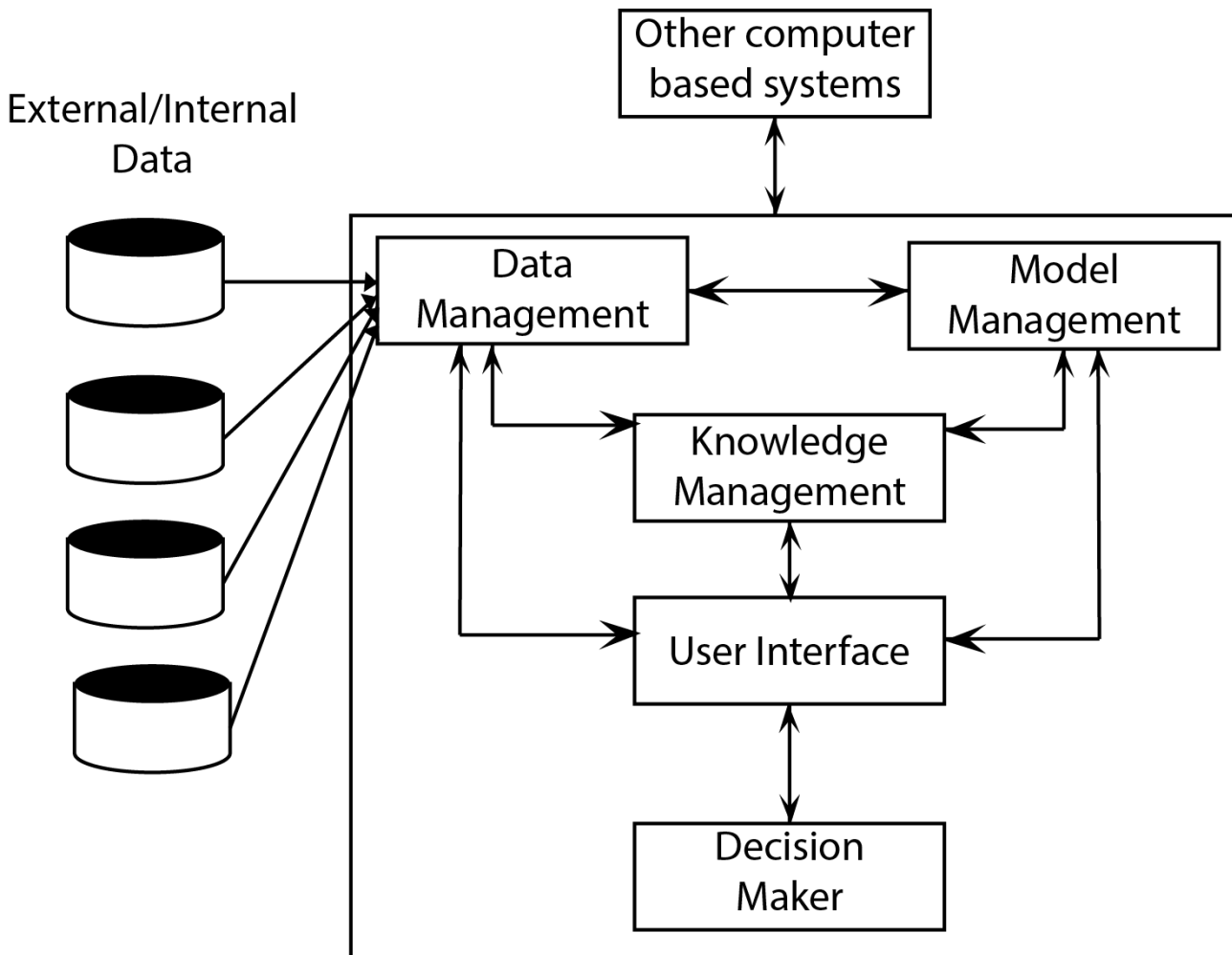


FIGURE 2.2 – Conceptual Overview of the Architecture of DSS.

be seen in Figure 2.2 there exist five main applications of DSS that consist of multiple techniques and sub-technologies for decision making as shown in the coming subsections.

2.2.1.1 Model-driven DSS

For decision support, a model-driven DSS employs optimization, finance, simulation, and algebraic decision-analytic models. It is intended to assist decision-makers in understanding a particular situation and allowing the user to alter model parameters. In general, it is not data-intensive: big databases are not required. They may, however, need to be removed for certain studies. One or more quantitative models that offer functionality are the key component of this DSS's architecture.

Analytical tools that use algebraic models assign a basic degree of capability. They

are typically created in spreadsheets and are frequently utilized in the development of model-driven DSS systems. Simulation approaches, optimization, and mathematical programming models, as well as decision analysis, are used to design and develop increasingly complicated decision-making models. Models in a model-driven DSS are, in general, a simplified depiction of reality.

Model-driven DSS using simulation techniques conduct a multitude of experiments to display the effects of alternative courses of action and conditions [147]. "Simulation methods are commonly used in the area of supply chain management. Several examples are visual simulation, system dynamics, agent-based and multi-agent simulation, discrete simulation, and Monte Carlo simulation" [144].

In many environments, optimization models are integrated into DSS. Mostly, in supply chain management and production & operations management, the area of optimization models has gained importance. Nowadays, multiple decision support models exist for the different levels of the supply chain, including logistics planning, production planning, and scheduling and demand management.

Decision analysis models are the statistical methods and tools such as probabilistic forecasting, decision tree analysis, AHP (analytical hierarchy process), and multi-criteria decision analysis. A decision analysis aims at the discovery of the most favorable alternative under the given situation.

2.2.1.2 Data-driven DSS

A data-driven DSS allows to access and manipulate structured data. It can handle real-time data and time-series of external and internal company data. "Data-driven DSS are separated by functionality. Simple file systems are accessed by retrieval tools and queries that facilitate an elementary level of functionality" [144]. More in-depth functionality is provided by management reporting systems such as EIS (Executive Information Systems) and Data Warehouses. They allow computerized tools to manipulate data. The data-driven DSS that provides the highest mode of decision support and operation is the BI (Business Intelligence) Systems and the OLAP (Online Analytical Processing). BI systems

help in the creation of the decision: they trigger, manipulate, and analyze information or data stored in historic databases. Their main objective is to ensure a higher quality of information for decision making. The efficiency of the data-driven DSS is linked to certain requirements: to have access to a large quantity of data and also high quality, i.e. accurate, organized, and well-structured data.

2.2.1.3 Communication-driven DSS

Communication-driven DSS connects users through information and resource sharing environment. Users can communicate and collaborate through a hybrid network and electronic communication. One main sub-category is group decision making. Over several years of research, the GDSS (group DSS) are developed [145]. They include problem structuring techniques like modeling and planning tools.

2.2.1.4 Document-driven DSS

The quantity of documents, videos, images, sounds, correspondence, and hypertext documents in companies is increasing exponentially. Not only the amount is huge but also the size of the documents is very large. Document management is now a must. The worldwide web contains very big document databases which augmented the development of document-driven DRR. Search engines that are linked to these systems form decision-aiding tools. It is important to note that documents are not standardized in patterns and are therefore unstructured. Information retrieval systems are used to extract information and give a structure for documents to provide better support for decision making.

2.2.1.5 Knowledge-driven DSS

Knowledge-driven DSS originates from AI (Artificial Intelligence), more specifically Intelligent DSS. In the knowledge-driven DSS communication mechanisms, data mining technologies, management expert systems, and AI are integrated. Intelligent DS can be divided into two evolutionary developments.

The first type is about rule-based expert systems [148]. It is commonly used in production systems, for scheduling. These expert systems use heuristics, strategies leading to the correct solution for a problem. In this type of system, human expert knowledge is necessary.

The second generation relies on genetic algorithms, fuzzy logic, and neural networks [149]. These methods are "similar to linear programming models but they conduct random experiments by selecting variables without identified values to find the fitness function" [144].

2.2.2 Legacy technology adoption models

2.2.2.1 Technology Adoption Model (TAM)

TAM is a widely used theory in Information Systems that studies the adoption level of a studied technology under a certain organizational context [150] as shown in Figure 2.3. It is based on two beliefs which are:

- "Perceived usefulness: the degree to which a user thinks a technology would enhance performance or productivity in the workplace" [150].
- "Perceived ease of use: the degree of lack of effort required by the user in adopting a given technology" [150].

These beliefs help in predicting users' attitudes toward the evaluated technology and thus its overall effectiveness. The predicted users' attitudes and intentions to use the studied technology affect the behavior of actual system usage as shown in Figure 2.3.

2.2.2.2 Technology – Organization – Environment Framework (TOE)

The TOE framework identifies the organization's adoption influencers to be three elements of a firm's context [151] as shown in Figure 2.4. These elements are:

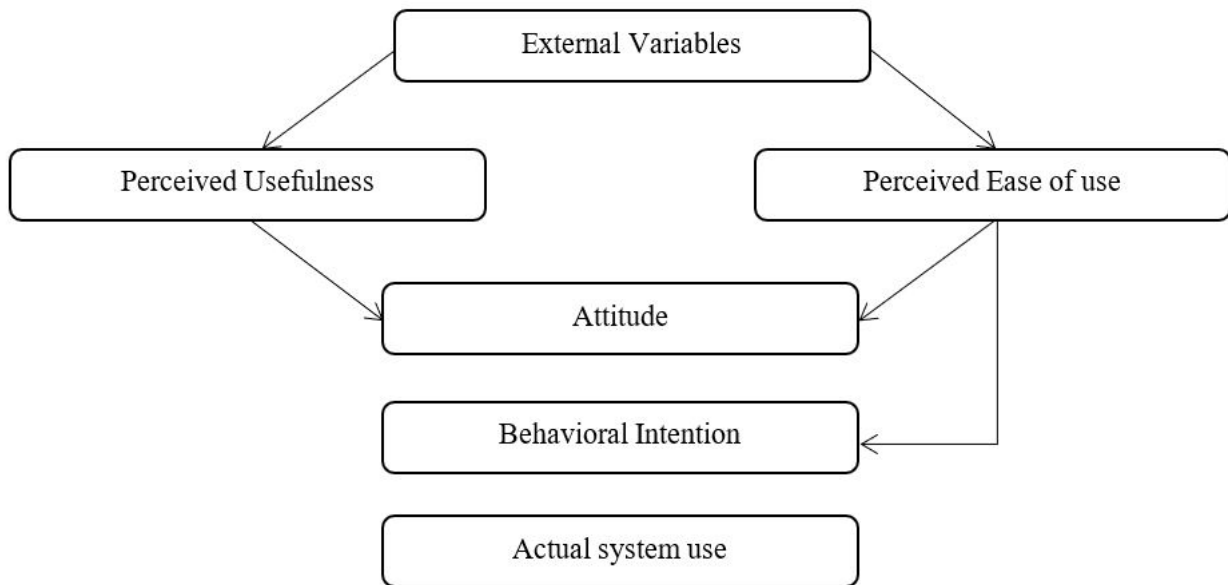


FIGURE 2.3 – Technology Adoption Model.

- **Technological context:** includes the technology already implemented at the organization and the technology available by vendors.
- **"Organizational context:** includes the firm's resources such as intra-firm communication processes, firm size, and the amount of slack resources" [151].
- **"Environmental context:** includes the market's structure such as the presence or absence of technology service providers and the regulatory environment" [151].

2.2.2.3 DeLone and McLean Information Systems Success Model

"It is a framework and model for measuring the complex dependent variable in IS research" [152]. The variables belong to six interrelated dimensions, as shown in Figure 2.5, which are:

- information
- system and service quality
- (intention to) use
- user satisfaction

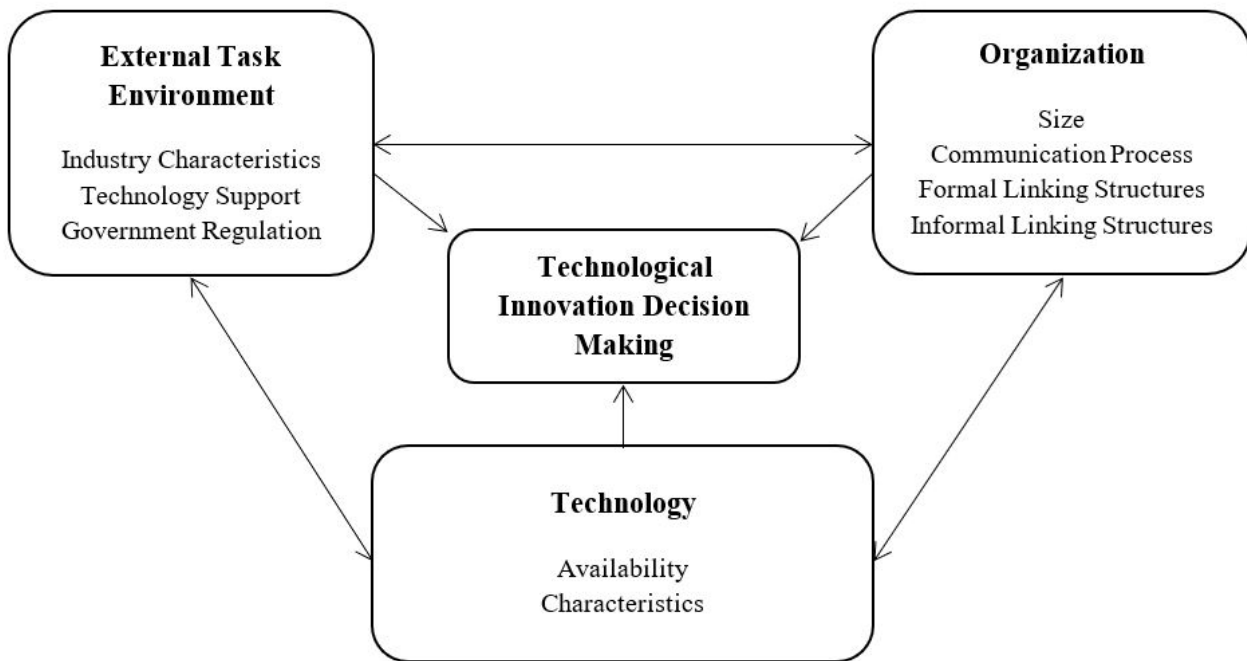


FIGURE 2.4 – Technology – Organization – Environment Framework.

- net benefits

"A system can be evaluated in terms of information, system, and service quality; these characteristics affect the subsequent use or intention to use and user satisfaction. The net benefits will (positively or negatively) influence user satisfaction and the further use of the information system" [152].

2.3 Related Work

Cloud computing represents a new field of research in the academic field. In information systems, for example, 205 'peer-reviewed' academic articles were recorded in a review of descriptive literature on 'cloud computing' [153]. According to the same review on cloud computing research, studies on the topic range into four types:

- ***"Technical issues: data management, cloud performance, data center management, software development, security, service management"*** [25]

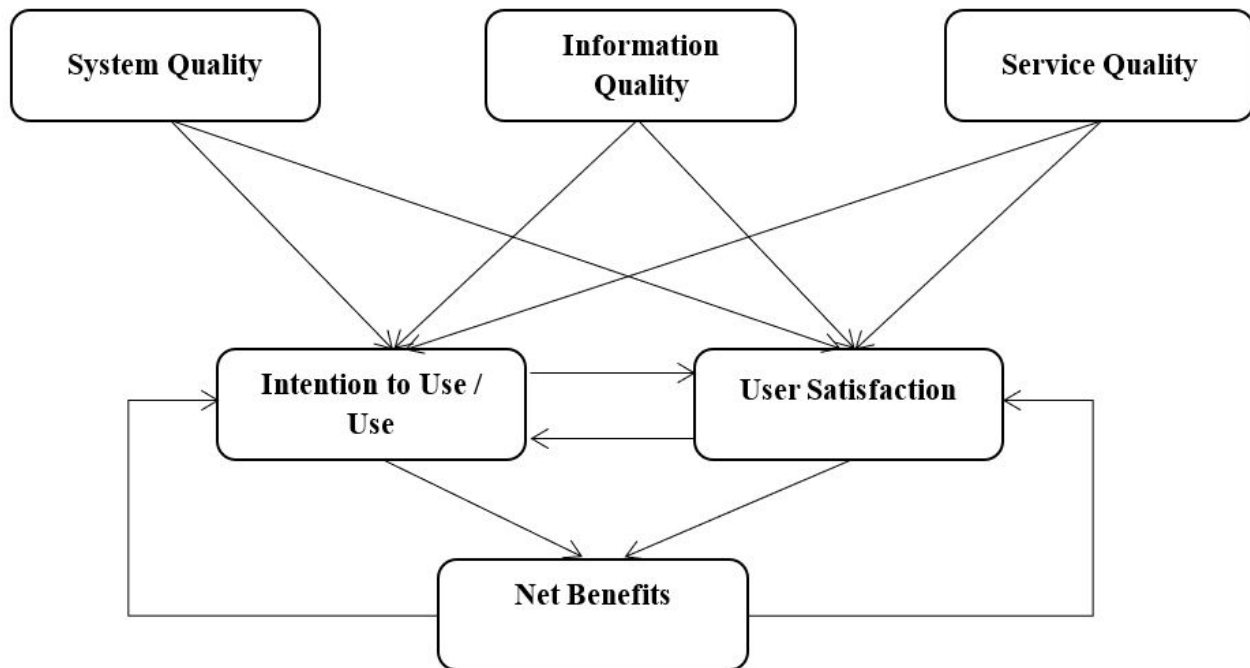


FIGURE 2.5 – DeLone and McLean IS Success Model.

- ***"Business / Management issues: cost, pricing, legal issues, ethical issues, trust, adoption"*** [25]
- ***"Conceptualizing cloud computing: foundational, introduction, predictions"*** [25]
- ***"Domains and applications: E-government, E-science, education, open-source, mobile computing, other domains"*** [25]

In the field of technical issues, the software development subcategory refers to a stream of software developer-focused research. The topics covered in this area vary from general discussions on producing distributed and parallel software in cloud computing settings to specific articles on developing distributed and parallel software in cloud computing environments [154], [155], [156], to specific analyses of particular cloud-based programming frameworks such as MapReduce [157]. Novel studies also consider component-based approaches for developing composite applications [158] and automation in restructuring traditional applications into distributed/partitioned cloud-based ones [159].

Indeed, cloud computing adoption is a complicated phenomena with a wide range

of potential and difficulties, but cloud computing research is still in its infancy. Much of the present research focuses on the advantages and hazards of cloud computing, as well as organizational case studies on cloud adoption and cloud computing designs [160]. More specifically, with respect to business decisions regarding cloud computing, it focuses primarily on *"identifying the determinants that influence the adoption of cloud computing and the impact of a predefined set of factors on the environment."*[25]

"Researchers studying cloud computing adoption have drawn on a variety of ideas from the Management and Information Systems literature. The Technology Acceptance Model (TAM), which [150] was used to offer an integrated picture of the adoption element, is an example. The model has been criticized for its narrowness and inability to provide a thorough explanation of adoption when considering the utility and simplicity of use as factors of usage."[25]

"Another line of research used the DeLone and McLean IS Success Model to assess the commercial benefits of cloud computing migration. Many attempts have been made to enhance this model to boost its accuracy while investigating the adoption of cloud computing [161] [152]. Another stream of research mobilized the TOE (Technology-Organization-Environment) to expand the scope of analysis by adding new dimensions of explanation [151]. Also, researchers addressed the topic of cloud computing adoption determinants through the diffusion theory of technology, initially developed by Rogers 1995 aiming at identifying attributes of technology diffusion."[25]

Low et al. [138] addressed the problems of adopting cloud computing using the TOE framework and argued for better understanding of the adoption of cloud computing and its environmental and organizational factors.

In fact, the issues of cloud computing adoption constitute, according to [162], one aspect from four aspects that have dominated the literature on cloud computing, to know: cloud computing characteristics, cloud computing adoption, governance mechanisms, and business impact pointing out « a shift from purely technical aspects of research on cloud computing to a broader understanding of cloud computing as a new IT delivery model» [162]. We enroll in our work within this perspective.

Gap

"Despite the fact that the IS (Information Science) literature have witnessed the development of decision support systems with the objective of guiding managers when deciding about their future investments in cloud computing services such as [163] [164], [164], and others, we assess a clear lack of an integrative tool that combine a large mix of heterogeneous and interdependent decision dimensions. Indeed, the decision support tools have been developed either based on a limited number of dimensions like the storage and computing capacities added to the network [165] or regarding a specific service like [163]." [25]

"Ours suggests a more integrative view of cloud services choice by organizations. In fact, we propose to both handle a richer range of dimensions that determine the decision and match them with a richer range of cloud computing solutions that does not only take into account traditional services like IaaS, PaaS, or SaaS, but also consider other solutions like virtualization or grid computing. Consequently, we answer the needs of a larger sample of organizations by integrating more criteria in the decision model we propose. As argued by Hevner et al. [166], the design research branch of the research in the information systems field aims at 'extending the boundaries of human or organizational capabilities by creating new and innovative artifacts' [166]. Our study aims at fulfilling this objective by proposing an analytical approach, both functional and technical, to support managers make sense of the environment surrounding them in terms of cloud computing technologies and capabilities offers. Beyond the commercial approach, adopted by a variety of 'Cloud Decision Engines', we seek to provide a more comprehensive method that includes 1) objective and critical determinants of cloud computing decision that matches different organizational needs and 2) rich propositions of cloud computing solutions that range from the classic solutions to others such as the virtualization, the dedicated servers, the grid computing, and others." [25]

Indeed, our study fits into the 'Business /Management' class of the typology proposed above and more particularly in the subject 'Adoption of the Cloud'. Indeed, only

21% of the articles listed in the literature review deal with the subject of adoption. As such, we propose to focus on the decision-making process that companies undertake to invest in cloud computing and what variables do they consider in this decision-making? We also propose a decision model (a rule-based modeling approach).

2.4 Design Constraint

The literature presented us with an ad hoc list of relevant factors, with the majority of studies focusing on specific cloud computing services. We'll do the following in this chapter:

- Determine the factors that influence an organization's choice to use cloud solutions.
- Create a uniform and well-defined classification system for the determinants listed in the literature.
- Create a vendor-neutral, accurate DSS that meets the demands of businesses. This tool should be able to meet the organization's technological requirements.

Every determinant has some effect on an organization's choice. Each organization's demand will be represented by a vector, with each dimension representing an influential factor. The words determinant and dimension will be used interchangeably throughout the rest of this chapter. The term degree will relate to the extent to which a factor has an impact on each business. The phrases "organizational need" and "vector" will be used interchangeably throughout this document.

Constraints *The design of the DSS tool is very complicated and faces many constraints. The first constraint is extremely sparse data. To ensure precision and accuracy, a large number of determinants should be used, each with a range of degrees. As can be seen in the DSS tool, the number of determinants we identified is 10, each with approximately 5 degrees. An organization's need can thus be represented by a 10-dimension vector with 5 possible values for each dimension.*

The studied universe (the number of different possible vectors) is $510 = 9,765,625$. It is impractical to manually study each possible vector and propose a suitable technology mix. In addition, the number of manual entries individually studied by our team is very small compared to the universe's size. For this reason, the DSS tool has to adapt to the scarcity of the available data." [25]

"The second constraint is the absence of decision principles. The literature doesn't propose well-defined rules linking a vector to a suitable cloud technology. We personally believe that if such principles exist, they are emergent and can't be deduced without observing combinations of vectors and their suitable technologies." [25]

"The third constraint is correlation. Since the data is extremely sparse, it is very difficult to correlate between the organization's needs and the already available data. If an organization's needs match one of the few vectors manually evaluated, it is easy for the DSS tool to query the suitable technologies; otherwise, a distance should be defined in order to match the organization's need to the closest available vectors and then the suitable technology mix can be deduced." [25]

"The fourth constraint is distance. Euclidean distance is not suitable in this case since it considers the magnitude of the distance without considering the sense. Example: Consider a user who accepts a 3-star hotel, if 2 options are available; the first is a 2-star hotel and the second is a 5-star hotel. The Euclidean distance shows that the 2-star hotel is closer to the user's preference. Logarithmic distance is not suitable also since equal differences have different impacts depending on the position. To face this constraint, we had to develop a new distance as will be shown later." [25]

"The fifth constraint is the absence of well-defined priorities. Different users can emphasize different dimensions. This prevents the possibility of having a fixed distribution of weights /priorities for dimensions." [25]

2.5 Design

2.5.1 Determinants

"Based on literature review and our conducted survey, the determinants influencing the adoption of cloud computing are:" [25]

- *"Business Domain: This dimension refers to the affected area of business activity. This dimension is of high importance to the decision process because it allows, based on previous content choices, to determine the future orientations and strategy of the company concerning the management of its cloud solutions. It forms the basis of other dimensions (such as technical choices (infrastructure), managerial choices (such as governance and management), and strategic choices (choice of the cloud service provider))."* [25]
- *"Price: The literature suggests that cost savings are manifested in two aspects: energy and cost savings"* [25]
- *"Data Management: Clients must carefully consider these legal requirements and how the CSA (Cloud Security Alliance) deals with issues such as data flow when redundancy on multiple sites involves submitting data to different jurisdictions at different times. The issue of competence takes on more complexity when global compliance is taken into consideration and more than one cloud computing provider is used. In these cases, the client may have to coordinate negotiations between suppliers to ensure the management of the necessary data. This includes: Data preservation and redundancy, Data localization, Data entry, Data confidentiality, and Data availability."* [25]
- *"Traffic: It refers to the degree of traffic predictability (general workloads predictable or not in intensity, fluctuations, frequency, etc.)"* [25]

- ***"Control: This dimension refers to the level of control the company wants to have on the cloud computing solutions it adopts. It is true that once the company is deprived of some of its control, by using the services of a cloud provider, it requires different levels of control over their data, infrastructure, and processes." [25]***

- ***"Lock-in: This dimension refers to the degree of lock-in or lock-up that the cloud provider has on the company adopting its solutions. The lock-in is used not only to choose the solution but the supplier also. The locking situations that companies experience are the result of the rising difficulty they experience when it comes to changing cloud providers or replacing cloud services." [25]***

- ***"Support: Support is an interface provided by the cloud service provider to address issues and queries raised by the cloud service client. It comprises response time, support responsiveness, and resolution time." [25]*** ***"On the other hand, 19 possible technologies are covered i.e. could be recommended by our DSS. The technologies are:" [25]***
 - ***"Public Cloud (IaaS, PaaS, SaaS)" [25]***
 - ***"Private Cloud (IaaS, PaaS, SaaS)" [25]***
 - ***"Managed Private Cloud (IaaS, PaaS, SaaS)" [25]***
 - ***"Hybrid Cloud (IaaS, PaaS, SaaS)" [25]***
 - ***"Community Cloud (IaaS, PaaS, SaaS)" [25]***
 - ***"Dedicated servers / Multi cloud / Virtualization / Grid computing and Legacy IT" [25]***

"The proposed DSS is flexible (as will be described in the coming section) and can handle other technologies if needed." [25]

2.5.2 DSS objectives

"The DSS tool is an integral part of this work and its final product. Its recommendation accuracy is highly required since it supports decision-makers in setting the organization's strategy. In this section, we describe the design of our DSS tool, its objectives, and the constraints it faces. The foundational objectives of the DSS tool are:" [25]

- *"Simple user interface: The used dimensions and degrees should be generic and well formulated. This objective is aligned with the dialog generation and management system's requirement of intuitive and easy-to-use interfaces [167]." [25]*
- *"Precision and accuracy: For this objective to be achieved, a sufficient number of dimensions and a sufficient number of degrees per dimension are required. This objective has a severe consequence on the constraints as will be discussed later in this section." [25]*
- *"Flexibility: The selected dimensions and degrees are not exclusive, thus future needs and technology innovations might enforce changes. The DSS tool should be flexible to adopt any change in dimensions and their degrees without the need for manual intervention." [25]*
- *"Auto-learning and self-correcting: Any decision model used to automatically propose a technology mix may need fine-tuning and calibration to enhance its performance. Auto-learning makes the DSS tool in a continuous process to optimize its performance." [25]*

2.5.3 Components

To meet the constraints and design objectives shown above, we designed a Non-Personalized Collaborative Filtering Recommender System that receives the user's re-

quirements and helps to match with the suitable cloud mix. As will be shown in Chapter 3, market factors (external to the organization) will affect the future of cloud adoption and its success. For this reason, it is impossible to deduce the cloud adoption decision objectively solely from the organization's internal factors. For this reason, we decided to build an RS DSS to help benefit from the subjective influence of the decision-makers and the market trend.

"The designed DSS tool (Recommender System) is divided into 3 components which are the Web component, the backend server, and the database. As shown in Figure 2.6, the user (decision maker) interacts with the Web component where he responds to multiple questions. The answers represent the organization's needs and are filled into a vector (each question targets a 1 determinant and each answer represents its degree). The vector is submitted to the backend server which in turn retrieves all the stored data from the database server. The user's vector and all the retrieved data are processed, and 3 technology mixes are recommended each with an accuracy level. These 3 technologies are recommended to the user through the Web component. The user will be then asked to select the technologies he will implement. The user's selected technologies are stored in addition to his answers on the database server. The stored data will help the system increase its accuracy while serving future users." [25]

2.5.4 Design

The flowchart of the "Processing operation" presented in Figure 2.6 is shown in Figure 2.7.

2.5.4.1 Step 1

"As presented in Section 2.4, a distance should be able to calculate the correlation between the user's answer vector (organization's need) and any vector stored in the database. As also presented in Section 2.4, the existing distances do not

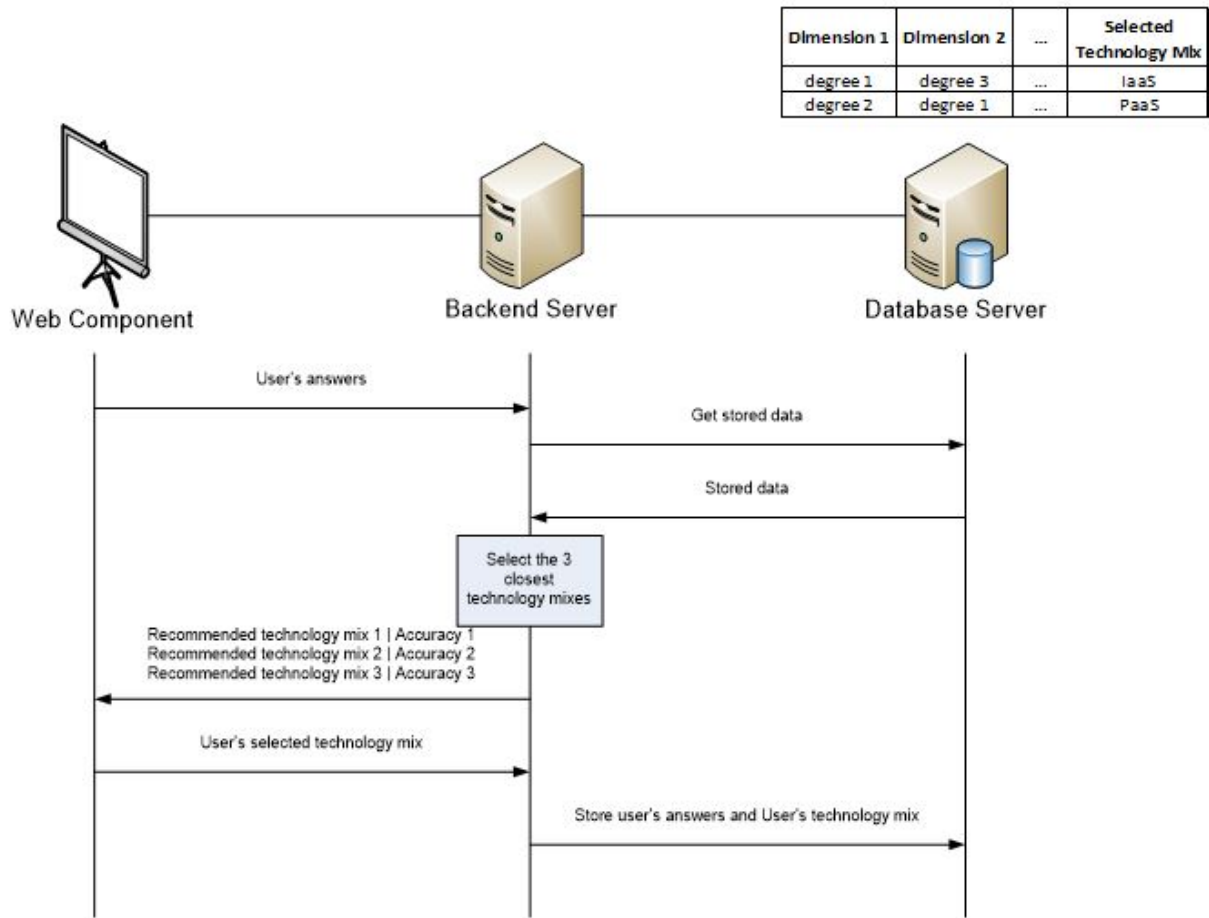


FIGURE 2.6 – The proposed DSS' message flow diagram.

satisfy our requirements, so, we had to develop a distance formula that satisfies our needs as shown next." [25]

"The backend server calculates the distance between the user's vector and every row in the stored data (row 0 in Figure 2.6 is degree 1, degree 3, ..., IaaS). The distance expression we developed is as follows:" [25]

$$Distance[k] = \sum_{j=0}^{M-1} \beta[j] \times \alpha \times (A[j] - S[k, j])$$

"Where $\beta[j]$ is the priority of metric j (in the current version of the DSS tool, all priorities are set to 1). α is a small positive value when $S[k, j] \geq A[j]$ (it is set to 1 in this version of the DSS tool) and a large positive value otherwise (it is set to 2 in this version of the DSS tool). α is used to represent the higher impact of a downgrade in comparison with an upgrade. $A[j]$ is the user's answer for

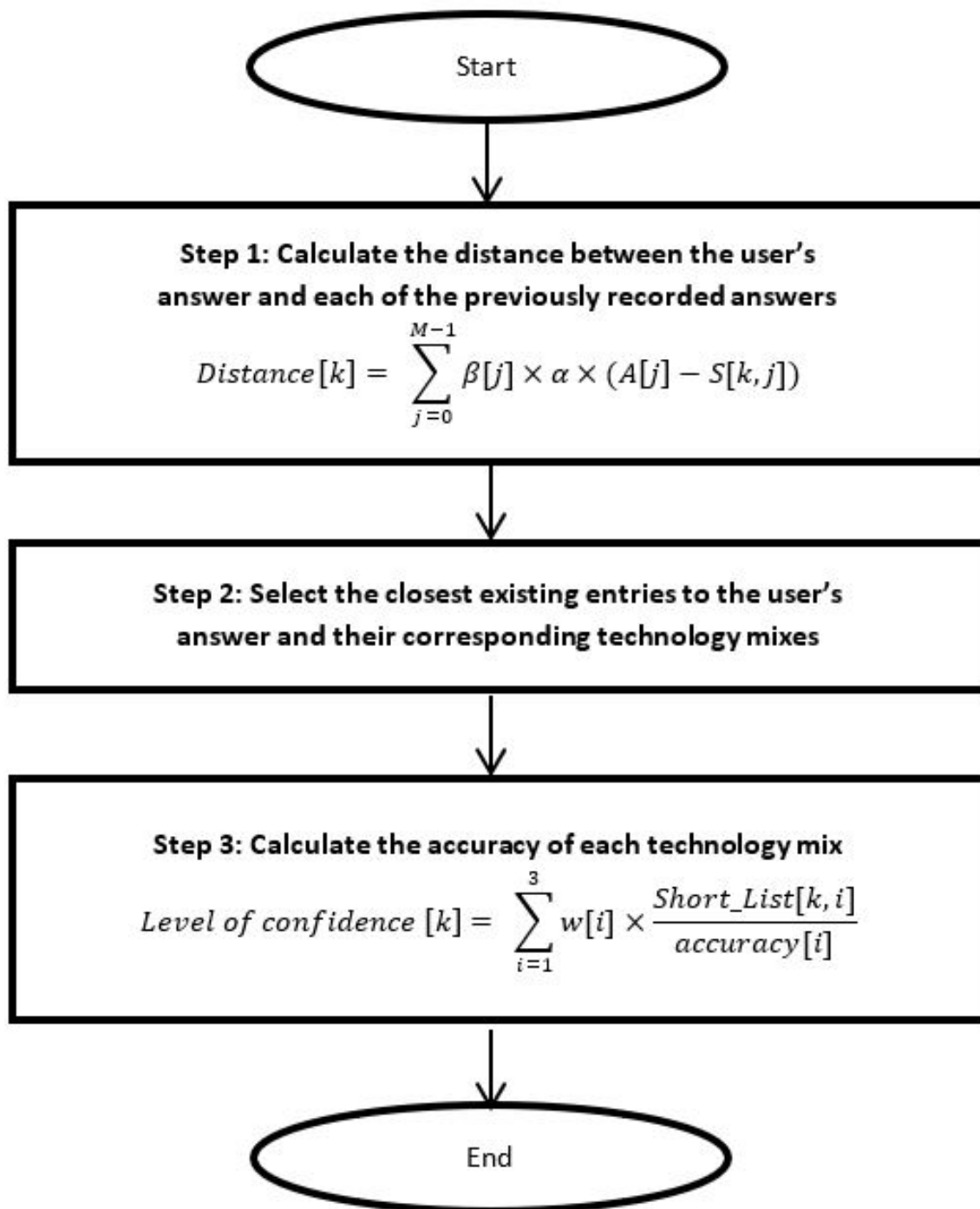


FIGURE 2.7 – Flowchart of the processing operation i.e. to select the closest 3 technologies.

dimension j while $S[k, j]$ is the stored value for row k and for dimension j . M is the number of used metrics." [25]

2.5.4.2 Step 2

"The backend server selects the technology mixes having the smallest distance (closest to the user's answer)." [25]

2.5.4.3 Step 3

"The server then calculates the level of confidence in each recommendation. The equation calculating the level of confidence is: " [25]

$$\text{Level of confidence}[k] = \sum_{i=1}^3 W[i] \times \frac{\text{Short_List}[k, i]}{(\text{accuracy}[i])}$$

"Where $\text{short_List}[k, i]$ is the number of rows having i th smallest distance and select technology mix k . $\text{accuracy}[i]$ is the number of rows having i th smallest distance. $W[i]$ has the following values:" [25]

- $W[1] = 1 - (\text{weighted_min}[1])^{\text{accuracy}[0]}$.
- $W[2] = \text{weighted_min}[1]^{\text{accuracy}[0]} \times \text{weighted_min}[2]$.
- $W[3] = \text{weighted_min}[1]^{\text{accuracy}[0]} \times \text{weighted_min}[3]$.

"Where $\text{weighted_min}[1] \leq 0.66$ and $\text{weighted_min}[2] + \text{weighted_min}[3] = 1$. $\text{weighted_min}[1]$ is set to 0.5 in this version of the DSS tool, while $\text{weighted_min}[2]$ is set to 0.7 and $\text{weighted_min}[3]$ to 0.3." [25]

2.5.5 Auto-learning and Self-correcting

"This DSS has 2 levels of auto-learning and self-correcting. The first level is intrinsic to all RS since the measurement of the new distance and level of confidence will be affected by every new entry to the database. Users' answers will

normalize the effect of inaccurate entries and the system will have better performance with more accurate entries in the database. The second level of auto-learning and self-correcting is design extrinsic. The DSS accuracy depends on its configuration (the values of $\beta[j]$, α and $weighted_min[i]$). The tool runs a periodic algorithm to fine-tune its configuration."[25]

2.5.6 Fine-tuning algorithm

The fine-tuning algorithm will try for all possible combinations of ($\beta[j]$, α and $weighted_min[i]$) to predict the technology mix for every input vector. After that, the algorithm will compare, for every parameter combination, the predicted technology mix to the selected one. The difference between the predicted and selected technologies is calculated using RMSE. The parameter combination that scores the smallest RMSE value will be used by the RS DSS, since it increases the system's predictive accuracy the most. The fine-tuning algorithm is presented in the flowchart illustrated in Figure 2.8.

We selected RMSE as an accuracy metric since the DSS will offer one technology mix for every user, thus rank accuracy and classification accuracy metrics become useless. We can deduce that predictive accuracy metrics are the only ones suitable. RMSE's advantage over MAE and MAUE is its lower tolerance to large deviations between the predicted and selected mixes.

2.5.7 Data quality

The collaborative filtering recommender system model, no matter what type of field it is used on, be it e-commerce or education, is not only affected by its parameter and the tuning methods followed to best fit the training data. To achieve the best accuracy results from evaluation metrics, it is necessary to analyze and study the quality and the quantity of the data itself. As shown in [168], working with the data is most of the time risky. Even with the most efficient algorithms, the output might end up biased, un-expected, and

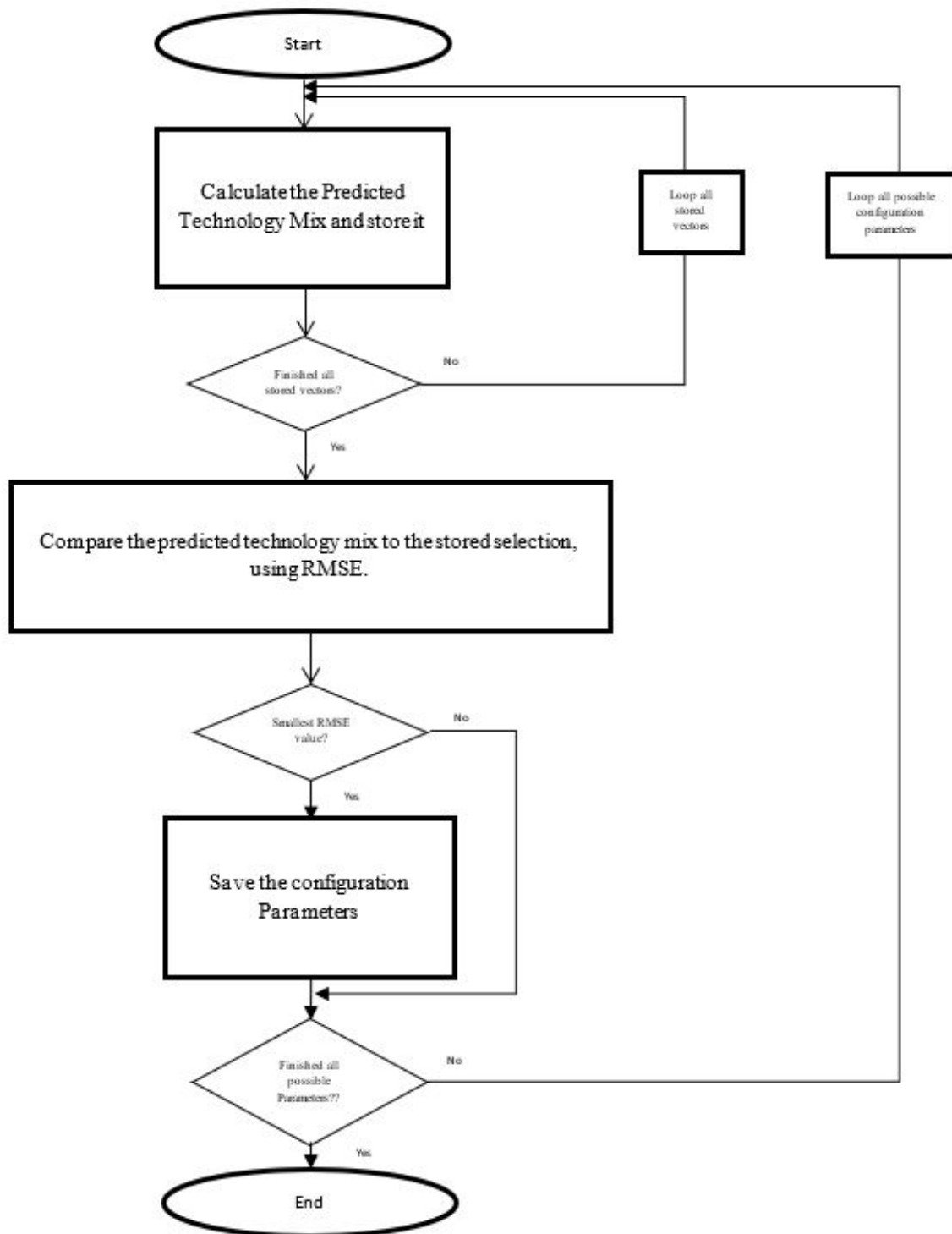


FIGURE 2.8 – Fine-tuning algorithm flowchart.

fundamentally flawed. A more interesting work [169] [170] demonstrates how the content in the datasets can be managed to shape the recommender’s output and immensely affect hundreds of users of a certain system. It is valid that randomness and noise in data can not only affect the accuracy results of a model [171], [172] but ultimately affect the quality of recommendation presented to a certain user, however, this shows that the consequences

of engineering certain data patterns in a recommender dataset can present markedly more considerable risks on the system's users.

This leads to two types of problems that are faced when implementing recommender systems:

- Small datasets (the quantity of the data)
- Noise in the data (the quality of the data such as natural and malicious noise, obfuscation)

The issue with small datasets when employing recommender models such as collaborative filtering (CF) approaches is the cold-start problem that it encounters with data that is inevitably sparse especially in new online systems. That content is just not dense enough to fill the huge user-item matrix. During the cold-start phase, the knowledge-based system produces more accurate results, but the collaborative system produces more accurate results later on. For dealing with the cold-start problem, including knowledge-based systems is often preferred [173]. Other solutions such as active learning [174] can also be efficient when addressing such a problem faced by CF recommenders, however, the user will eventually need to accurately provide insight on the queries presented to him when he initially connects to the system.

Problems that result from noise in the systems can be tackled by manipulating data pre-processing methods for noise management before loading the recommender with the dataset and training it. Various methods exist depending on the type of noise present in the data, be it malicious [175], natural [168], or obfuscation [170]. Unfortunately, there is yet to be a unified noise system that fundamentally deals with the noise in a dataset irrespective of the recommender used, therefore, the data needs to be manually analyzed and it is more adequate to run tests that cater to all noise types before running tests on an algorithm. In a CF environment, some easy and efficient noise management solutions can be adopted to deal with the problem using pre-processing methods such as in [176], however, for other models that don't solely consider ratings such as knowledge-based, other methods need to be considered to overcome this issue.

2.6 Collected Data

The tool has been publicly available for a period of one year, and we were able to collect 278 responses, mostly from the Middle East and Lebanon specifically. The respondents have their profiles distribution as shown in Figure 2.9.

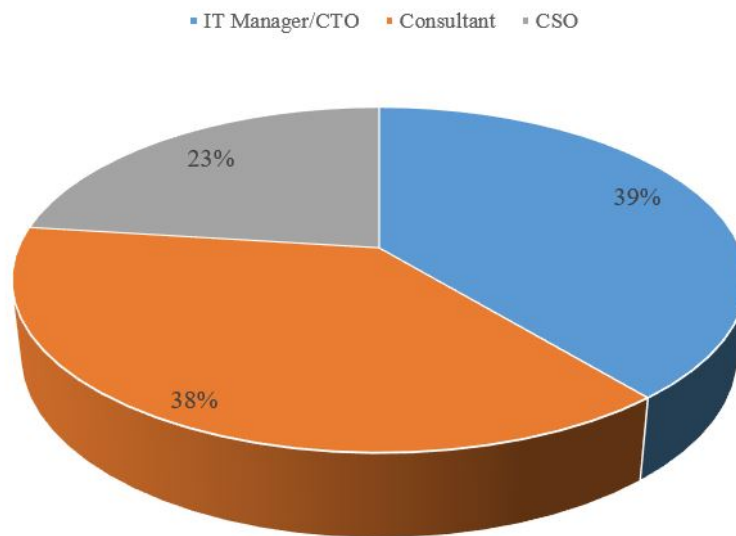


FIGURE 2.9 – Distribution of respondents by position.

As can be seen in Figure 2.9, all the respondents are decision-makers or experts, and their opinions are considered authoritative. The respondents represent industries across different market sectors. These market sectors are distributed as shown in Figure 2.10.

As seen in Figure 2.10, a large share of the respondents belongs to the financial sector, whose members are usually reluctant to adopt a new technology unless proven reliable. We expect to see in the selected technologies a considerable portion of private and hybrid technologies selected. The participants represent companies of different sizes. The distribution of respondents by company size is shown in Figure 2.11.

As seen in Figure 2.11, a large share of the respondents belongs to small companies. Small non-technology companies usually find variations of SaaS very convenient. The respondents represent companies of different ages. The distribution of respondents by company age is shown in Figure 2.12.

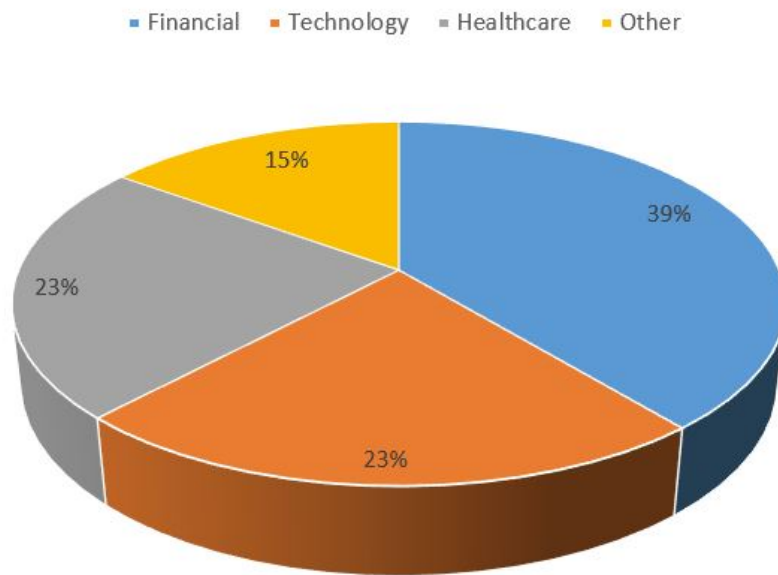


FIGURE 2.10 – Distribution of respondents by market sector.

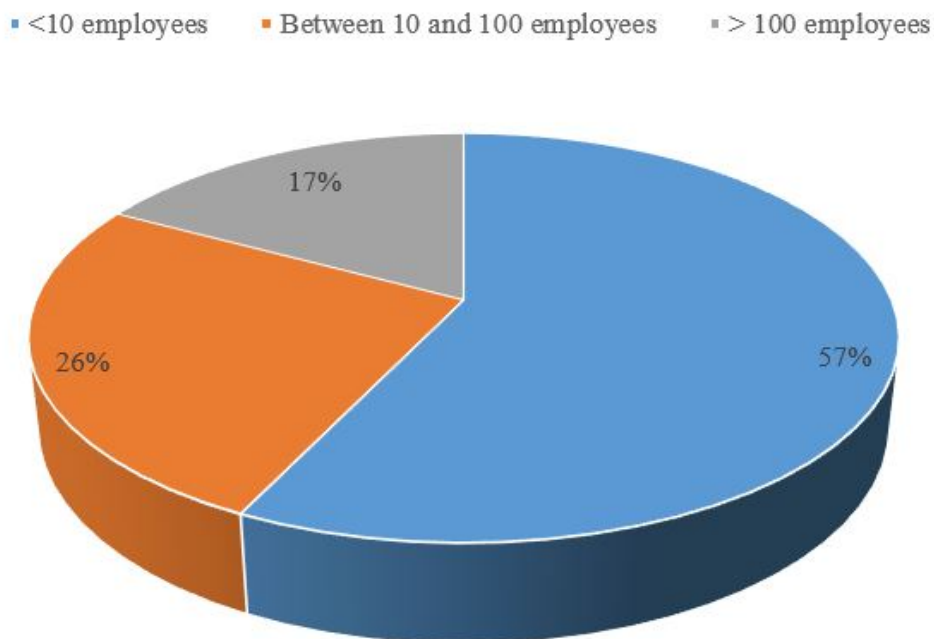


FIGURE 2.11 – Distribution of respondents by company size.

As seen in Figure 2.12, a large share of the respondents belongs to new companies. Previous expenditures on technology and the quality of a company’s system influence the adoption decision. The distribution of selected technologies is shown in Figure 2.13.

As seen in Figure 2.13, legacy technologies such as “Dedicated servers” and “Grid Computing” were selected by 14% of the respondents. Public cloud technologies sum up

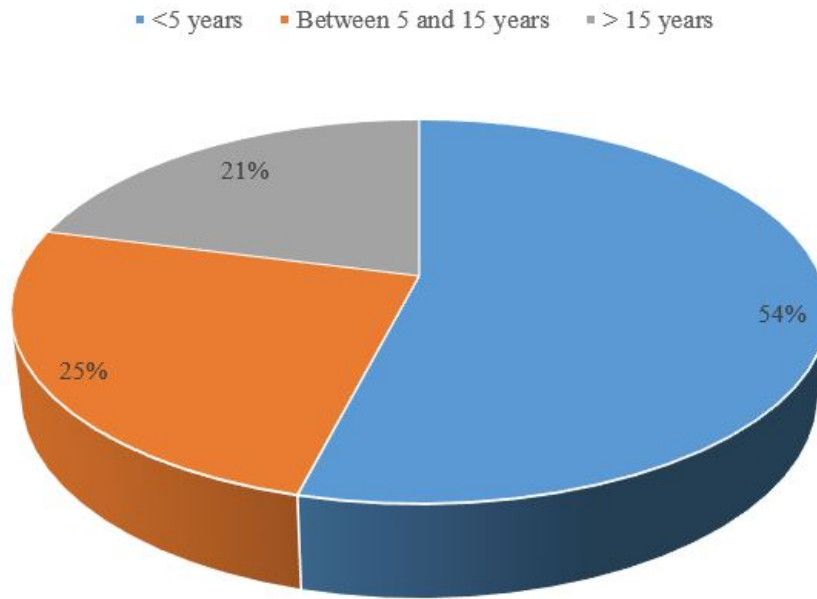


FIGURE 2.12 – Distribution of respondents by company age.

to 31%, while private and managed cloud technologies sum up to 60% of the respondents' decisions. The total percentages are different than 100% since we are measuring the percentage of respondents who selected a specific technology, while the respondent has the freedom to select any number of technologies simultaneously (Technology Mix).

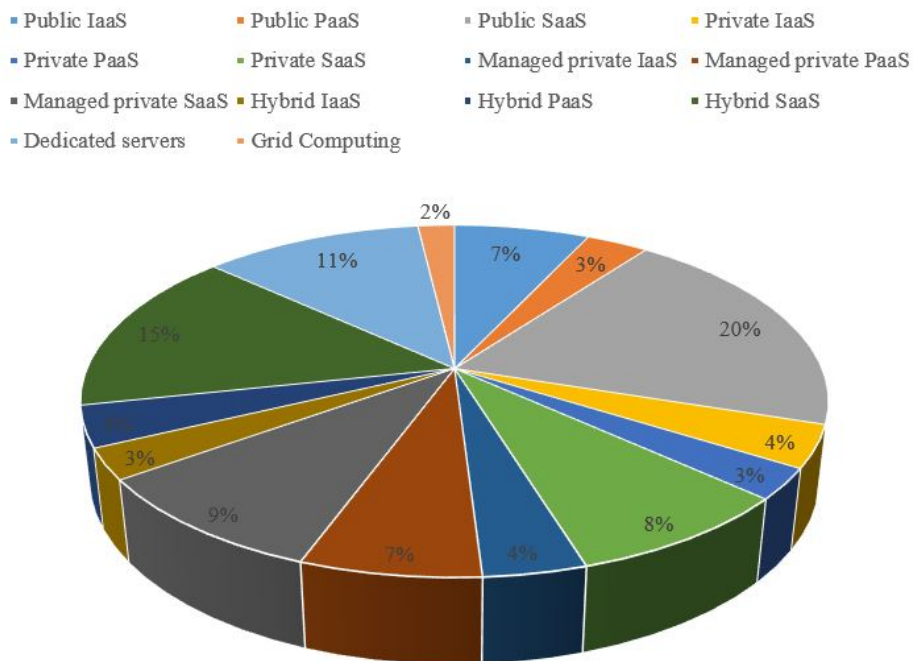


FIGURE 2.13 – Technology mixes selected by respondents.

2.7 Evaluation

The accuracy of the tool's recommendations, over the process of data collection, has been measured using MAE and the results are shown in figure ???. The y-axis shows MAE while the x-axis shows the number of populated answers in the tool.

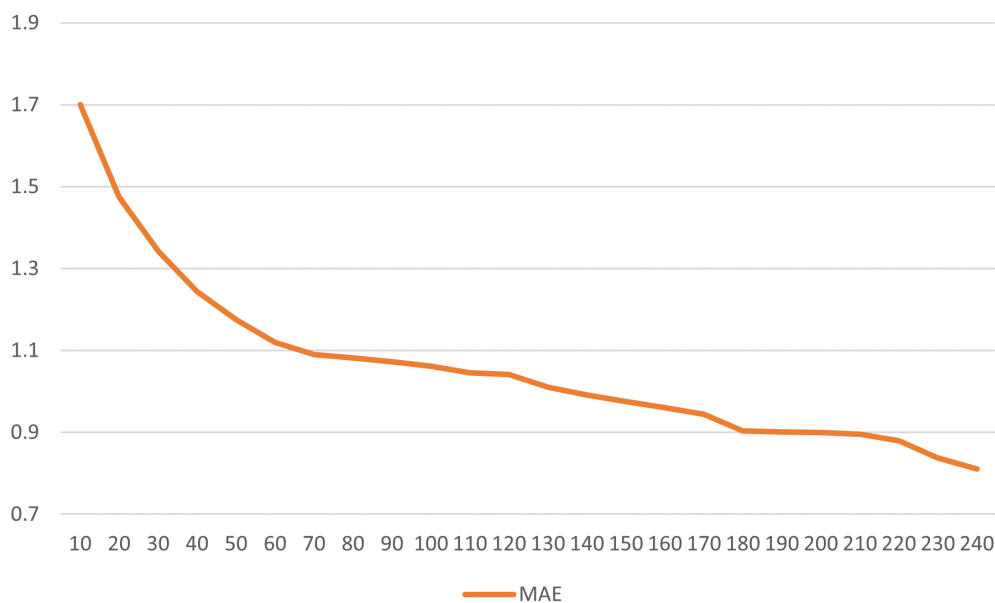


FIGURE 2.14 – Evaluation of the recommendation's accuracy Using Predictive Accuracy Metrics - MAE

As can be seen in figure 2.14, the system is following a gradient decent towards low MAE values which means that the tool is achieving good accuracy.

2.8 Summary

This work is our response to the need for a holistic, generic, and non-trivial DSS that helps decision-makers in their strategy of cloud computing adoption. We tried to do so by: integrating a richer mix of cloud computing adoption that goes beyond the traditional price/capacity mix and proposing a richer offer of cloud computing services and similar solutions; and finally, by targeting a larger sample of users and organizations.

The designed DSS satisfies CBOD's task 4. The updated project status is shown in table 2.1.

TABLE 2.1 – Chapter 2 contributions to CBOD objectives and tasks

	Status		Status
<i>Objective 1</i>	Done	<i>Task 1</i>	Done
<i>Objective 2</i>	Done	<i>Task 2</i>	Done
<i>Objective 3</i>	Pending	<i>Task 3</i>	Pending
<i>Objective 4</i>	Pending	<i>Task 4</i>	Done
<i>Objective 5</i>	Pending	<i>Task 5</i>	Pending
<i>Objective 6</i>	Pending	<i>Task 6</i>	Pending

The designed DSS is based on RS since, as will be shown in the coming chapter, market factors affect the success of cloud computing in a studied market.

Appendix - A: Active Learning Questions

The questions asked to the user and their respective possible answers are:

- General Questions (Business & Strategy)

1. Does your enterprise have a business strategic vision for the next 2-3 years?
 - a. Do not know
 - b. No vision in place or being developed
 - c. Partially – we may have an initial vision but it is incomplete, not well formulated or communicated
 - d. Yes, we have well formulated strategic vision but haven't taken significant actions to communicate or implement it yet, we may not have time, resource, commitment or knowledge to implement it
 - e. Yes and it is being implemented, it is the foundation of our business direction and priority-setting
2. Does your organization have a strategy for using cloud technology?
 - a. Do not know

- b. NO - No strategy, cloud computing is a topic of discussion with the business and/or within IT but we have yet developed our point of view. No plans to develop additional strategy
 - c. Partially - We have an informal approach to cloud, may be doing limited pilots to get knowledge, we may have a strategy but no written plans or roadmap at any level. We expect to make improvements in next 1-2 years
 - d. Yes - We have IT centric cloud strategies, plans, and roadmaps that is shared across the IT organization
 - e. Totally – we have strategy, plan and roadmap that is enterprise-wide and includes It and business.
3. How will your organization’s investments in cloud computing change in the coming 1-2 years?
- a. Do not know
 - b. Plan to decrease
 - c. Would be the same
 - d. Increase
 - e. Significantly increase
4. What cloud related product or service is of greatest interest to your organization?
- a. Social business / media
 - b. Mobile computing
 - c. Analytics / big data
 - d. IT service Management
 - e. DevOps
 - f. Software, infrastructure or platform as a service
 - g. Integration including service broker
- Metric Questions
5. How do you characterize your organization’s level of data traffic?
- a. Unpredictable

- b. Considerably predictable
 - c. Predictable
 - d. Very predictable
6. How do you characterize the data used in cloud operations?
- a. Non-sensitive
 - b. Considerably sensitive
 - c. Sensitive
 - d. Very sensitive
7. How are the organization's operations in which cloud computing would be used?
- a. Public facing
 - b. Critical
 - c. Mission – critical
 - d. Specific
 - e. Combination of above
8. What are your organization's security requirements?
- a. Non-maintained
 - b. Average
 - c. Maintained
9. How are your organization's objectives in terms of cloud performance?
- a. Low
 - b. Maintain existing levels
 - c. Average cloud services performance
 - d. Above average
 - e. High
10. What are your organization's control requirements over the cloud service?
- a. None
 - b. Maintain the existing control over data and operations
 - c. High
11. What are your organization's requirements in terms of legal compliance?

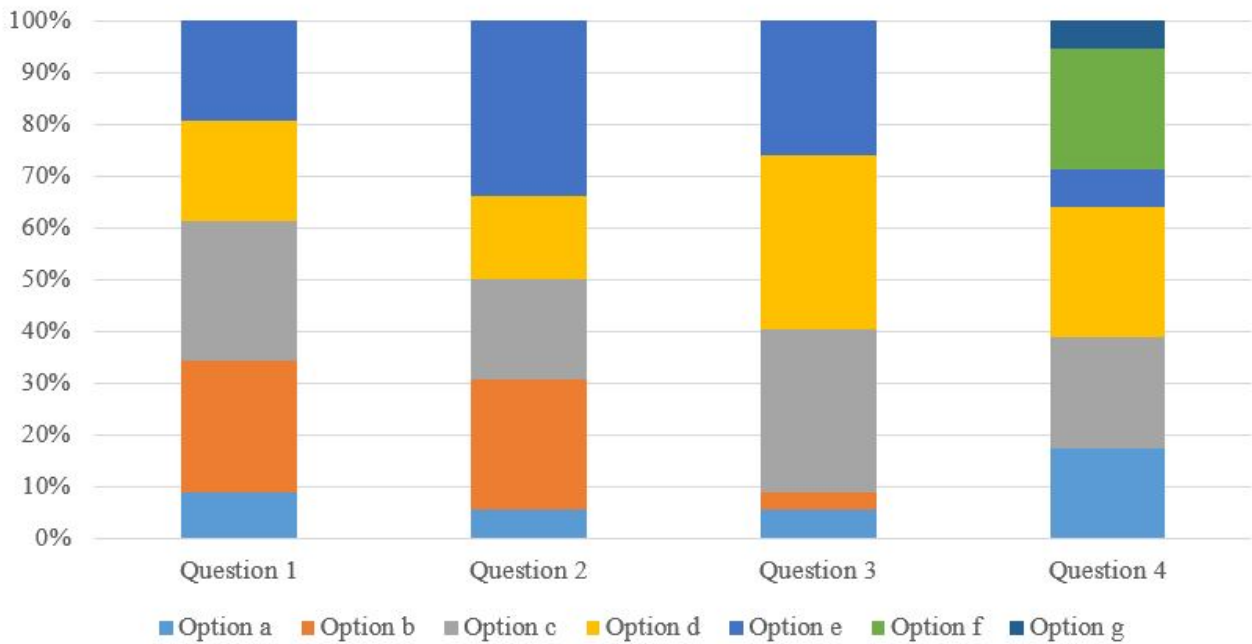
- a. None - accept the provider's SLA
 - b. Yes - negotiate the agreements
12. What are your organization's acceptable levels of lock-in?
- a. None
 - b. Moderate lock-in
 - c. Complete lock-in
13. Do you think you need a sophisticated IT support to manage cloud solutions?
- a. Extremely sophisticated needs
 - b. Sophisticated needs
 - c. Average needs
 - d. No needs
14. How do you characterize the degree technical compliance (between the cloud technology and your legacy technology)?
- a. No compliance problems
 - b. Some compliance problems
 - c. Many compliance problems

Appendix - B: Accuracy metrics for recommender systems

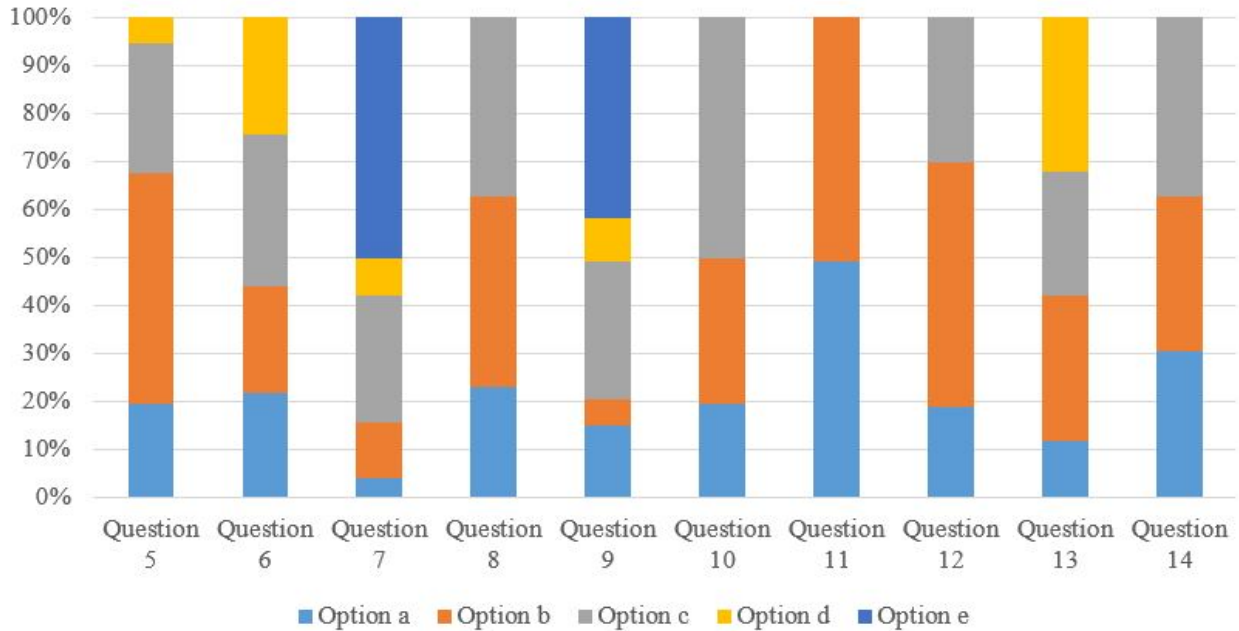
The performance of any RS is measured by one or more metrics depending on the designer's intentions. *"The accuracy metrics are divided into three major classes [177] [178]:"* [25]

- *"Predictive accuracy metrics: they measure how close the ratings estimated by a recommender system are to the true user ratings. They are usually used to evaluate non-binary ratings. The most popular metrics in this category are Mean Absolute Error (MAE), Mean Squared Error (MSE), Root*

Responses on General Questions (Business & Strategy)



Responses on Metric Questions



Mean Squared Error (RMSE), Normalized Mean Absolute Error (NMAE), and Mean Absolute User Error (MAUE) [179], [180], as shown in Table 2.2." [181]

- **"Classification accuracy metrics: they ignore the exact rating or ranking**

of items, and measure only the correct or incorrect classification. The most used metrics in this category are precision and recall, in addition to fall-out, miss rate, inverse precision, inverse recall, F1-measure, Mean Average Precision (MAP), Geometric Mean Average Precision (GMAP), Harmonic Mean Average Precision (HMAP) and Quadratic Mean Average Precision (QMAP). For more information about these metrics, the reader can refer to [182]." [181]

- "Rank accuracy metrics: they measure how much the recommender system is able to estimate the correct order of items with respect to the user's preferences. These metrics are useful when we care about giving the user the recommendations in a certain ranking. They use relative ordering regardless of the exact values. Therefore, even if the recommender system fails to predict the ratings accurately, if it gives the items in the correct order of preference then these metrics will still achieve a great score. Some used metrics from this category are Kendall's τ , Spearman's ρ , DCG, and nDCG [180]." [181]

TABLE 2.3 – Confusion Matrix Used in Recommender Systems

	Relevant	Irrelevant
Recommended	tp	fp
Not Recommended	fn	tn

"A major problem with the frequently used metrics presented in Table 2.4 is that they can include great biases. This issue can be solved by three new metrics"[181] introduced by Powers [183]:

$$\text{Markedness} = \text{Precision} + \text{InversePrecision} - 1 \quad (2.1)$$

$$\text{Informedness} = \text{Recall} + \text{InverseRecall} - 1 \quad (2.2)$$

TABLE 2.2 – Details of the Predictive Accuracy Metrics

Metric	Definition	Formula	Comments
Mean Absolute Error (MAE)	<i>"It computes the deviation between predicted ratings and actual ratings."</i> [181]	$MAE = \frac{1}{n} \sum_{i=1}^n p_{-i} - r_{-i} $	<i>"Prediction error of a heavy rater is very small compared to that of a cold start user. However, MAE weighs every prediction error in the same way. But in reality, the heavy rater is probably satisfied with the prediction error while cold start users are not."</i> [181]
Mean Absolute User Error (MAUE) [65]	<i>"It computes the MAE for every single user independently, then averages all the MAEs."</i> [181]	$MAUE = \frac{1}{ U } \sum_{u \in U} MAE(u)$	<i>"This method solves any possible bias introduced in the calculation of the MAE. In this way, all the users will have the same weight in the computation."</i> [181]
Root Mean Square Error (RMSE)	<i>"As MAE, it also computes the deviation between predicted ratings and actual ratings."</i> [181]	$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (p_{-i} - r_{-i})^2}$	<i>"Similar to MAE, but it places more emphasis on the larger deviation."</i> [181]

$$MatthewsCorrelation = \pm \sqrt{Markedness.Informedness} \quad (2.3)$$

TABLE 2.4 – Details of the Classification Accuracy Metrics Used in this Study

Metric	Definition	Formula	Comments
Precision	"It computes the deviation between predicted ratings and actual ratings." [181]	$\text{Precision} = \frac{tp}{tp+fp}$ $= \frac{\text{gooditemsrecommended}}{\text{allrecommendations}}$	"Prediction error of a heavy rater is very small compared to that of a cold start user. However, MAE weighs every prediction error in the same way. But in reality, the heavy rater is probably satisfied with the prediction error while cold start users are not." [181]
Recall	"It computes the MAE for every single user independently, then averages all the MAEs." [181]	$\text{Recall} = \frac{tp}{tp+fn}$ $= \frac{\text{gooditemsrecommended}}{\text{allpreferences}}$	"This method solves any possible bias introduced in the calculation of the MAE. In this way, all the users will have the same weight in the computation." [181]
Inverse Precision	"As MAE, it also computes the deviation between predicted ratings and actual ratings." [181]	$\text{InversePrecision} = \frac{tn}{tn+fn}$ $= \frac{\text{baditemsnotrecommended}}{\text{allnotrecommendeditems}}$	"Similar to MAE, but it places more emphasis on the larger deviation." [181]
Inverse Recall	"As MAE, it also computes the deviation between predicted ratings and actual ratings." [181]	$\text{InverseRecall} = \frac{tn}{tn+fp}$ $= \frac{\text{baditemsnotrecommended}}{\text{allbaditems}}$	"Similar to MAE, but it places more emphasis on the larger deviation." [181]
F1-measure	"As MAE, it also computes the deviation between predicted ratings and actual ratings." [181]	$F1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$	"Similar to MAE, but it places more emphasis on the larger deviation." [181]

Chapter 3

The Network Economics of Cloud Computing

Contents

3.1 Introduction	78
3.2 Literature Review	80
3.2.1 Traditional EPC vs. vEPC	80
3.2.2 EPCaaS and Multi-tenancy	82
3.2.3 Pricing scheme	84
3.3 Proposed Approach and Evaluation	93
3.3.1 Expected scenario	93
3.3.2 Proposed approach and metrics	94
3.3.3 Metrics	100
3.3.4 Evaluation	100
3.4 Conclusion and Future Challenges	103
Appendix	104

3.1 Introduction

Cloud Computing vendors and researchers promise competitive advantage and financial savings for potential clients. When we consider individual businesses, migrating to the cloud can be financially feasible and the most rewarding option. When we consider the ecosystem as a whole, the rewards of cloud computing can become blurry. The literature considers the individual business' requirements to decide on cloud adoption without having a vision into the market's future. Mobile operators' decision-makers experience the same limitation when considering Multitenancy cloud computing for their networks.

Mobile operators are busy planning for the coming 5G era which supports a wide range of potential applications. A new ecosystem of content providers is growing around this communication infrastructure and some of the main concerns is how will the mobile operators slice their spectrum to offer dedicated services to these content providers. 5G is going to change how business is performed in many industries; according to the Next Generation Mobile Networks (NGMN) alliance, "5G is an end-to-end ecosystem to enable a fully mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with a consistent experience, and enabled by sustainable business models" [184]. It is really a disruptive technology that has the potential to change even the mobile operator's business model.

Yousaf et al. claimed that Virtualized Network Functions (VNF), Evolved Packet Core as a Service (EPCaaS), and Multi-tenancy decrease the total cost of ownership and increase a mobile operator's competitiveness [185]. In reality, such a claim is true when part of the mobile operators adopts these new technologies that give them an advantage over other operators; but when all the mobile operators migrate to multi-tenancy cloud-based core services, the claimed advantages are not necessarily maintained. In addition to that, the promised reduced Capital Expenditures (CAPEX) can considerably reduce the startup-cost which is an important economic barrier-to-entry that works for the advantage of already running mobile operators and hinder other players from joining. The Pay-as-you-go feature of cloud computing also reduces the effect of the economy of scale which is another important economic barrier-to-entry that also works for the advantage of already

running mobile operators. EPCaaS and other forms of Cloud-based mobile operators can be invasive to the current stability in the market and current “business may not be able to recover costs and effectively compete” [186].

Various programmable ABM environments exist in the literature. ABM can also be performed using custom-made object-oriented programs. In this chapter, Netlogo [187] will be used as the programmable modeling environment for simulating the cloud computing market behavior.

Research framework

Market prediction is left for a dedicated few who are experts in their market. Nevertheless, history is full of experts who failed to successfully predict market behavior, especially in the technology sector. Using ABM for cloud market prediction is courageous and risky at the same time. For this reason, we decided to consider a specific application of cloud computing as a reference.

We are interested in evaluating whether multi-tenancy cloud-based core services (also called carrier cloud) are viable and economically feasible. We are also interested in studying its effect on major players especially that this technology frees the market from oligopoly and small players from the control of dominant players. Although virtual mobile operators and infrastructure sharing is currently implemented, the business model in place makes virtual mobile operators dependent on dominant operators who own the infrastructure and set the prices. In this chapter, we will study the market behavior using Agent-Based Modeling as a carrier cloud emerges, thus creating a model that predicts the effect of this new technology on prices, customers, and telecom operators. To the best of our knowledge, this work is the first to study and predict the mobile network’s market behavior under the effect of multi-tenancy cloud-based core services.

Existing literature barely touches on the mobile market behavior as EPCaaS and multitenancy get implemented. As this technology emerges, the current market stability may diverge into a purely competitive market or converge into a monopolistic market. The originality of this work can be identified as:

- This work is the first, to the best of our knowledge, to raise the issue of market structure

uncertainty due to the introduction of EPCaaS/multitenancy as part of 5G.

- Existing predictions used in the mobile market are based on historical data. Such methods are notoriously inaccurate in predicting the implications of emergent technologies (such as the introduction of EPCaaS in 5G). This work is the first, to the best of our knowledge, to simulate the market and predict its behavior based on the interaction between different players, not by interpolating previous behaviors.
- The mobile market differs between countries, thus country-specific studies have limited impact and may not be valid for different countries. This study is designed to be country-independent, where the user can configure the simulator (we developed) to match the studied market's parameters.
- This study can be used by decision-makers to find the right parameters for their market's case to ensure a suitable outcome.

3.2 Literature Review

In this section, we start by presenting the related technologies behind EPCaaS such as EPC, vEPC, and NFV. We then discuss cloud computing's business model and pricing schemes.

3.2.1 Traditional EPC vs. vEPC

Efforts to transform the traditional EPC into a set of virtualized modules started since 2011 [188]. Sama et al. [189] proposed cloud-based network sharing between mobile operators for the LTE/EPC architecture. This proposal didn't introduce a new business model since existing mobile operators were advised to co-invest in a shared cloud network that offers services to the partnering operators, thus, using the cloud's community deployment model. On the contrary, this paper emphasizes the cooperation between mobile operators, thus inherently causing the competition to stabilize.

The term carrier cloud started to be present in research papers such as in [190], [191], [192], [193], and other papers, and this announced the start of an interest in cloud-based core services. Similarly, NFV (Network Function Virtualization) emerged as a facilitator for dynamic mobile network [194] management, carrier cloud, and multi-tenancy. NFV is also expected to "change the core structure of the telecommunications infrastructure to be more cost-efficient" [195].

Bagaa et al. [196] designed an algorithm for calculating the most suitable number and locations of vEPC's virtual instances over the federated cloud which is suitable for carrier clouds and EPCaaS. This placement algorithm ensures QoS and maximizes the profits of cloud operators. Resource pooling has been proposed by Rodriguez et al. [130] to enhance the performance of vEPCs running in resource-limited general-purpose datacenters.

Khan [197] proposed to use NFV over SDN (Software Defined Networks) and backed his proposal by predicting OPEX reductions. These reductions include, among others, eliminating the takedown and provisioning of network upgrades and eliminating physical boxes and cable migration. Sama et al. [198] discussed the realization of an operational VNF/SDN stack and control architecture. Valtulina et al. [199] studied the Mobility Management in vEPC and proposed a Distributed Mobility Management under VNF/SDN environment.

Sousa et al. [200] proved the technical feasibility of migrating existing mobile networks to a fully cloudified environment. They also proposed an architecture that includes a business lifecycle optimizing CAPEX/OPEX and a technical lifecycle leveraging a deployment model virtualizing MNO's core network and RAN elements. The authors of [201] discussed vEPC from vendors' point of view, listed EPC market revenue projections, and compared vEPC suppliers. This paper is one of the rare publications looking at the mobile network industry from an economic perspective.

3.2.2 EPCaaS and Multi-tenancy

Cloudified EPCs received attention from the research community and some unique services have been proposed which makes vEPC own a competitive advantage against legacy deployments. Zhao et al. [202] proposed MOBaaS (Mobility and Bandwidth prediction as a service), uniquely for cloudified EPCs, which provides location predictions of a single/group user equipment (UEs) in the future moment. This information can be used for self-adaptation procedures and optimal network function configuration during run-time operations.

Samdanis et al. [203] envisioned future multi-tenant systems to include Over-The-Top (OTT) and Vertical industries. The first is simply a Mobile Virtual Network Operator (MVNO), where the leasing party is not a mobile operator. The second focuses on providing complementary services to the telecommunication industry. They also proposed multi-tenancy at the radio level using their 5G Network Slice Broker, which was defined by 3GPP's Services Working Group SA1. A required attribute to allow the 5G Network Slice Broker to work, among other attributes, is Dedicated Core Network (DCN) where each DCN is designed to serve a different type of user. DCNs are important in facilitating specialized carrier clouds.

Taleb et al. [204] demonstrated the feasibility of the on-demand creation of cloud-based elastic mobile core networks. They also described two implementation scenarios for EPCaaS. The first scenario uses full virtualization where both user plane and control plane functional entities are implemented in VMs. The second scenario uses partial virtualization where only control plane functional entities are used in VMs.

Li et al. [205] proposed Caching as a Service as a new feature for cloud-based 5G networks that matches and exceeds the already proposed front-haul and back-haul caching techniques. The virtualization of Caching as a Service has been proposed in [206] by the same authors. Additional EPCaaS features are proposed such as resiliency [207].

Jeon et al. [208] proposed a traffic offloading framework between legacy EPC and vEPC. This work is based on the fact that existing design and deployment initiatives for 5G

do not consider that their adoption by operators will need to pass through a co-existence period with the existing legacy network.

Cau et al. [209] proposed novel solutions for effective subscribers' state management in quality-constrained 5G scenarios which will help ensure efficient elasticity provisioning of EPCaaS stateful components. This work leverages SDN and NFV in addition to proposed protocols and network nodes to move network control functions close to eNB (Mobile Edge Computing) which results in robust network decisions. Solozaba et al. [210] benefitted from the previous work to propose Non-Standalone 5G ETSI MEC-based architecture for Mission-Critical Push-to-Talk. This work is among many (such as [211], [212], and [213]) that leverage EPCaaS functionalities at the edge level to offer new services.

3.2.2.1 Business models

EPCaaS business model hasn't been touched before in the literature and this work is considered the first to look at EPCaaS from a business/economic perspective. In this section, we survey the cloud computing business model as discussed in the literature.

Chang et al. [214] classified the business models under eight dimensions which are: 1- Entertainment and Social Networking. 2- Venture Capitals. 3- In-House Private Clouds. 4- All-In-One Enterprise Cloud. 5- One-Stop Resources and Services. 6- Government funding. 7- Support and Services Contracts. 8- Service Provider and Service Orientation. Weinhardt et al. [26] described CBMF (The Cloud Business Model Framework) which is divided into three main business models which are: 1- Infrastructure as a Service. 2- Platform as a Service. 3- Software as a Service. They also listed the cloud offerings and matched them to the business models in CBMF.

Martson et al. [215] surveyed and identified various issues that will affect the different stakeholders of cloud computing. They issued a set of recommendations for the practitioners who will provide and manage this technology.

The authors of [216] and [217] studied the effect of cloud computing on the value chain and listed some of cloud computing's success factors which include simplicity of

service deployment, references, flexible price models, integration and migration interfaces, and architecture frameworks that support automatic scaling and economies of scale.

3.2.2.2 Cost analysis

Yousaf et al. [185] studied the cost analysis of EPCaaS' VNF (Virtualized Network Functions) deployment. The study evaluated cost as a function of CPUs which can be translated to dollars based on the current pricing of a VM (Virtual Machine).

3.2.3 Pricing scheme

In this section, we will be identifying the pricing schemes, found in literature, of each of the agents participating in the studied market. It is worth noting that a generic currency is used to represent pricing as recommended by [218] who defined it as dimensionless and [77] who defined it as average aggregate quantities.

3.2.3.1 Cloud Service Provider (CSP)

Each CSP (Cloud Service Provider) enhances its competitiveness through value-added services [26], but pricing remains a decisive factor in offer selection [219]. All available business models share the same possible pricing models which can be categorized into two groups:

- **Static:** The user (the cloud-based mobile operator in our case) has either a fixed resource cost or fixed lump sum fee. The static pricing models have dominance over dynamic ones due to accounting and psychological reasons even if it costs more [26], [220]. Static pricing models are:
 - **Pay-per-use:** Resource units are priced at a fixed value. This pricing model is used for “products whose mass production and widespread delivery have made price negotiation impractical” [26], [221].

- **Subscription:** The client subscribes for a pre-selected collection of resources over a fixed period of time for a fixed price [26].
- **Dynamic:** The user pays a dynamic cost, specified based on supply and demand, for the used resources. Such models achieve differentiated services and better prices for low-end services [26], [222]. Dynamic pricing models are:
 - **Auctions/Bidding:** Prices are proposed by clients and the CSP selects the price that optimizes his revenues.
 - **Revised pricing:** Resource units are priced a new value for each new unit of time. Existing pricing models found in the literature are:
 - **RPM1:** This RPM is based on the basic principles of economics. In This RPM the price is specified as follows: $P_{new} = P_{old} + \Delta_{system\ capacity} \times C$ where C is a constant value representing the capacity change to price change ratio (inverse of price elasticity of demand).
 - **RPM2 for $M/M/1$ Queuing system [223]:** $P = \frac{C}{(\mu-\lambda)\lambda}$; where C is a constant, P is the offered price at certain instance, λ is the rate of job arrival (tasks /sec) at the same instance (following process distribution) and μ is the average service rate (tasks /sec). The problem in this pricing model is its severe responsiveness to fluctuating traffic.
 - **RPM3 [224]:** The authors of [224] proposed a pricing model based on the Black-Scholes-Merton Model and Moore's law.

3.2.3.2 Cloud-based mobile operator

The literature has limited proposals for pricing models specially designed for virtual or cloud-based mobile operators. Meidanis et al. [225] studied the pricing scheme of a Mobile Virtual Network Operator who rents the infrastructure from a Legacy Mobile Operator. This work uses user profiles from a crowdsourcing platform to maximize revenues for both operators. Although this study is not identical to our environment (EPCaaS), we can deduce the pricing correlation between these two types of operators. The correlation can be simplified as:

$$P_{MVNO}(U_i) = C(d_i) \times P_{Legacy}(U_i)$$

Where U_i is user i , $P_{MVNO}(U_i)$ is the selling price for user i by the virtual mobile operator and d_i is the traffic demand by user i . $C(d_i)$ is a linear function and $P_{Legacy}(U_i)$ is the price charged by the legacy mobile operator against the virtual mobile operator. The authors have identified a linear function between both pricing schemes even though $P_{Legacy}(U_i)$ is a function of d_i . Thus, $P_{MVNO}(U_i)$ is a function of the square of d_i which makes high traffic users pay extremely high fares.

Ma et al. [226] proposed a dynamic pricing scheme as a function of time and location. The price increases in hotspots and at peak hours. Such a pricing scheme will demotivate low-income users from using the network during high-fare periods and incentives them to communicate during low-traffic periods.

Xiao et al. [227] proposed a non-uniform pricing scheme that tries to motivate users to utilize the spectrum resources more predictably while ensuring high QoS (Quality of Service). Predictable user behavior allows the mobile operator to offer consistent service to its virtual mobile operators.

Zhang et al. [228] proposed a pricing framework for MCA (Mobile Crowdsourced Access), where the direct traffic and tethering traffic are charged independently according to a data price and a tethering price, respectively. The literature didn't touch the pricing strategies for cloud-based mobile operators specifically, thus the general pricing strategies, discussed earlier, are also implementable.

3.2.3.3 Legacy mobile operator

Wang et al. [229] listed green pricing schemes for mobile operators and identified the absence of real green pricing schemes and the existence of a few related research proposals. The listed schemes are [230] and [231]. In the first [230], the authors proposed a compensation-based pricing model by studying the game where the MVNO invests in content /advertising to compensate for the quality of service degradation. It is done by modeling the system as a supply-chain. In the second [231], the authors proposed a

pricing mechanism to mediate between the user-centric and network-centric resource management problems.

Sen et al. [232] surveyed the data pricing strategies and divided them into two categories, static and dynamic. The static pricing strategies include: Fate-rate, Usage-based, QoS classes, Negotiated contracts, Application-based, and Time-of-day. The dynamic pricing strategies include: Raffle-based, Real-time congestion, Auction-based, and Day-ahead. Although these pricing strategies are ISP oriented but can be extended to legacy CSPs. Kim et al. [233] studied the own- and cross-price elasticities of SMS and voice services. They found that voice services and SMS are substitutes with 0.8% increase in demand on SMS for 10% increase in the price of voice services. Vincenzi et al. [234] studied the possibility of cooperation among different MNOs that provide service to the same area by sharing their C-RAN (Cloud Radio Access Network). The authors set rules, among which is a pricing scheme, for ensuring profitable collaboration. Nicoletta and Zirulia [235] studied the changes in tariff plans in small and large operators over time and competition. Tariff plans are not necessarily related to pricing, but rather market segmentation through service differentiation. Ding et al. [236] studied the effectiveness of time-dependent pricing mechanisms for large mobile operators and concluded that adding location factors can enhance its performance. Asghari and yousefi [237] studied monopolistic and oligopolistic markets of VMVoIP in which a single VMVoIP and several VMVoIP operators available in the market respectively using game theory. Koski and Kretschmer [238] studied the competition between 2G mobile operators across 32 different countries. They also studied the competition between technologies (substitute technologies) and their effect on pricing. It was deduced that as different technologies exist, the prices decrease dramatically. Papai et al. [239] compared the number of broadband operators vs. the aggressiveness (challenger) of these operators. It was concluded that aggressiveness seems more important than the mere number of operators. Consul et al. [240] studied the use of bi-objective heuristics for the construction of Pareto-optimal network topologies that result in an optimum Pareto between the incumbent operators' income and the quality of service deterioration suffered by end-users as a result of tethering was investigated. They demonstrated that the market interactions between such operators greatly influence the Pareto-optimal collection of topologies.

The related work discussed in this section is summarized in Table 3.1.

TABLE 3.1 – Related Works

	Ref.	Summary	Comments
Traditional EPC vs. vEPC	[122]	Proposed cloud-based network sharing between mobile operators for the LTE/EPC architecture.	The predicted/discussed business model is not compatible with the current design of 5G networks.
	[129]	Proposed an algorithm that derives the optimal number and locations of vEPC's virtual instances over the federated cloud which is suitable for carrier clouds and EPCaaS.	The paper's scope is limited to the VM allocation and didn't discuss the impact of their proposal on the pricing scheme.
	[130]	Proposed resource pooling in resource-limited general-purpose datacenters.	
	[133]	Studied the Mobility Management in vEPC and proposed a Distributed Mobility Management under VNF/SDN environment.	
	[131]	Proposed to use NFV over SDN. They promised OPEX reductions which include, (eliminating the take down and provisioning of network upgrades and eliminating physical boxes and cable migration).	
			The proposed contribution is applicable for both legacy and virtual operators, thus doesn't affect the competitiveness of one operator type over the other.

	[134]	Proposed an architecture that includes a business lifecycle optimizing CAPEX/OPEX and a technical lifecycle leveraging a deployment model virtualizing MNO's core network and RAN elements.	
	[135]	Listed EPC market revenue projections and compared vEPC suppliers.	It helps in benchmarking the market situation and in in calibrating our predictions.
EPCaaS and multi-tenancy	[136]	Proposed MOBaaS (Mobility and Bandwidth prediction as a service)	Offer competitive advantage for cloud-based mobile operators
	[137]	Envisioned future multi-tenant systems to include Over-The-Top (OTT) and Vertical industries	
	[138]	Demonstrated the feasibility of on-demand creation of cloud-based elastic mobile core networks.	
	[139]	Proposed Caching as a Service as a new feature for cloud-based 5G networks	
	[140]	Proposed virtualization of Caching as a Service	

	[143]	Proposed novel solutions for effective subscribers state management in quality-constrained 5G scenarios	
	[142]	Proposed a traffic offloading framework between legacy EPC and vEPC.	Offer legacy-based mobile operators a tool to migrate to cloud-based operations.
Business Models	[148]	Divided the cloud computing business models into 8 dimensions.	All these papers discussed cloud adoption without evaluating its effect on the mobile market.
	[149]	Divided cloud computing into 3 main business models	
	[150]	Surveyed and identified various issues that will affect the different stakeholders of cloud computing	
	[151]	Listed some of cloud computing's success factors	
	[152]		
Pricing Scheme	[156]	Static pricing: Pay-per-use (flat rate)	Cloud Service Provider Pricing Scheme
	[153]	Static pricing: Subscription $P_{new} = P_{old} + \Delta_{system\ capacity} \times C$	
	[157]	Dynamic Pricing: Auctions /Bidding	

[153]	Dynamic Pricing: Revised pricing	
[158]	Dynamic Pricing: Revised pricing for M/M/1 Queuing system $P = \frac{C}{(\mu-\lambda)\lambda}$	
[159]	Dynamic Pricing: Revised pricing based on Black-Scholes-Merton Model and Moore's law	
[161]	Price = f(time, location)	Cloud-based Mobile Operator Pricing Scheme
[162]	Price = f(predictable traffic, non-predictable traffic)	
[163]	Price data=f(data traffic,tether traffic) Price tethering =f(data traffic,tether traffic))	
[165]	Compensation-based pricing model where the MVNO invests in content/advertising to compensate for the quality of service degradation.	
[166]	Pricing mechanism to mediate between the user-centric and network-centric resource management problems	Legacy Mobile Operator Pricing Scheme

[168]	Studied the own- and cross-price elasticities of SMS and voice services
[169]	Proposed pricing scheme for successful collaboration between MNOs sharing their C-RAN
[170]	Studied the changes in tariff plans in small and large operators over time and competition
[171]	Studied the effectiveness of time-dependent pricing mechanisms for large mobile operators
[172]	Studied monopolistic and oligopolistic markets of VMVoIP
[173]	Studied the competition between 2G mobile operators across 32 different countries
[174]	Compared the number of broadband operators vs. the aggressiveness (challenger) of these operators

	[175]	Studied the use of bi-objective heuristics for the construction of Pareto-optimal network topologies that result in an optimum Pareto between the incumbent operators' income and the quality of service deterioration suffered by end-users as a result of tethering was investigated.	
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3.3 Proposed Approach and Evaluation

3.3.1 Expected scenario

The current players in the mobile industry are either legacy operators (own and manage the physical infrastructure) or virtual operators (rent access to the physical infrastructure of other legacy operators). With the emergence of EPCaaS, two new players will join the scene. The first new player is the CSP offering its EPCaaS services (Usually mobile technology vendors will play this role such as Nokia, Ericsson, Huawei, etc.). The second new player is the cloud-based mobile operator which uses EPCaaS services to support its business. Finally, the clients are the pool of customers currently served by legacy operators. Legacy and cloud-based mobile operators will compete on the finite pool of customers. Figure 3.1 shows the clients, EPCaaS offering CSPs, legacy mobile operators, and cloud-based mobile operators.

The black link represents the legacy backhaul interface between a legacy mobile operator's Radio and Core network. The blue link between a mobile user and a mobile operator (legacy or cloud-based) represents a client-operator subscription. In Figure 3.1, all the blue links are connected to legacy mobile operators since current markets do not have emerging cloud-based mobile operators yet. As cloud-based mobile operators

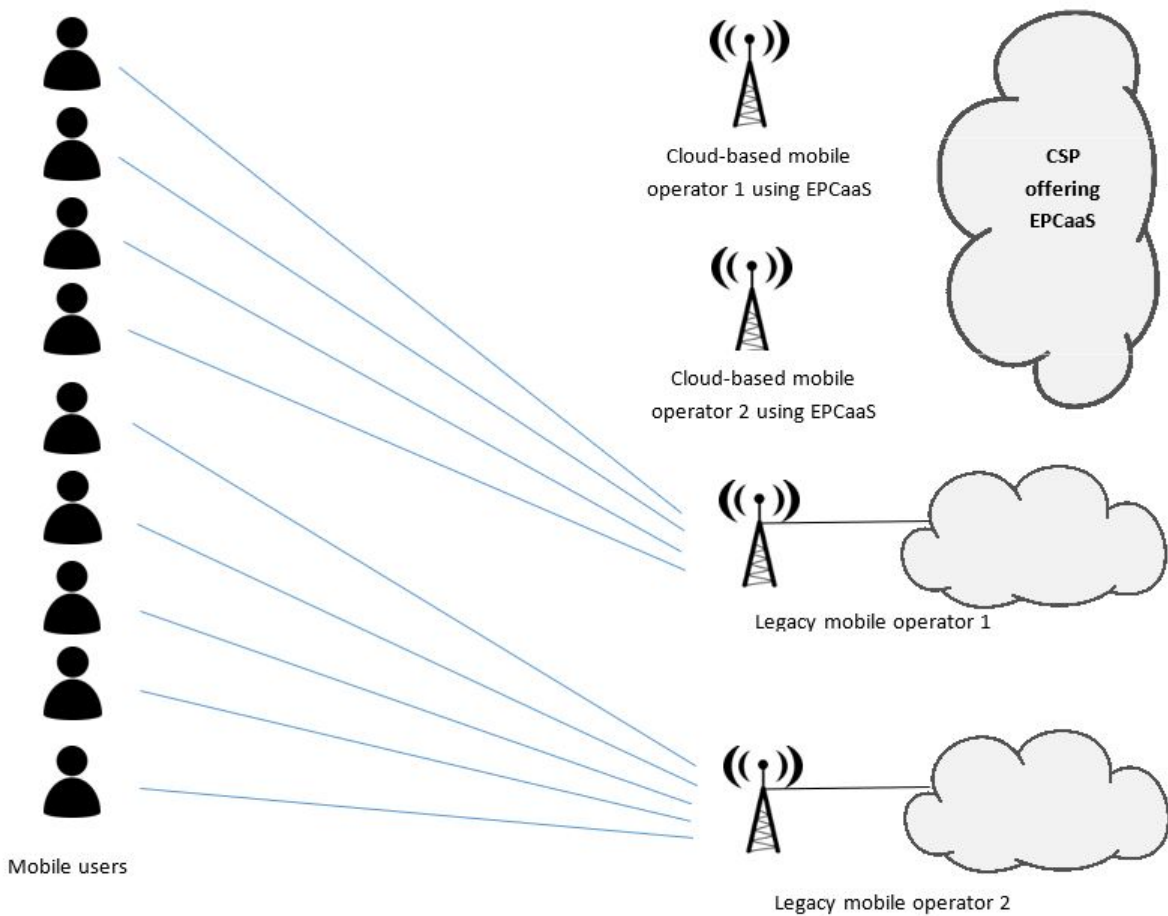


FIGURE 3.1 – Scenario.

emerge, mobile users will subscribe with the new operators thus some of the mobile users will connect their blue lines to the new operators.

3.3.2 Proposed approach and metrics

3.3.2.1 Agent-based modeling

The exact number of factors affecting any system is nearly impossible to identify, and the effect magnitude of every factor also varies. Designing the modeling environment requires selecting which factors to include, the abstraction level and the detailing level [241]. The factors we decided to include in this study are:

- **CSP:** Pricing Scheme.
- **Cloud-based mobile operator:** Pricing scheme, Reputation.
- **Legacy mobile operator:** Economic model, Pricing scheme, Reputation.
- **Mobile user:** Degree of knowledge and Readiness to Migrate

Many factors haven't been included in this study such as:

- Economic/financial level of every user.
- Types of users (personal, corporate, tourist, etc.).
- Market growth.
- Marketing techniques such as targeted bundles, advertising campaigns, and political and corporate social responsibility advertising.
- Resource capacity of a CSP.

3.3.2.2 Agent modeling

In this section, we specify the included factors and model the market players (agents).

1. EPCaaS offering CSP (CSP)

A cloud-based mobile operator has to pay the "EPCaaS offering CSP" for the resources used, thus the pricing model of the CSP directly affects the pricing of a cloud-based mobile operator and the market in general. The "EPCaaS offering CSP" is modeled as follows:

In the current version of our study, the CSP is modeled as an infinite resource provider following the pricing scheme RPM3 which is nearest to reality. There are many general pricing strategies in literature such as: Cost-plus pricing (markup), Competitive pricing, Price skimming, Penetration pricing, and Price bundling, but specifically for cloud computing RPM3 is the most realistic. The assumptions behind this model are that the CSP has no other business lines (and no other source of

revenues) and none of the CSPs has a competitive advantage. In a reality, a cloud-based operator can get services from different CSPs to acquire a wide spectrum of services, but the model's complexity and tuning make its realization impractical.

2. Cloud-based mobile operator

A cloud-based mobile operator has to pay the "EPCaaS offering CSP" for the resources used and then implements a pricing strategy that identifies the selling price. These strategies differ in their aggressiveness, duration, and profit margin. Factors, other than price, affect how appealing a cloud-based mobile operator offer looks. These factors include Reputation and SLA. A more expensive bundle from a well-established and reputed operator can be a wiser choice compared to a cheaper bundle from a mobile operator with bad coverage and bad customer service. The used factors are detailed next.

- **Factors:** - Reputation and SLAs (RaS): Reputation is a decisive factor other than price. A client will select a more expensive offer if complemented by a better reputation and a satisfying SLA. PoP is a decimal number between 0 and 1 representing the percentage of the CSPs with a good reputation. In our simulator, we consider 2 reputation levels only (with a good reputation, without a good reputation). RaS is a decimal number between 0 and 1 representing the maximum difference a user is willing to pay for a better reputation. If $RaS = 0$ then the user is indifferent to the reputation and uses price as the only decisive factor. If $RaS = 1$ then the user will select the provider with a better reputation.
- **Model:** In the current version of our study, the used pricing scheme is the markup where all cloud-based mobile operators set their selling price to the cost they are paying the EPCaaS CSP in addition to a markup margin of a unified percentage. If all cloud-based operators are using the same markup percentage, then the value of this percentage will not affect the inter-operator pricing.

The number of cloud-based mobile operators is set by the user using the variable " $Number_of_CMSPs$ ". CMSP refers to a Cloud-based Mobile Service Provider. Since the CMSPs are not currently available, we give the legacy mobile operators, in this simulator, a certain amount of time to stabilize their

prices and their market shares. The time CMSPs start joining the market is set by a random variable ranging between 0 and $2 \times$ “*Average_entry_time*”. When the new CMSP joins the market, he uses a predefined price equals to the variable “*Initial_momentum*”. This price is going to be used for a certain time after joining the market. This time is set by the variable “*Number_of_rounds_before_elasticity*”. When this grace period ends, the CMSP will start using the following pricing model.

$$Price = general_cost \times \frac{((1 + coefficient_of_price))}{(Number_of_active_CMSPs \times CMSP_users)}$$

The “*general_cost*” is a constant that is used as a starting benchmark for cloud pricing and can be changed to accommodate different currencies. The variable “*coefficient_of_price*” is used to represent the markup percentage. “*coefficient_of_price*” ranges from -1 to $+1$. Negative values represent extremely competitive pricing strategies to drive legacy mobile operators out of business. “*Number_of_active_CMSP*” is the number of current CMSPs using EPCaaS. As this number increases, it means that the CSP has more clients and this results in an economy of scale, so the CSP can offer lower pricing. The variable “*CMSP_users*” is the number of users connected to this CMSP. The mobile operator can survive 3 periods without customers and if this period extends, the operator becomes out of business.

3. Legacy mobile operator

Legacy mobile operators have been around for more than 30 years and are the driving force behind consecutive developments in mobile technology. Some of the mobile operators have a presence in more than 10 different countries such as MTN, Orange, Telenor, Deutsche Telekom, Etisalat, Airtel, Vodafone, América Móvil, and Telefónica.

- **Factors:**

- Economic Model and Market Structure Madden and Coble-Neal [242] studied the relationship between fixed-line and mobile telephony. They deduced

that the mobile subscription elasticity with respect to mobile subscription price is inelastic. Inelasticity means that an increase in price results in a slight variation in demand.

It is not found in the literature whether the mobile market follows a perfect competition, oligopoly, or monopolistic competition. The three market structures have been studied in [186] and considered applicable in different markets. It is deduced by [242] that “a certain level of cooperative price-setting” exist between mobile operators “but no fully-fledged joint-profit maximization”. In this chapter, we study the market under perfect competition.

- Reputation and SLAs (RaS) Reputation is a decisive factor other than price. A client will select a more expensive offer if complemented by a better reputation and a satisfying SLA. PoP is a decimal number between 0 and 1 representing the percentage of the CSPs with a good reputation. In our simulation, we consider 2 reputation levels only (with a good reputation, without a good reputation). RaS is a decimal number between 0 and 1 representing the maximum difference a user accepts to pay for a better reputation. If $RaS = 0$ then the user is indifferent to the reputation and uses price as the only decisive factor. If $RaS = 1$ then the user will select the provider with a better reputation.
- **Model:** In the current version of our study, the considered market structure is the perfect competition and the used pricing scheme is markup. The number of legacy mobile operators is configured by the user using the variable “*Number_of_DMSPs*”. DMSP refers to Legacy Mobile Service Provider. The price offered by a legacy mobile operator as follows:

$$Price = \begin{cases} Initial_price_of_DMSP; & \text{where } t = 0 \\ General_cost \times \frac{1}{(DMSP_{users})}; & \text{Otherwise} \end{cases}$$

The “*general_cost*” is the same as the one used in cloud-based mobile operators and it represents a constant that is used as a starting benchmark for cloud pricing and can be changed to accommodate different currencies. The variable “*DMSP_users*” is the number of users connected to this DMSP (legacy mobile

operator). The variable “*Initial_price_of_DMSP*” represents the price that all legacy mobile operators start with. It is used to represent the current status of the market where the prices are nearly equal across all mobile operators. Every legacy mobile operator has a binary reputation (0 or 1) generated as shown in the previous section. The mobile operator can survive 3 periods without customers and if this period extends, the operator becomes out of business.

4. Mobile user

- **Factors:**

- Degree of knowledge (DoK) “Bounded rationality” adopts a restricted search for alternatives [243], thus the decision-maker has a partial view over the market offers. *DoK* is a decimal number between 0 and 1 representing the search range for each user, where 1 means that the client (decision maker) has information about all possible alternatives and 0 means that the client has no access to alternatives or offers.
- Willingness and readiness for migration (RoM) “Bounded rationality” adopts the tendency to “block out” alternatives that require substantial changes to the existing position. *RoM* is a decimal number between 0 and 1 representing the maximum difference a user accepts to pay to stay at the same position (In-house or CSP). If $RoM = 0$ then the user has no interest in changing its position. This term could also be related to customer loyalty. If $RoM = 1$ then the user has perfect loyalty.

- **Model:** The user has access to the list of available operators (both cloud-based and legacy), but based on the “bounded rationality” concept every user selects randomly a list of operators to contact for offers. This list is called *knowledge_list*, which is of size $(Number_of_active_MSPs \times Degree_of_knowledge)$. When the variable “*Degree_of_knowledge*” is set to 1, the user can access all prices offered in the market. Every round, the user searches his knowledge-list and compares the best-offered price (*minimum_price*) to his current price. If the $minimum_price \times (RoM) > current_price \times (1 - RaS)$ the user will move to the new operator and his price becomes equal to the *minimum_price*. In case the

user is to stay with his current operator, the user's price will be updated to the operator's new price.

3.3.3 Metrics

To better understand the market behavior, multiple metrics should be used. The used metrics are:

1. **Average cost paid by clients:** The average cost per resource paid by the clients.
2. **Percentage of CMSPs in business:** Percentage of CSPs having at least 1 customer.
3. **Percentage of DMSPs in business:** Percentage of CSPs having at least 1 customer.
4. **Average operator size:** Average number of clients per operator.

3.3.4 Evaluation

The market behaved very differently under different configurations; thus, we can expect the impact of EPCaaS to differ between countries. We were able to distinguish 4 different consequences (outcomes) that could affect the telecom market if EPCaaS was introduced and cloud-based mobile operators joined. The outcomes are:

3.3.4.1 Outcome 1: All legacy mobile operators driven out of the market with the final user cost exceeding the initial cost.

As can be seen in Figure 3.2, as new players joined the market, the legacy mobile operator was driven out of the market to be replaced by new cloud-based mobile operators who competed on the market share until one dominated the whole market. As can be seen

in the average price plot, as a new member joins the market, the prices severely drop (perfect competition) and rise as one leaves the market and competition stress decreases. Since one player dominated the market, the user cost elevated and stabilized much higher than what was during the competition of legacy mobile operators.

3.3.4.2 Outcome 2: All legacy mobile operators driven out of business with the final user cost less than the initial cost.

As can be seen in Figure 3.3, at tick 2 all legacy mobile operators were in business (100% DMSPs in business) and the cost was around 70 monetary units. Starting tick 3 legacy operators started to exit the market as new cloud-based mobile operators entered. The cost gradually dropped (except for a peak when all legacy operators left the market) as more users moved from legacy to cloud-based operators. The users were distributed over the cloud operators who offered the same price which is an all-time low.

3.3.4.3 Outcome 3: Co-existence between legacy and cloud-based mobile operators. Some of the legacy and cloud-based operators left the market.

As can be seen in Figure 3.4, the cloud-based mobile operators started replacing legacy operators until they lost their initial-momentum and had to abide by the discussed pricing scheme. The pricing scheme, with the users distributed among them, prevented the cloud-based operators from offering more competitive prices and failed to drive the legacy operator out of business. Since the users are divided over the active legacy and cloud-based operators, the resultant price is higher than the start price, so we deduce that this competition resulting from the introduction of EPCaaS is against the financial benefit of users.

3.3.4.4 Outcome 4: Cloud-based mobile operators join the market and leave later because of competition from the legacy mobile operators.

As can be seen in Figure 3.5, the cloud-based mobile operators joined the market and left sequentially as the cost dropped into very competitive rates. Finally, some of the legacy

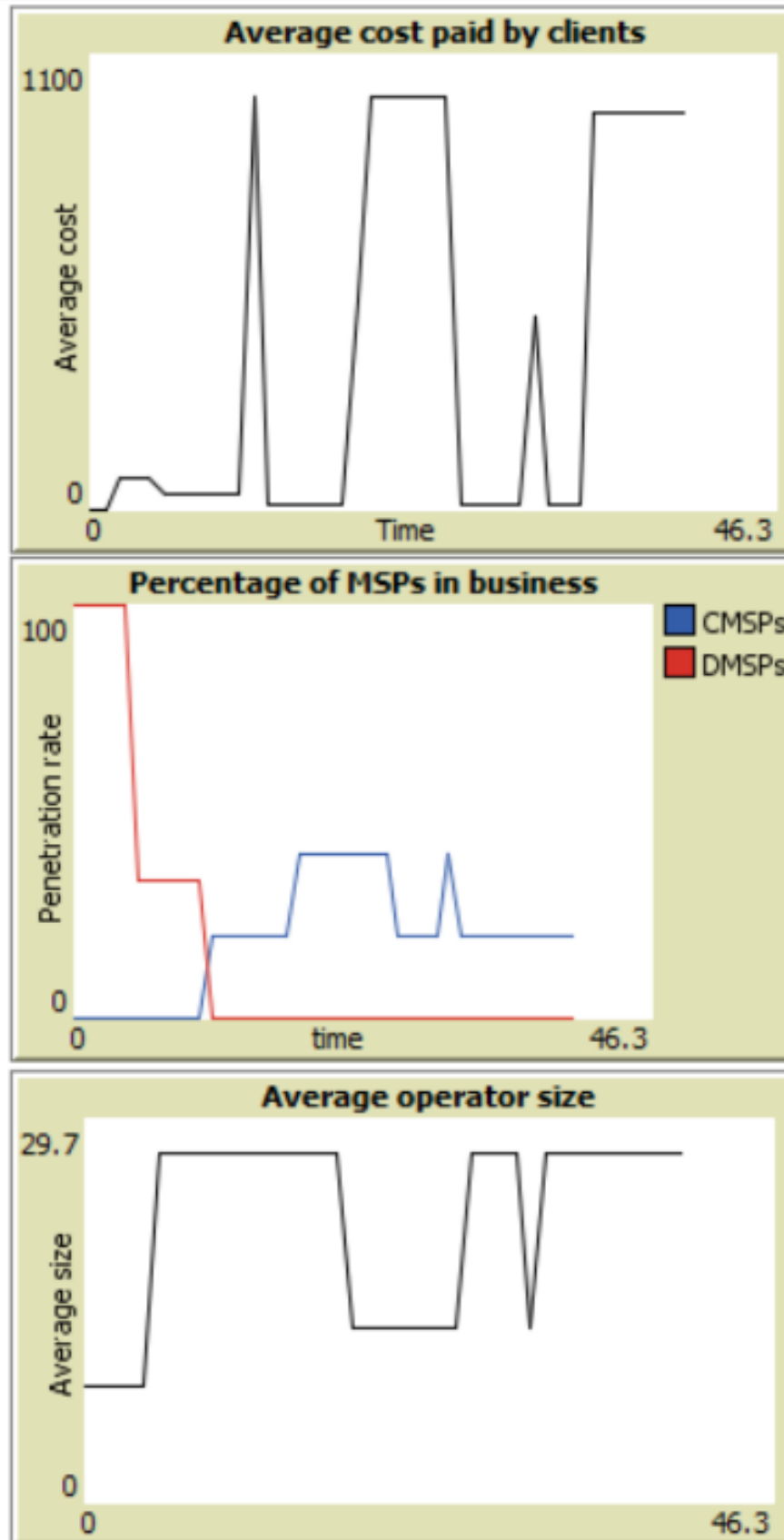


FIGURE 3.2 – Outcome 1: All legacy mobile operators driven out of business with the final user cost exceeding the initial cost.

mobile operators withstood the emergence of EPCaaS which wasn't surviving competitive pricing.

3.4 Conclusion and Future Challenges

In this chapter, we raised the issue of market structure uncertainty due to the introduction of a multitenancy cloud to the 5G mobile network. As delicate as this issue may get, no historical data is available to guide us during the emergence of multitenancy in the mobile market. We modeled the 5G network using the Agent-Based-Modeling technique and the market behavior has been predicted using this model. Since the mobile market differs between countries, we tested our model for various configurations, and we observed 4 different market behaviors listed as:

1. All legacy mobile operators driven out of the market with the final user cost exceeding the initial cost.
2. All legacy mobile operators driven out of business with the final user cost less than the initial cost.
3. Co-existence between legacy and cloud-based mobile operators. Some of the legacy and cloud-based operators left the market.
4. Cloud-based mobile operators join the market and leave later because of competition from the legacy mobile operators.

As EPCaaS/multitenancy emerges, mobile markets' behavior will range from adaptation (remain oligopoly) to complete market revolution (changing its nature to monopolistic competition). The conclusions of this chapter can be generalized to all applications of cloud computing. Thus, any DSS for cloud adoption should not rely solely on the business' requirements, but consider the market behavior in general and its possible economic implications. We can deduce that the businesses' actions towards cloud computing are active during the cloud's first stages but becomes reactive with its introduction to the market.

This chapter considered competitive markets only (monopolistic competition and markup pricing). An important upgrade is investigating the market behavior in oligopoly, which affects the modeling (pricing scheme) of legacy-mobile operators who will be collaborating in countering the impact of cloud-based mobile operators.

As EPCaaS becomes a reality, the collected data will help us validate and fine-tune the performance of our model. A fine-tuned model will help decision-makers plan their investments based on the predicted market price.

Finally, this model is expected to be the fundamental framework for testing the readiness of the mobile market to accept new services/technologies and a decision-support solution for policy makers and executives.

This chapter satisfies CBOD’s task 3 and objective 3. The updated project status is shown in table 3.2.

TABLE 3.2 – Chapter 3 contributions to CBOD objectives and tasks

	Status		Status
<i>Objective 1</i>	Done	<i>Task 1</i>	Done
<i>Objective 2</i>	Done	<i>Task 2</i>	Done
<i>Objective 3</i>	Done	<i>Task 3</i>	Done
<i>Objective 4</i>	Pending	<i>Task 4</i>	Done
<i>Objective 5</i>	Pending	<i>Task 5</i>	Pending
<i>Objective 6</i>	Pending	<i>Task 6</i>	Pending

Appendix

a. Output format explanation

This section shows the output of a sample scenario to introduce the output formats, which will be used in the coming sections to measure the market behavior.

When the setup button is pressed, a new instance of the simulation is generated. This instance is based on the inputs set in the left part of the Main view. The visual representation of the simulation is shown in the black box on the right side of the Main view in Figure 3.6. The components in the black box are positioned similar to

Figure 3.1 where the left side represents the mobile users, the upper-right agents are cloud-based mobile operators and the lower-right (represented by big houses) are the legacy mobile operators.

When the “go once” button is pressed, the users start looking for the best offers and subscribing with their best local operator (based on “bounded-rationality”). In Figure 3.7, we can see that the users are connected with the legacy mobile operators, and next to each user, his subscription price is shown in addition to the MSP id using this format: price – MSP id. The cloud-based operators haven’t entered the market yet and their printed prices are 0 (not active) using the following format: Offered price - Reputation. The legacy mobile operators are connected with lines from the users and their prices are printed using the following format: Reputation – Number of subscribed users – Offered price.

The fifth sample round, shown in Figure 3.8, shows the outputs plotted in three windows. The first window shows the average cost paid by the users where we can deduce that the price peaked at the start of the simulation and then converged towards a constant price similar to what happens in real-life where the introduction of the mobile service leads to peak prices and then competition drives the prices down to a stable price. In the second window, we see that the percentage of legacy mobile operators (red line) was 100% and then converged to 66%, so we can deduce that the market settings set in this simulation can’t accept three legacy operators (since the market is small) and stabilize at just two mobile operators. Increasing the “*number_of_clients*” variable can keep the third operator in the business. The percentage of cloud-based mobile operators (blue line) is still zero, which means that none joined the market yet. As the third legacy operator was kicked out of business, the subscribed were distributed over two mobile operators which increase the average number of subscribers per active operator and this can be seen in the third window.

The twentieth sample round, shown in Figure 3.9, shows three cloud-based mobile operators joining the market and driving all legacy mobile operators out of business.

b. Netlogo Code

```
globals [
```

```

cout ;; Used as the xcor value for the first Mobile Service Provider.
counter ;; Used to index the IDs of the clients. The value is set to 0
    in setup.
counter-DMSP-CMSP ;; Used to index the IDs of the Cloud-based Mobile
    Service Providers and Dominant Mobile Service Providers.
General_Cost ;; c = 1000
Number_of_active_CMSPs ;; n

number_of_changes
average_cost
CMSP_count
DMSP_count
List_of_active_MSPs
Number_of_active_MSPs
]
breed [clients client] ;; Breed of clients.
breed [CMSPs CMSP] ;; Breed of CMSPs.
breed [DMSPs DMSP] ;; Breed of CMSPs.

clients-own [
    cost ;; Used to represent the cost the company is paying for its IT
        services that could be offloaded.
    id ;; Client's ID.
    connected_to ;; CMSP's OR DMSP's ID
    knowledge_list ;; list of CMSPs and DMSPs the user knows
]
CMSPs-own [
    price ;; Used to represent the price the CMSP is offering its client.
        Price = ( general_cost * ( 1 + coefficient-of-price ) / (
            Number_of_active_CMSPs * CMSP_users ) )
    CMSP_users ;; Number of users connected to this CMSP
    id ;; CMSP's ID. Starts at 10.

```

3.4. CONCLUSION AND FUTURE CHALLENGES

```
entry_period ;; When should enter business. Random number between 0 and
    2*Average-entry-time
in_business ;; Boolean value. If tick > entry_period and CMSP_users > 0
Elasticity_starts ;; Before elasticity, CMSP_users will be
    Initial_momentum; Elasticity_starts = entry_period + Number-of-
    rounds-before-elasticity
Good_Reputation ;; 1 is true, 0 is false
]
DMSPs-own
[
    price ;; Initially it is set to Initial-price-of-DMSP; Used to
        represent the price the DMSP is offering its client. P =
        general_cost / DMSP_capacity
    DMSP_users ;; Number of users connected to this user
    id ;; CMSP's ID. Starts at 1
    in_business ;; Boolean value. If DMSP_users > 0
    Good_Reputation ;; 1 is true, 0 is false
]

to fill_List_of_active_MSPs
;;
;; Identify the active MSPs so that a user can search for a suitable
    price between the active ones. It will decide the searched list
    based on the degree-of-knowledge
;;
set Number_of_active_MSPs 0
set List_of_active_MSPs []
ask DMSPs [if in_business = 1 [set Number_of_active_MSPs
    Number_of_active_MSPs + 1
set List_of_active_MSPs sentence List_of_active_MSPs id]]
ask CMSPs [if in_business = 1
    [set Number_of_active_MSPs Number_of_active_MSPs + 1
```

```

set List_of_active_MSPs sentence List_of_active_MSPs id]]
;;print "Number_of_active_MSPs"
;;print Number_of_active_MSPs
if Number_of_active_MSPs > 0
[
  let list1 [id] of DMSPs
  let list2 [id] of CMSPs
  let list_of_ids sentence list1 list2
;;
;; Fill a knowledge list i.e. the list of MSPs the user contact looking
  for the best offer. This is because of bounded rationality
;;
ask clients [
  ;;
  ;;Currently the user selects a new knowledge-list every tick, and
  the new knowledge-list may not include his current operator. The
  best way to be done is to keep the current operator in the list
  ;;since the user will cover all operators after certain number of
  ticks
  ;;
let start_of_knowledge random Number_of_active_MSPs
  ifelse start_of_knowledge + ( Number_of_active_MSPs * Degree-of-
    knowledge) < ( Number_of_active_MSPs )
  [set knowledge_list sublist List_of_active_MSPs start_of_knowledge (
    round (start_of_knowledge + (Number_of_active_MSPs * Degree-of-
      knowledge)) )]
  [let subl1 sublist List_of_active_MSPs start_of_knowledge (
    Number_of_active_MSPs )
    let subl2 sublist List_of_active_MSPs 0 (Number_of_active_MSPs *
      Degree-of-knowledge - (Number_of_active_MSPs - start_of_knowledge
        ) )
    set knowledge_list sentence subl1 subl2

```

```
    ]
  ]]

end

to setup
  clear-all
  ;;ask patches [set pcolor white]
  set-default-shape clients "person"
  set-default-shape CMSPs "house"
  set-default-shape DMSPs "house"
  set cout (100 / (Number-of-CMSPs + Number-of-DMSPs + 1) ) ;; It is a
    dynamic value for ycor which is the position of the first CMSP.
    Other CMSPs will be shifted by a dynamic value called space
  set counter 0 ;; Used to index the IDs of the clients
  set counter-DMSP-CMSP 1 ;; Used to index the IDs of the DMSPs and CMSPs

  set Number_of_active_CMSPs 0
  set General_Cost 1000

  create-DMSPs Number-of-DMSPs [
    let space ( 90 / ( Number-of-CMSPs + Number-of-DMSPs ) ) ;; Dynamic
      value for CMSP locations
    set size 5

    set price Initial-price-of-DMSP
    set DMSP_users 0
    set in_business 1

    let reputation random 100
      set Good_Reputation 0

    if reputation < 100 * PoP
```

```
[set Good_Reputation 1]

set xcor 70
set ycor cout
set cout cout + space
set id counter-DMSP-CMSP
set counter-DMSP-CMSP counter-DMSP-CMSP + 1
set number_of_changes 1
]

set DMSP_count 0
ask DMSPs with [ in_business = 1 ] [ set DMSP_count DMSP_count + 1 ]

create-CMSPs Number-of-CMSPs [
let space ( 90 / ( Number-of-CMSPs + Number-of-DMSPs ) ) ;; Dynamic
value for CMSP locations
set size 1

set entry_period random ( 2 * Average-entry-time )
set in_business 0
set Elasticity_starts ( entry_period + Number-of-rounds-before-
elasticity )
set CMSP_users Initial_momentum

set price 0

let reputation random 100
set Good_Reputation 0

if reputation < 100 * PoP
[set Good_Reputation 1]
```

```
set xcor 70
set ycor cout
set cout cout + space
set id counter-DMSP-CMSP
set counter-DMSP-CMSP counter-DMSP-CMSP + 1
set number_of_changes 1
]

set Number_of_active_CMSPs 0
ask CMSPs with [ in_business = 1 ] [ set Number_of_active_CMSPs
  Number_of_active_CMSPs + 1 ]

set cout (100 / (number-of-Clients + 1) )
let list1 [id] of DMSPs
let list2 [id] of CMSPs
let list_of_ids sentence list1 list2
;;print list_of_ids

fill_List_of_active_MSPs
;;print List_of_active_MSPs

create-clients number-of-Clients [
  set size ceiling ( 20 / number-of-Clients) ;; be easier to see
  let space (90 / number-of-Clients)

  set cost 100000
  set id counter
  set counter counter + 1

  set connected_to -1
  set xcor 20
```



```

set ycor cout
set cout cout + space

;;
;; Fill a knowledge list i.e. the list of MSPs the user contact looking
   for the best offer. This is because of bounded rationality
;;
ask clients [
let start_of_knowledge random Number_of_active_MSPs
  ifelse start_of_knowledge + ( Number_of_active_MSPs * Degree-of-
    knowledge) < ( Number_of_active_MSPs )
  [set knowledge_list sublist List_of_active_MSPs start_of_knowledge (
    round (start_of_knowledge + (Number_of_active_MSPs * Degree-of-
      knowledge)) )]
  [let subl1 sublist List_of_active_MSPs start_of_knowledge (
    Number_of_active_MSPs )
    let subl2 sublist List_of_active_MSPs 0 (Number_of_active_MSPs *
      Degree-of-knowledge - (Number_of_active_MSPs - start_of_knowledge
        ) )
    set knowledge_list sentence subl1 subl2
  ]
]]

ask CMSPs [ set plabel (word (precision price 2) "□-□" Good_Reputation)
  ]
ask DMSPs [ set plabel (word (precision price 2) "□-□" Good_Reputation)
  ]
ask clients [ set plabel precision cost 2 ]

reset-ticks

end

to count_customers

```

```
end
to exiting_business

  if ( ticks > 3 ) [
ask CMSPs [ set in_business 0 ]
ask DMSPs [ set in_business 0 ]

set CMSP_count 0
set DMSP_count 0

foreach sort-on [id] Clients
  [ ?1 ->
let CMSP_connected_to [connected_to] of ?1
ask CMSPs with [id = CMSP_connected_to][set in_business 1]
  ]

ask CMSPs
[
  if in_business = 1
  [
    set CMSP_count CMSP_count + 1
  ]
]

foreach sort-on [id] Clients
  [ ?1 ->
let DMSP_connected_to [connected_to] of ?1
ask DMSPs with [id = DMSP_connected_to][set in_business 1]
  ]
```

```

ask DMSPs
[
  if in_business = 1
  [
    set DMSP_count DMSP_count + 1
  ]
]
]

set Number_of_active_CMSPs 0
ask CMSPs with [ in_business = 1 ] [ set Number_of_active_CMSPs
  Number_of_active_CMSPs + 1 ]

set DMSP_count 0
ask DMSPs with [ in_business = 1 ] [ set DMSP_count DMSP_count + 1 ]
end

to Join_business
ask CMSPs
[
  if ( ticks > entry_period - 1 ) AND ( ticks < Elasticity_starts )
  [
    set in_business 1
    print id
    set price initial_momentum
  ]
]
end

to update_pricing
set Number_of_active_CMSPs 0
ask CMSPs with [ in_business = 1 ] [ set Number_of_active_CMSPs
  Number_of_active_CMSPs + 1 ]

```

```
ask CMSPs with [in_business = 1 ]
[
  let CMSPU 0
  ask clients with [ connected_to = id ] [ set CMSPU CMSPU + 1 ]
  set CMSP_users CMSPU
  ifelse CMSP_users > 0
  [
    ifelse ticks < Elasticity_starts [set price initial_momentum]
    [set price ( general_cost * ( 1 + coefficient-of-price ) / (
      Number_of_active_CMSPs * CMSP_users ) )]
  ]
  [
    set in_business 0
    ;;set price 1000
  ]
]

ask DMSPs with [in_business = 1]
[
  let DID id
  let DMSPU 0
  ask clients with [ connected_to = DID ] [ set DMSPU DMSPU + 1 ]
  set DMSP_users DMSPU
  print DMSPU
  ifelse DMSP_users > 0
  [set price ( general_cost / DMSP_users )]
  [set price general_cost ]
]
end
to go
```

```

;;Update list of active MSPs
fill_List_of_active_MSPs
;;Linking users
dynamic-revised-pricing
;;Update pricing
update_pricing
;;Linking users
dynamic-revised-pricing

;;Anybody wants to go out of business
exiting_business
;;Anybody to join the market
Join_business

measure-CMSP-involvement
  ask CMSPs [ ifelse in_business = 1 [set plabel (word (precision price
    2) "□-□" Good_Reputation)] [set plabel "" ] ]
  ask DMSPs [ ifelse in_business = 1 [ set plabel (word id "□-" (
    DMSP_users) "□-□" price)] [set plabel "" ] ]
  ask clients [ set plabel ( word (precision cost 2 ) "□-□" connected_to
    ) ]
  tick
end
to measure-CMSP-involvement

end
to optimizeprofits

ask CMSPs[
  let checker_price price
  let number_of_prices_lower_than_checker 0
  let second_lowest_price 2 * Initial-price-of-DMSP

```

```
foreach sort-on [id] CMSPs
[ ?1 ->
  let read_CMSP_price [price] of ?1
  if read_CMSP_price < checker_price
    [set number_of_prices_lower_than_checker
      number_of_prices_lower_than_checker + 1]
]
if number_of_prices_lower_than_checker = 0 ;I am the lowest price. I
  can increase price without loosing customers
[
  foreach sort-on [id] CMSPs
  [ ?1 ->
    let read_CMSP_price [price] of ?1
    if (read_CMSP_price < second_lowest_price) AND (
      read_CMSP_price > checker_price)
    [
      set second_lowest_price read_CMSP_price
    ]
  ]
  set price second_lowest_price - 1
]
;If I am not the lowest price, I shall not increase it to remain as much
  competitive as possible.
]
end
to dynamic-revised-pricing ; Business Model

let read_CMSP_price 0
let read_CMSP_id 0
let read_DMSP_price 0
```

```

let read_DMSP_id 0

ask clients[

  let read_client_connected_to connected_to
  let read_client_id id
  let read_client_cost cost
  ;;let read_client_client_capacity 1
  let klist knowledge_list
  ;;let node1 end1
  let node1 one-of clients with [ id = read_client_id]
  let minimum_price 0
  ;;let Reputation_of_the_CMSP_offering_minimum_price 0
  let id_of_CMSP-with_minimum_price 0
  ;;let Reputation_of_the_CMSP_connected_to 0

ask CMSPs
  [
    set read_CMSP_price price
    set read_CMSP_id id
    ;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1

    if read_client_connected_to = read_CMSP_id ; Updating the cost
    [

      ;;set Reputation_of_the_CMSP_connected_to
        read_CMSP_Good_Reputation

      set read_client_cost read_CMSP_price ; the client has to pay
        for his resourcesBased on the new price the CMSP is
        offering
      set cost read_CMSP_price ; Both increasing and decreasing
    ]
  ]

```

```

        costs
    ]
]

ask DMSPs
[
    set read_DMSP_price price
    set read_DMSP_id id
    ;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1

    if read_client_connected_to = read_DMSP_id ; Updating the cost
    [

        ;;set Reputation_of_the_CMSP_connected_to
            read_CMSP_Good_Reputation

        set read_client_cost read_DMSP_price ; the client has to pay
            for his resourcesBased on the new price the CMSP is
            offering
        set cost read_DMSP_price ; Both increasing and decreasing
            costs
    ]
]

set minimum_price read_client_cost
set id_of_CMSP-with_minimum_price -1
;;set Reputation_of_the_CMSP_offering_minimum_price
    Reputation_of_the_CMSP_connected_to

ifelse ticks = 1 [
```



```
ask CMSPs
[
  set read_CMSP_price price
  set read_CMSP_id id

foreach klist
[
  ?2 ->
  if(read_CMSP_id = ?2)
  [
    if (read_CMSP_price < minimum_price )
      [ set id_of_CMSP-with_minimum_price read_CMSP_id ]
  ]
]
]

ask DMSPs
[
  set read_CMSP_price price
  set read_CMSP_id id

foreach klist
[
  ?2 ->
  if(read_CMSP_id = ?2)
  [
    if (read_CMSP_price < minimum_price )
      [ set id_of_CMSP-with_minimum_price read_CMSP_id ]
  ]
]
]
]
```

```
[
  ask CMSPs
  [
    set read_CMSP_price price
    set read_CMSP_id id
    ;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1
    ;;set read_CMSP_capacity [CMSP_users] of ?1

    if (minimum_price * (1 - RaS) * (RoM) > read_CMSP_price)
    [
      foreach klist
      [ ??1 ->
        let xid ??1
        if read_CMSP_id = xid
        [
          set minimum_price read_CMSP_price
          set id_of_CMSP-with_minimum_price read_CMSP_id
          ;;set Reputation_of_the_CMSP_offering_minimum_price
            read_CMSP_Good_Reputation
        ]
      ]
    ]
  ]

  ask DMSPs
  [
    set read_DMSP_price price
    set read_DMSP_id id
    ;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1
    ;;set read_CMSP_capacity [CMSP_users] of ?1

    if (minimum_price * (1 - RaS) * (RoM) > read_DMSP_price)
```

```

[
  foreach klist
  [ ??1 ->
    let xid ??1
    if read_DMSP_id = xid
    [
      set minimum_price read_DMSP_price
      set id_of_CMSP-with_minimum_price read_DMSP_id
      ;;set Reputation_of_the_CMSP_offering_minimum_price
        read_CMSP_Good_Reputation
    ]
  ]
]

]

]

foreach sort-on [id] CMSPs
[ ?1 ->
  set read_CMSP_price [price] of ?1
  set read_CMSP_id [id] of ?1
  ;;set read_CMSP_capacity [CMSP_users] of ?1

  if (id_of_CMSP-with_minimum_price = read_CMSP_id) ; User
    found better price
  [
    ;show connected_to
    let was_connected_to connected_to

    if connected_to > -1 ; If not first round
    [

```

```
ask links with [ color = 12 + read_client_id] [die] ;
    Disabling the connection with the old CMSP

]

set connected_to read_CMSP_id ; Connecting to the new CMSP
set cost read_CMSP_price
let node2 one-of CMSPs with [ id = read_CMSP_id]
ask node1 [ create-link-with node2 [ set color 12 +
    read_client_id] ]
;ask CMSPs with [id = iCMSP] [ create-link-with end1 [set color
    12 + idinput + idinput]]
]
]

foreach sort-on [id] DMSPs
[ ?1 ->
set read_DMSP_price [price] of ?1
set read_DMSP_id [id] of ?1
;;set read_DMSP_capacity [DMSP_users] of ?1

    if (id_of_CMSP-with_minimum_price = read_DMSP_id) ; User
        found better price
[
;show connected_to
let was_connected_to connected_to

if connected_to > -1 ; If not first round
[

ask links with [ color = 12 + read_client_id] [die] ;
    Disabling the connection with the old CMSP
```

```
    ]
    set connected_to read_DMSP_id ; Connecting to the new CMSP
    set cost read_DMSP_price
    let node2 one-of DMSPs with [ id = read_DMSP_id]
    ask node1 [ create-link-with node2 [ set color 12 +
        read_client_id] ]
    ;ask CMSPs with [id = iCMSP] [ create-link-with end1 [set color
        12 + idinput + idinput]]
    ]
    ]
    ]
end
```

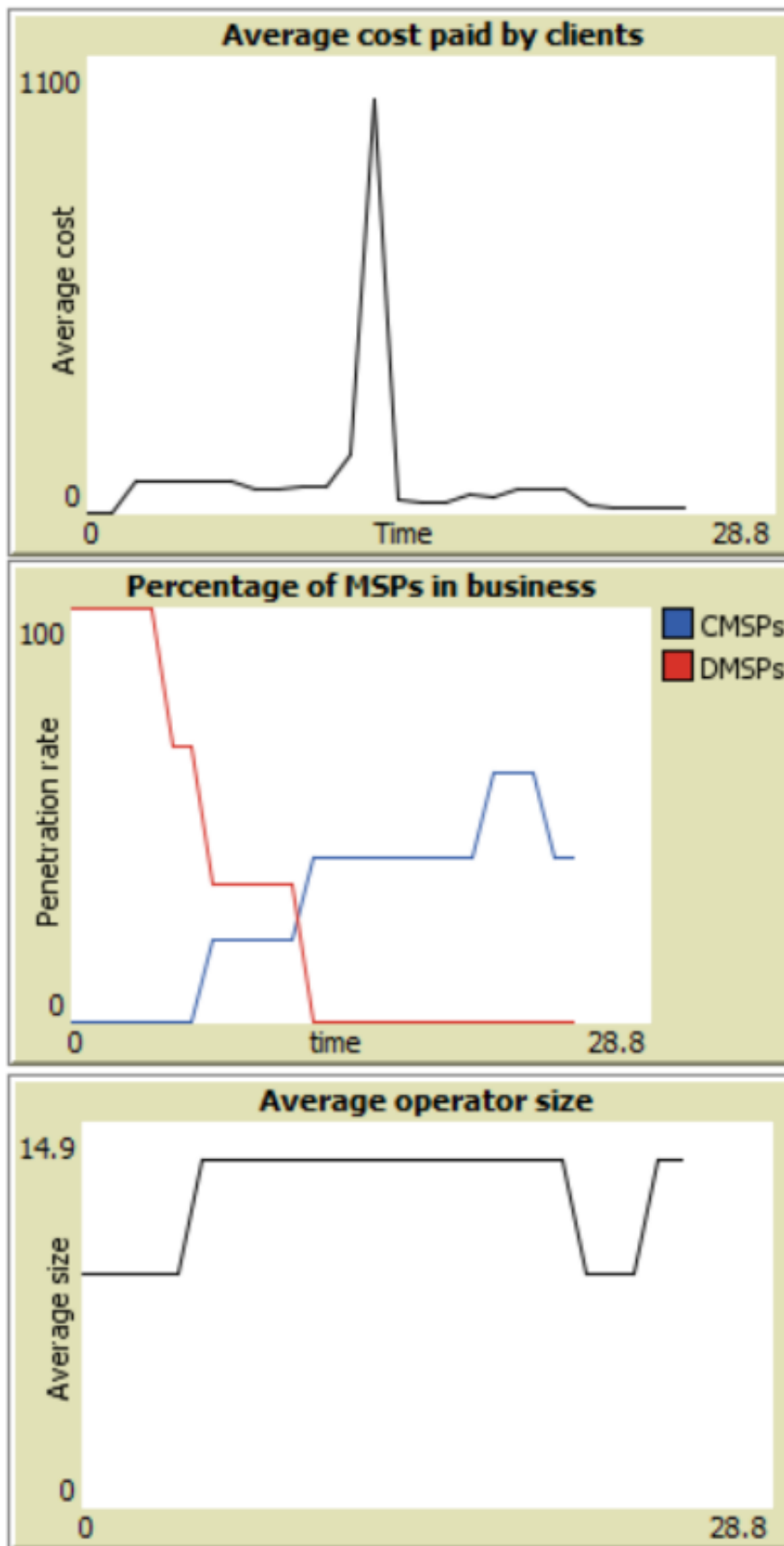


FIGURE 3.3 – Outcome 2: All legacy mobile operators driven out of business with the final user cost less than the initial cost.

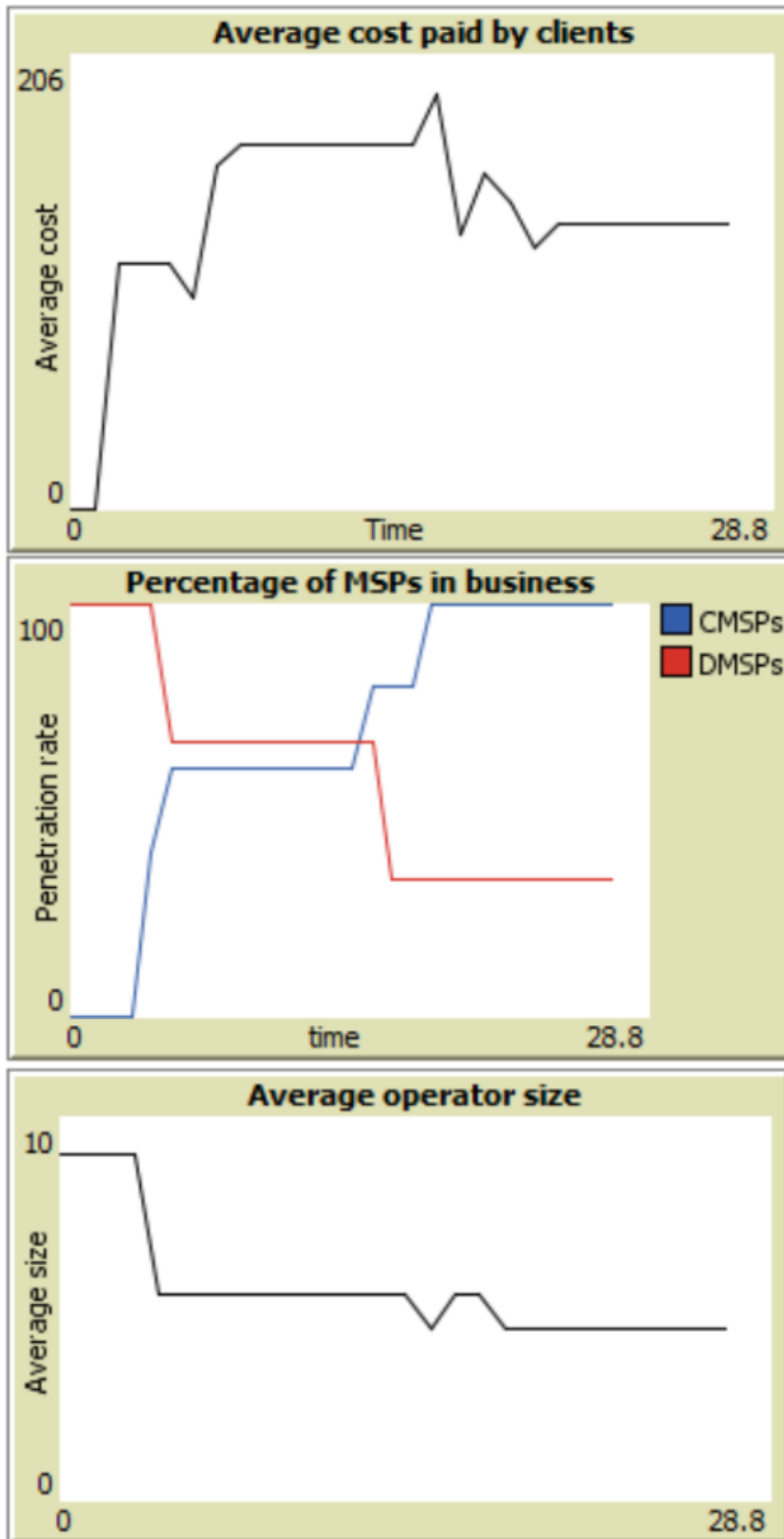


FIGURE 3.4 – Outcome 3: Co-existence between legacy and cloud-based mobile operators. Some of the legacy and cloud-based operators left the market.

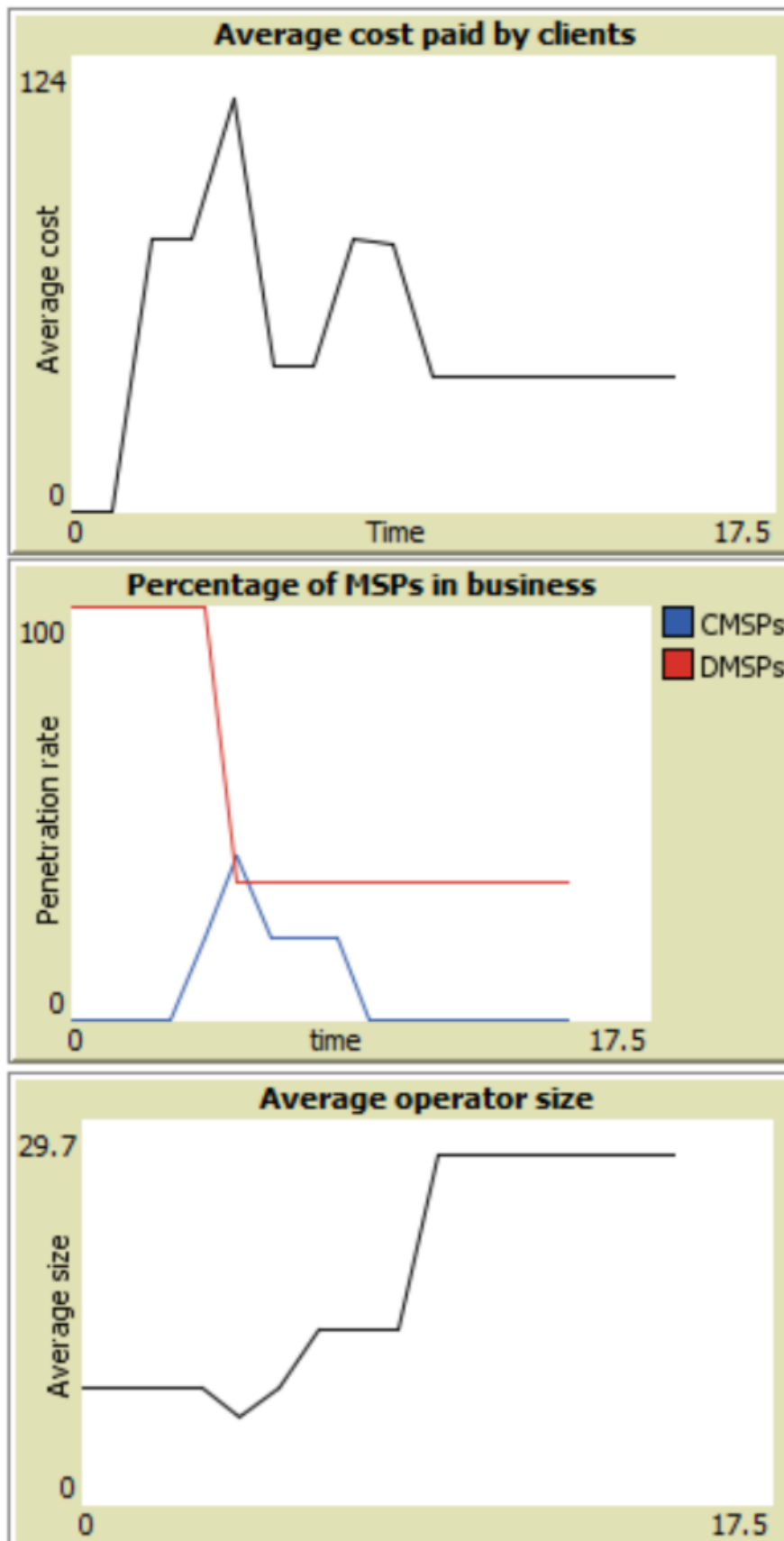


FIGURE 3.5 – Outcome 4: Cloud-based mobile operators join the market and leave later because of competition from the legacy mobile operators.

3.4. CONCLUSION AND FUTURE CHALLENGES



FIGURE 3.6 – Simulator’s Main View.



FIGURE 3.7 – First Sample Round.

3.4. CONCLUSION AND FUTURE CHALLENGES

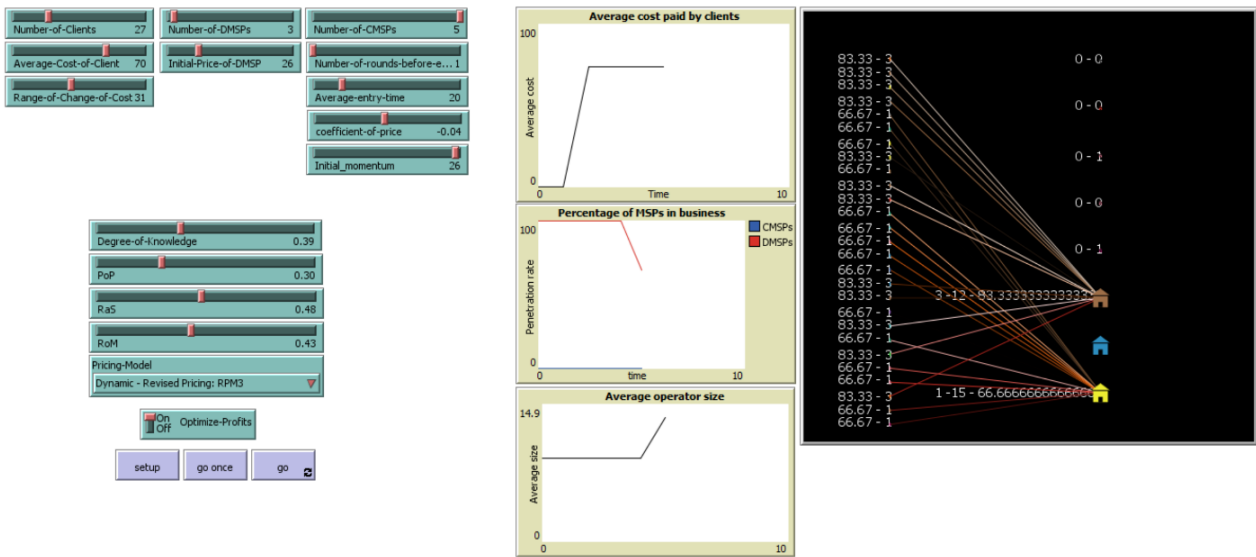


FIGURE 3.8 – Fifth Sample Round.

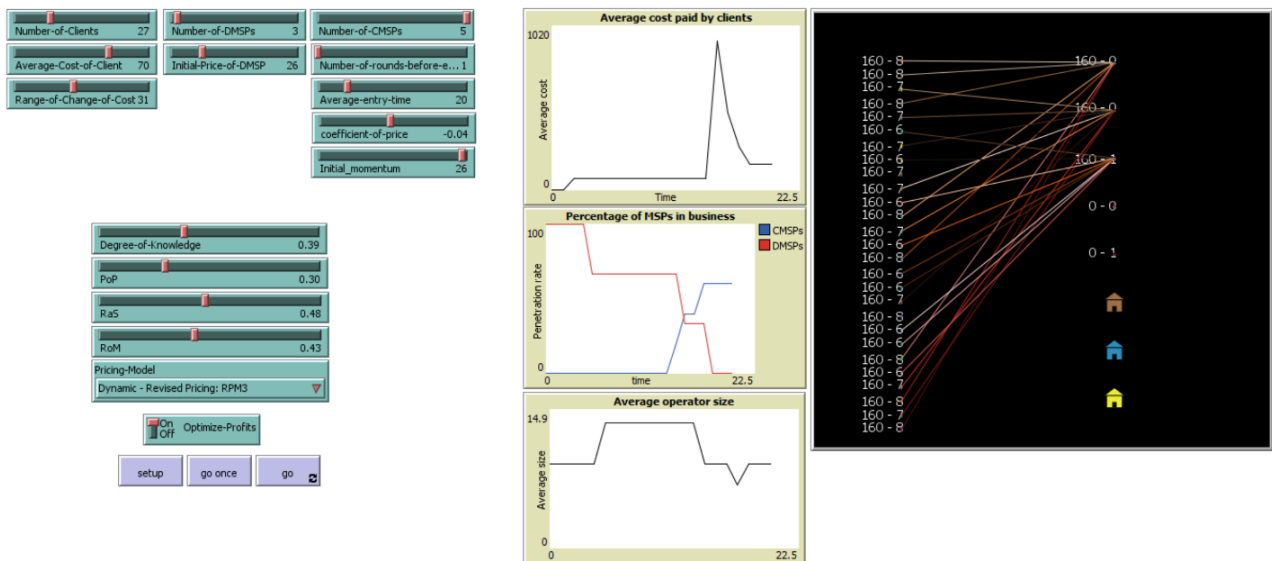


FIGURE 3.9 – Twentieth Sample Round.

Chapter 4

The Oligopoly of Cloud Computing

Contents

4.1 Introduction	131
4.2 Research Background	132
4.2.1 Dynamics of oligopoly	133
4.2.2 Game theory	136
4.3 Research Framework	137
4.4 Literature Review	138
4.5 Oligopoly of Cloud Computing	140
4.5.1 Oligopoly of Cloud Computing: elastic demand use case	141
4.5.2 Oligopoly of Cloud Computing: inelastic demand use case	145
4.6 Conclusion and Future Work	146
Appendix	149

4.1 Introduction

The adoption of cloud computing divides the market into two categories namely adopters and non-adopters. This division identifies the organizations' business models, pricing

models and chances of success and failure. We are interested in investigating the market dynamics when those two categories collide.

In the previous chapter, we studied the market dynamics under the assumption of perfect competition for a cloud computing scenario namely the adoption of multitenancy by mobile operators. The legacy mobile operators are few in number, but huge in size and have the capability to alter the market price, so they match the definition of oligopolistic players [244]. As current prices are relatively stable, we can safely expect that the market has reached a form of oligopolistic equilibrium (not necessarily Cournot's or Bertrand's). This equilibrium has been reached due to barriers to entry and limited licensed mobile spectrum which made the market relatively closed in terms of operators. As cloud-based mobile operators emerge, they will enter a stable market with reached equilibrium which makes their impact non-trivial in case they succeeded in unbalancing the market.

The dominant oligopoly models are Cournot's [245] and Bertrand's [246] where each is based on a set of assumptions that may or may not be applicable to a certain market. The oligopoly in the mobile market has no formal representation in literature and this is due to the incompatibility between the existing oligopoly models' assumptions and the market's condition. In this chapter, we will try to cover this gap by implementing Cournot's oligopoly model for the mobile market with additional assumptions and mathematically calculate its equilibrium price and stability. We will also simulate the oligopolistic behavior of legacy mobile operators using ABM and draw conclusions.

4.2 Research Background

As new players enter the market, it is expected that legacy mobile operators counter this new market penetration and either set coordinated competitive strategies or maintain oligopolistic strategies. Cooperative competitive strategies can be regulated by government policies so it is outside the scope of this work. In this work, we will consider that the legacy mobile operators adopt an oligopolistic strategy.

We are interested in studying the mobile market's transition state when EPCaaS

services get introduced and new cloud-based operators enter the market. This market penetration is expected to be faced with a non-coordinated opposition from the oligopoly of legacy mobile operators. To do so, we will study the dynamic interaction between different players (mobile user, legacy mobile operator, cloud-based mobile operator, and CSP) and predict the market's emerging status under oligopolistic rules. In this section, we discuss the dynamics of oligopoly which were used for studying the interaction between players in addition to game theory.

4.2.1 Dynamics of oligopoly

Cournot [245], defined oligopoly as the competition between a few sellers, placing it between monopoly and perfect competition. Monopoly is one seller explicitly dominating the supply of the market and having total control over the price/cost structure; while perfect competition is composed of small suppliers having no control over the market price. In perfect competition, firms with flexible cost functions will lower their cost ratio to get positive profit or lower their price to become more competitive and the others on the margin will earn nothing thus causing them to exit the market.

Duopoly, a particular case of an oligopoly with only 2 suppliers, is more complicated than either monopoly or competition. They take into account the "market demand and try to equate marginal revenue to cost"[244]. Yet in this case, marginal revenue will not only depend on a player's own supply, but also on the supplies of all the competitor(s). In this scenario "each of them is large enough to influence the market price" [244], thus taking into account the competitors' expectations and how they would react back to possible moves when calculating optimal decisions.

4.2.1.1 Equilibrium

Palander [247] found either a quasi-periodic orbit or a chaotic orbit, which has no discernible structure at all. The system was characterized by Cournot [245] as a recursive iterative map, which is a series of motions that leads to a conclusion where the orbit

might be a fixed point or equilibrium.

In the case of Cournot's equilibrium, self-consistency is the driver with an unproblematic situation. The competitors at equilibrium will have the same outcomes for the same actions, making it risk-free to operate the market while expecting the same results.

When it comes to the chaotic or the quasi-periodic orbit in an oligopoly when in sufficiently low periods, competitors can learn and adapt to them and generally voiding the periodicity. In other terms, when competitors learn and adapt to the dynamics of the market, they are implementing actions that return the periodic orbit into equilibrium. This is "unrealistic and blows up the concept of rational expectations in current economic theory." [244]

4.2.1.2 Multiplicity of attractors

Equilibrium can be around one fixed point which is considered to be a static equilibrium, or range between a set of fixed points. Equilibrium can also be around a set of fixed points "coexisting with other types of attracting orbits" [244]. The linear model for example has "one unique attractor, but nonlinearity opens up for coexistence between different attractors" [244].

Nonlinearities were first suggested for monopoly by Joan Robinson in 1933 [248], and for duopoly by Tord Palander in 1939 [247]. For the simple reason that prices and quantities cannot be negative, piecewise linear models are nonlinear. In the case of a monopoly with linear demand functions, a high-priced product is a amenity restricted for rich customers; as the price is reduced, other categories of consumers may buy it. As a result, marginal cost functions can cross at multiple locations, giving the monopolist multiple coexisting local profit maxima.

In an oligopoly, Palander [247] assumes that each seller will select the global maximum profit. However, it depends on the competitor's market share. The reaction function, representing the anticipated reaction of the competitor, comes in disjoint pieces leading to multiple attractors. In a duopoly, Palander described also the possibility of two coexisting "Cournot equilibria with a periodic oscillation" [247].

4.2.1.3 Strategy types

In the Cournot setting, a competitor can simply decide his best action if he is knowledgeable of the competitors' next move, which is not usually the case. Cournot process assumes that each agent considers all his competitors' actions will remain constant and select his best action based on this assumption. Definitely, the agent will be disappointed by this assumption, which is generally called naïve or myopic.

Even if orbits are simple and strictly periodic, the agent cannot learn them and modify his actions because this would affect the orbit's periodicity (since it is also assumed that the agents are large enough to change the price-supply structure). Furthermore, because chaotic and quasiperiodic orbits are hard to learn, the equilibrium is the only fixed-point orbit where competitors' expectations are not fooled.

Competitors are expected to practice conservatism, which is sticking to a linear action plan rather than leaping from their past movements to the current estimated optimum responses. The adaption weights are then increased from zero to one, transforming the duopoly into a two-dimensional system. If competitors simply react to the last competitor's action, a combination of two steps produces a second-order system which converts the market into iteration-based game.

4.2.1.4 Stability of Cournot Equilibrium

Achieving static equilibrium is very interesting in dynamic settings, for this reason, linearity is usually considered. Using linear demand functions and constant marginal cost, the corresponding reaction functions are linear with slope $a = -\frac{1}{2}$. Under this assumption, Cournot's static equilibrium and "Palander's two concurrent Cournot equilibria are stable" [244].

4.2.1.5 Stability of Bertrand Equilibrium

Bertrand's oligopoly model [246] is very similar to that of Cournot, but sets the price as the controlled variable (instead of quantity as set by Cournot). Bertrand's model considers the

supplied quantity as directly proportional to the demand and intrinsically assumes that the supplier has the capability of infinitely supplying a product [249]. This is problematic in markets with limited supply capacity or when the cost function has a fixed component, because in such cases, Bertrand's oligopoly model fails to reach nash equilibrium [249]. The mobile network market has limited supply capacity (limited spectrum) and its cost function has a fixed component (fixed spectrum lease). Accordingly, Bertrand's oligopoly model is considered impractical for this work.

4.2.2 Game theory

Game theory is a multi-agent decision-making theory [250] involving decisions and utilities for these economic agents. It has two important characteristics:

1. Dynamic: where the order of decisions is important.
2. Noncooperative: where agents pursue their interests which are partially conflicting with others.

We need a technique for thinking of utility maximizing in mathematical terms since game theory is a technology for formal modeling. A utility function is a technique that performs this purpose. A utility function is a measure of preferences for a collection of goods and services in economics. A game is defined as any circumstance in which at least one agent may only maximize his utility by predicting (either consciously or implicitly in his conduct) the responses to his actions by one or more other agents. In video games, agents are referred to as players.

The distinction between games with perfect and imperfect information is due to differences in how games are represented dependent on the order of play. There is a distinction to be made between sequential-move games, in which players select their tactics one by one, and simultaneous-move games, in which players select their plans all at once.

It's critical to understand the difference between cardinal and ordinal utility when discussing utility functions. "An ordinal utility function is a function that represents an agent's preferences on an ordinal scale in economics. According to ordinal utility theory, asking an agent about his choice for one option vs another alternative is only useful if not possible. A cardinal utility function or scale is a utility index that uniquely retains preference orderings up to positive affine transformations" [250], allowing the customer to express satisfaction in cardinal or quantitative values.

4.2.2.1 Nash equilibrium

A set of strategies is named to be Nash equilibrium if none of the participating players can improve his payoff, given the strategies of all other players in the game. Nash [251] explicitly defined the equilibrium of a noncooperative game as a profile of strategies, one for each participant in the game, where each player's plan optimizes his anticipated utility reward compared to the other players' strategies. A network of mutually restricting links may be described as an economic system, and the equilibrium of such systems are their stable states.

4.3 Research Framework

In the previous chapter, we evaluated the market behavior when multi-tenancy is introduced under the condition of free competition. Free competition can be enforced through government policies that are outside the scope of this research. In the absence of such policies, the market is most likely going to be oligopolistic especially when legacy providers face an existential threat like multi-tenancy and virtualized mobile operators [244].

In this chapter, we are interested in evaluating market behavior under oligopolistic conditions. Two cases will be considered both elastic and inelastic demands for cloud services and in particular mobile services. For the first case, the market stability is going to be modeled mathematically where legacy mobile operators have a limited capacity inherited from the nature of their infrastructures; while virtualized mobile operators

are free from this constraint [244]. The possibility of network expansion is neglected from this model because of its extreme mathematical complexity. The market behavior of the second case will then be modeled using ABM. The originality of this work can be identified as:

- This work is the first, to the best of our knowledge, to discuss the co-existence of limitless and limited capacity mobile operators.
- It extends the results of the previous chapter under more realistic assumptions. This work is the first, to the best of our knowledge, to formally represent an oligopoly in telecommunication.

4.4 Literature Review

Laffont and Tirole [252] studied the Endogenous Marginal Costs between telecommunication operators and their effect on the operators' strategies. In this study we assume that the terminating access is priced at the marginal cost, thus equating between inter-operator and intra-operator traffic. This assumption simplifies the model, discussed in this chapter, by eliminating size proportional pricing and Platform Competition in Two-sided Markets [253].

Hauge and Jaminson [254] examine common techniques for calculating market concentration, as well as suppliers' ability to raise prices, barriers to entrance and departure, and anticompetitive behavior. They also go through strategies for recognizing market power, with an emphasis on the telecoms industry, as well as methodologies for determining if corporations are using their market power.

Jaminson [255] argued that the telecommunication market is a workable competition, which is a market condition that does not meet the perfect competition model but has enough perfect competition characteristics that government intervention is unneeded and potentially destructive.

Vafamehr and Khodayar [256] studied the "oligopolistic competition among cloud

providers in electricity and data networks" [256]. At each of the electricity and data networks system, "the operation strategies of the market participants are determined by forming bi-level optimization problems in which the upper-level problem maximizes the payoff of the market participants while the lower-level problem represents the corresponding market settlement process" [256].

Helmes and Schlosser [257] studied oligopoly pricing in isoelastic adoption models and calculated the formulas for the equilibrium prices as a function of the number of competing firms. Farias et al. [258] proposed an approximation of dynamic oligopoly that is suitable for computer simulation and modeling. The authors suggest that their approach can significantly expand the set of dynamic oligopoly models that can be analyzed computationally. Desai et al. [259] extended the above work by using a smoothed linear program which yields more accurate results.

Klemperer and Meyer [260] studied the effect of per-supplier "supply function" on the equilibria of oligopoly. They proved that under uncertainty, symmetrical oligopoly with homogeneous production can reach uniqueness if Nash equilibrium in supply functions is reached.

Competing businesses incur actual resource costs in manipulating their marginal costs in order to affect the result of the game they intend to play in stage two, according to Long and Soubeyran [261]. They demonstrated that even for ex-ante symmetric companies, the best resource allocation inside an oligopoly may be asymmetric.

Ledvina and Sircar [262] are among the few who studied oligopoly between firms having different costs of production. They concentrated on the linear demand structure with constant marginal but asymmetric costs.

Chevalier-Roignant et al. [263] explored non-cooperative firms with different cost structures in the context of uncertainty in strategic investment. They discovered that for extremely non-linear capacity distributions, "(ex-ante) linear capacity investment cost asymmetry leads to (ex-post) heterogeneity" [263].

For two consecutive periods, Van den Berg et al. [264] looked at a dynamic Cournot duopoly in which providers had a restricted number of items available. It was discovered

that under commitment, tactics are independent of the rival's realized sales, that each allocation of beginning supply has a unique Nash equilibrium, and that prices rise with time. Sellers can modify their supply choice after the first period if there is no commitment. A subgame perfect Nash equilibrium may not necessarily exist in this scenario, and prices may fall over time.

Bischi et al. [265] based their dynamic oligopoly model with R&D externalities on the work of [231], [232], [233], [234], [235] to formulate a two-stage oligopoly game evaluating the suitability of sharing R&D results with partner firms as well as gaining knowledge for free through spillovers. As the mobile technology is guided by the 3GPP standards, such a model does not apply to our case assuming that mobile operators are not vendors or manufacturers of telecommunication technology. Mobile operators' R&D efforts are limited to the production of differentiating services that, as argued in the previous chapter, create a competitive advantage against small operators who can't afford to develop or to integrate all available services.

Ara et al. [266] studied the government imposing tariffs as a vertical oligopoly. The discussed case study has the Home market specialized in final goods while the foreign market specialized in intermediate inputs to mimic the Japan-China case. Other applications of the mixed Cournot game have been investigated by Zhe et al. [253] and it showed that private firms aim for profit maximization only while semipublic ones aim at social welfare and profit maximization.

4.5 Oligopoly of Cloud Computing

One of Cournot's basic assumptions when studying oligopoly is the existence of an inverse demand function where the price-quantity relationship is maintained. This assumption intrinsically includes the assumption of an elastic demand function, which is not always true. In this chapter, we will consider both elastic and inelastic demands for cloud services and in particular mobile services. For the first, we will mathematically calculate the Cournot equilibrium price and the stability constraints. While for inelastic demand, we

will simulate the market behavior using ABM.

4.5.1 Oligopoly of Cloud Computing: elastic demand use case

In this section, we will use the mathematical notation of [244]. Let the inverse demand function be $p = f(Q)$ Where p represents the price, f the inverse demand function and Q the market supply.

The market supply Q can be broken into the sum of each supplier's quantity denoted by $Q = \sum_{i=1}^n q_i$ Where n represents the number of suppliers, and q_i represents their relative supplied quantity. Accordingly, the residual supply can be represented by $Q_i = Q - q_i$.

The demand function of telecommunication services is a constant elasticity demand function [244] which results in a linear inverse demand function. Using the terms of [244], $p = a - bQ$ where a and b are two positive constants. It was reported by Laffont and Tirole [244] that details about the cost function of mobile operators are absent.

4.5.1.1 Limitless-capacity suppliers

Assuming a linear cost function, it can be represented by $C_i = c_i \times q_i$ where c_i are constant marginal, equal to average variable costs. The assumption of linear cost function is verified in section c below. Based on the above assumptions, the reaction function is:

$$q_i = \begin{cases} \frac{a-c_i}{2b} - \frac{1}{2}Q_i; & Q_i < \frac{a-c_i}{b} \\ 0; & elsewhere \end{cases}$$

Considering the equilibria of the general Cournot model, we reach the following equations:

$$q_i = \frac{a - c_i}{b} - Q$$

And

$$Q = \frac{n}{n+1} \frac{a-c}{b}$$

Where

$$c = \frac{1}{n} \sum_{i=1}^n c_i$$

To calculate the stability of the Cournot equilibria, we need to solve the following n by n Jacobian Matrix

$$J = \begin{bmatrix} 0 & -0.5 & -0.5 & -0.5 \\ -0.5 & 0 & -0.5 & -0.5 \\ \dots & -0.5 & \dots & -0.5 \\ -0.5 & -0.5 & -0.5 & 0 \end{bmatrix}$$

The solution of this matrix in its current form calculates the stability for a homogeneous limitless-capacity oligopoly which is not the aim of this work. This matrix will be utilized in Section 4.5.1.5 to calculate the stability of a mixed capacity environment.

4.5.1.2 Limited-capacity suppliers

Legacy operators are limited-capacity suppliers, but have already provisioned their infrastructure to accommodate the current traffic size. We can thus assume that with the introduction of cloud-based mobile operators, legacy mobile operators will run in the range of constant marginal costs without reaching the jump to infinity when the limit is reached. Assuming a constant cost function, it can be represented by $c_i = C_i/q_i$ where C_i is the running cost of operator i . Based on the above assumptions, the reaction function is:

$$q_i = \begin{cases} \frac{a}{2b} - \frac{1}{2}Q_i; & Q_i < \frac{a}{b} \\ 0; & elsewhere \end{cases}$$

Considering the equilibria of the general Cournot model, we reach the following equations:

$$q_i = \frac{a}{b} - Q$$

And

$$Q = \frac{m}{m+1} \frac{a}{b}$$

For the supplier to remain profitable, $p \times q_i > c_i$ then $c_i < \frac{a^2}{b(m+1)^2}$

To calculate the stability of the Cournot equilibria, we need to solve the following n by n Jacobian Matrix

$$J = \begin{bmatrix} 0 & -0.5 & -0.5 & -0.5 \\ -0.5 & 0 & -0.5 & -0.5 \\ \dots & -0.5 & \dots & -0.5 \\ -0.5 & -0.5 & -0.5 & 0 \end{bmatrix}$$

4.5.1.3 Mixed capacity environment

It is safe to represent the mobile market during the transition period when cloud-based mobile operators join the market as a mixed capacity oligopoly where legacy operators with their existing infrastructure represent the limited-capacity suppliers and the cloud-based operators represent the limitless-capacity suppliers. Legacy operators have nearly fixed costs when the supply is within their capacity and peaks when new infrastructure investment is required. As this peak increases, the jump in cost can tend to infinity and thus satisfy the definition of limited-capacity suppliers.

The cost function of limited-capacity mobile operators can be represented either with a piecewise function with a fixed cost below supply capacity and infinity otherwise or with constant elasticity of substitution (CES) function. As in the case of most technology-

based service provides, the CES function is not a good representation of its cost function, thus a piecewise function of 2 steps will be used to represent legacy mobile operators. Cloud-based operators, like all cloud clients, can be represented by a linear cost function as a simplification of the granular incremental piecewise cost function where the range of each step equals the capacity of 1 virtual server.

4.5.1.4 Exit conditions in mixed capacity environment

For limitless-capacity suppliers, the price is $p = \frac{a}{n+1} + \frac{n}{n+1}C$. The suppliers will remain profitable while $P \times q_i > c_i \times q_i$. Neglecting the opportunity cost, the supplier will remain profitable while $a > c_i$. The profitability is independent from the quantity sold, thus the cloud service provider will remain profitable and will only exit the market if he acquired 0 customers.

For limited-capacity suppliers, the price is $p = \frac{a}{n+1}$. The suppliers will remain profitable while $P \times q_i > c_i$. Neglecting the opportunity cost, the supplier will remain profitable while $q_i > \frac{c_i}{a}$.

The profitability is dependent on the quantity sold, thus, a legacy mobile operator will exit the market if he maintained a number of customers less than or equal to $\frac{c_i}{a}$.

4.5.1.5 Stability of Cournot equilibrium in mixed capacity environment

Studying the long-run stability of the mixed process, assuming that n legacy operators exist in the market (n limited-capacity suppliers) and m cloud-based operators joining the market (m limitless-capacity suppliers) we can compose the Jacobian for the mixed system as an $(n + m)$ by $(n + m)$ matrix:

$$J = \begin{bmatrix} 0 & -0.5 & -0.5 & -0.5 \\ -0.5 & 0 & -0.5 & -0.5 \\ \dots & -0.5 & \dots & -0.5 \\ -0.5 & -0.5 & -0.5 & 0 \end{bmatrix}$$

Luckily enough, the resulting matrix is similar to the limited-capacity and limitless-capacity cases and its eigenvalues are:

$$\lambda_1 \dots \lambda_{n+m-1} = \frac{1}{2}; \lambda_{n+m} = -\frac{1}{2}(n+m-1)$$

For the system to be in stability, all the eigenvalues should be in the unit circle of the complex plane which is always true for all the eigenvalues except the last. For λ_{n+m} to fall in the unit circle of the complex plane, $n+m < 3$. This means that the market will only be stable if less than 3 operators remain in the market.

4.5.2 Oligopoly of Cloud Computing: inelastic demand use case

In this section, the user is considered to have full market exposure without differentiation between operator service (Rationality) while neglecting the transfer cost (the cost and inconvenience to move from one operator to another). Operators can reject sharing the Porting Authorisation Code [[267], [268], [269]], thus, preventing their customers from switching to new operators while maintaining their phone numbers. This inconvenience can be represented by a transfer cost which reduces the customer's willingness to migrate between operators. In this section, we consider the user to have a complete willingness to move between operators. For these reasons, discrepancies in market price are usually punished and an equilibrium price is expected to be achieved. The relative source code is listed in the appendix and the simulation results are shown below.

In the absence of a demand function, the operators can't predict their best move and consequently, the overall behavior is unstable. Under oligopolistic pricing schemes, the cloud-based mobile operators will remain in the market if the selling price is higher than their customer price. On the other hand, the legacy mobile operators will remain in business if the selling price is higher than their cost divided by the number of their customers.

As competitive pricing push the prices towards the marginal cost (and in our

case to the operating cost since we neglect the opportunity cost), if we consider that all legacy mobile operators have the same operational cost and similarly for the cloud-based operators, we will end up with one type of operators remaining (Figure 4.1 and Figure 4.2). If the operational costs are different, the market will develop into a monopoly with the operator having the lowest operational cost remaining (Figure 4.3).

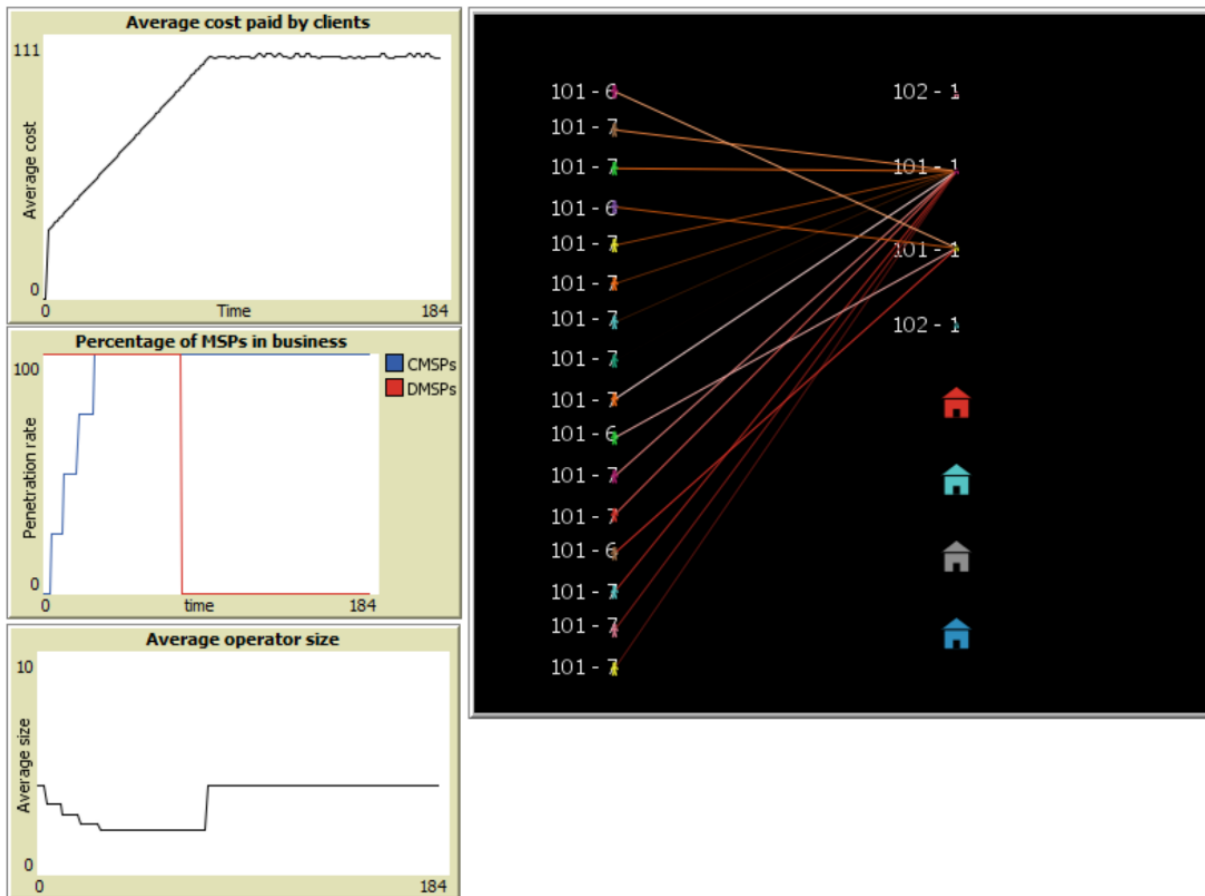


FIGURE 4.1 – Oligopolistic equilibrium with legacy operators out of business (cloud-based operators have the same operational cost which is lower than that of legacy operators for the considered number of clients).

4.6 Conclusion and Future Work

In this chapter, we raised the issue of oligopoly in the mobile network especially during the transition phase when cloud-based mobile operators emerge. We mathematically modeled the market behavior under the assumption of elastic demand. Cournot Equilibrium and its stability were calculated for the mixed environment of limitless suppliers (cloud-

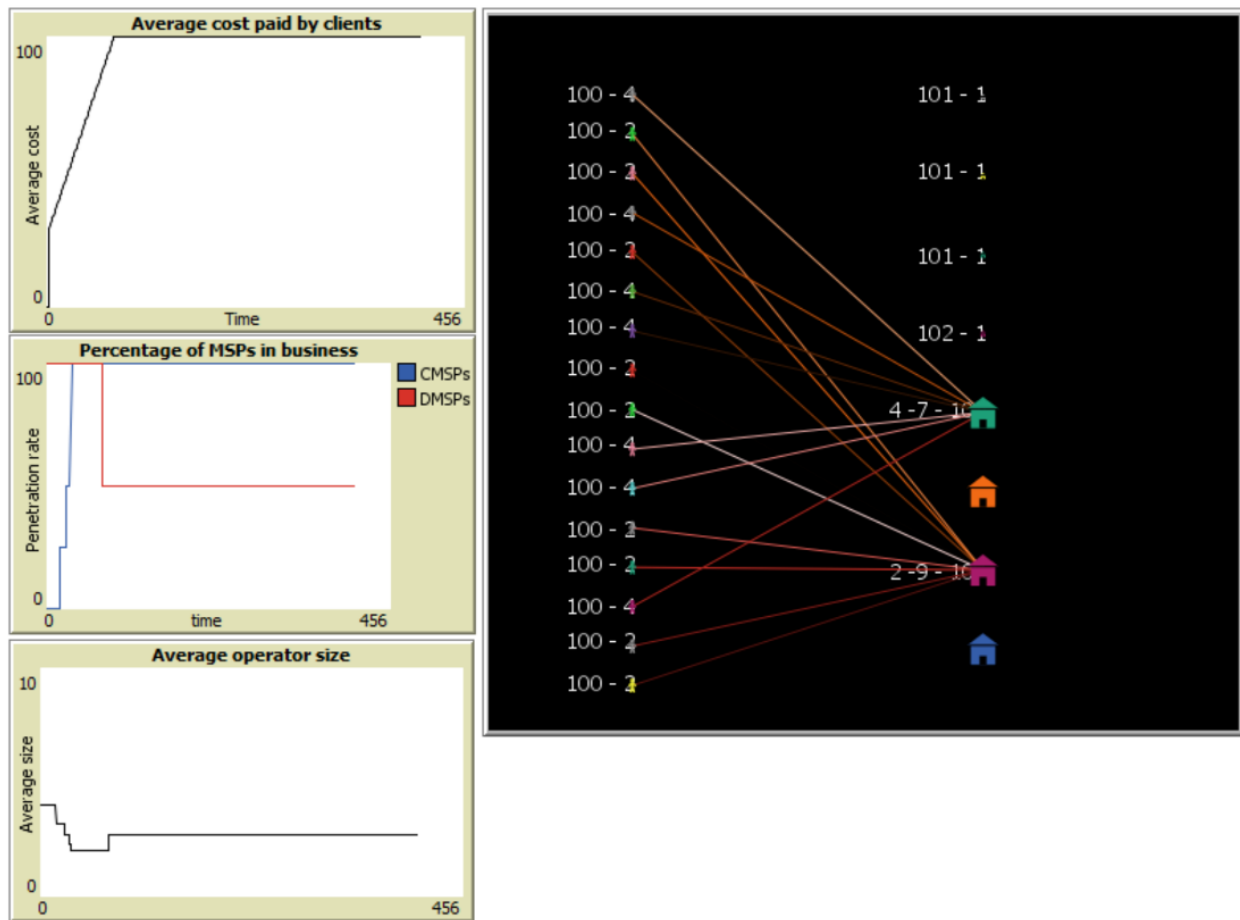


FIGURE 4.2 – Oligopolistic equilibrium with cloud-based operators out of business (cloud-based operators have the same operational cost which is higher than that of legacy operators for the considered number of clients).

based mobile operators) and limited-capacity suppliers (legacy mobile operators). We also modeled the 5G network using the Agent-Based-Modeling technique and the market behavior has been predicted for inelastic demand. The equilibrium and stability of the mobile market can't be ensured neither for elastic nor inelastic demand. The potential states have been presented in this chapter.

The outcomes of this chapter reinforce the outcomes of the previous chapter, which can be summarized as:

- Any DSS for cloud adoption should not rely solely on the business' requirements, but consider the market behavior in general and its possible economic implications.
- Businesses' actions towards cloud computing are active during the cloud's first stages but become reactive with its introduction to the market.

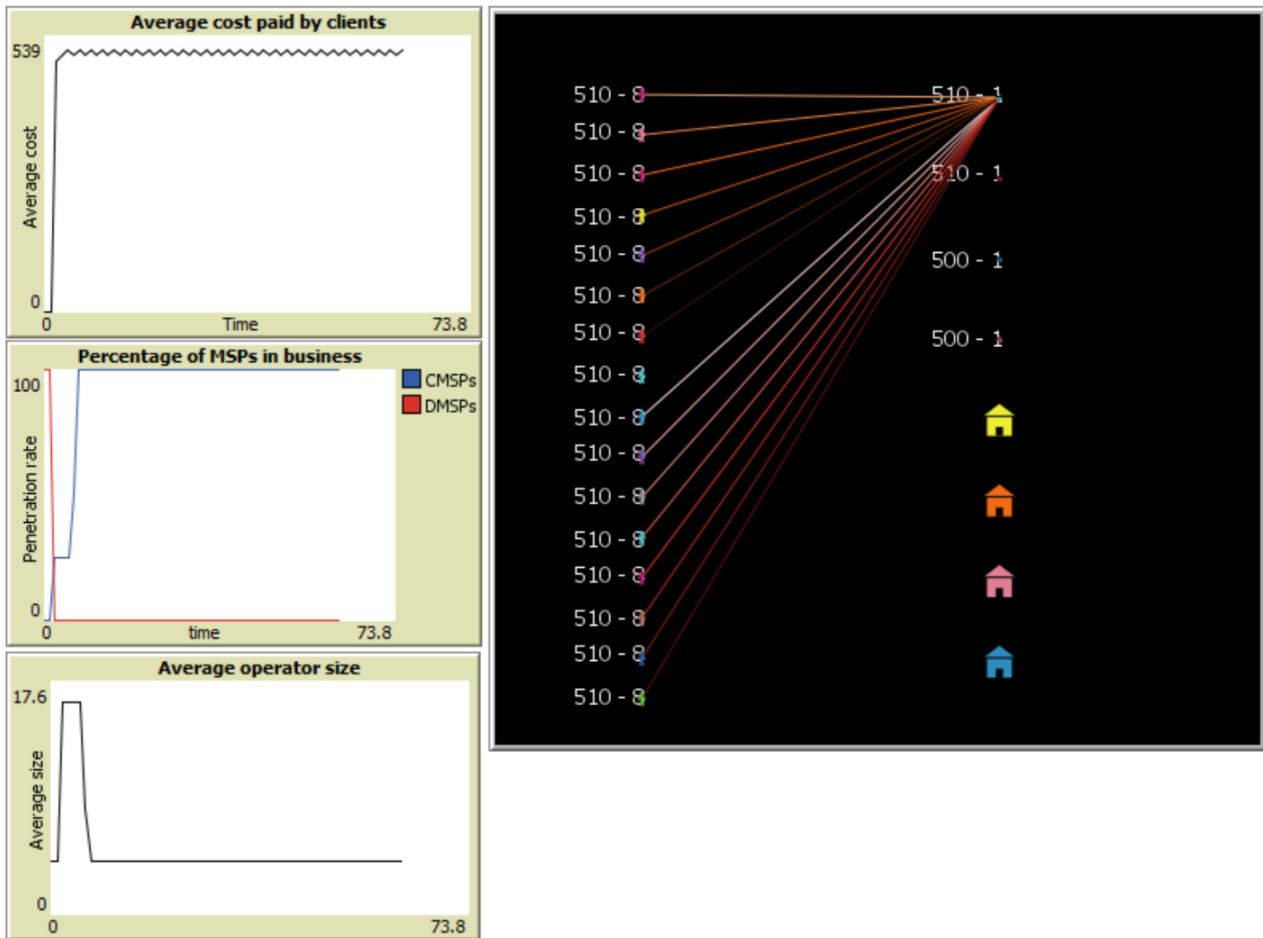


FIGURE 4.3 – Oligopolistic equilibrium ending up in monopoly.

This chapter covers one of the gaps faced in the previous chapter which is the oligopolistic nature of the mobile market, but it introduced many more challenges that are to be faced in our future work. Cournot’s oligopoly model is equipped with additional tools such as investment and time series that help users predict the market behavior as new players join the market over time. We have neglected these tools in this work, but are considered as future work for their importance.

We considered in this chapter Cournot’s oligopoly model without taking into consideration Bertrand’s oligopoly (although many economists refuse to call it so) or other models that could be more convenient for the mobile and cloud markets and disruptive technologies in general.

We have also considered in this chapter that inter-operator and intra-operator traffic have equal cost because of the mathematical complexity representing the more generalized form. Generalizing this work to include per-operator pricing is also important

for the advancement of this field.

This chapter satisfies CBOD’s task 5 and objectives 4, 5 and 6. The updated project status is shown in table 4.1.

TABLE 4.1 – Chapter 4 contributions to CBOD objectives and tasks

	Status		Status
<i>Objective 1</i>	Done	<i>Task 1</i>	Done
<i>Objective 2</i>	Done	<i>Task 2</i>	Done
<i>Objective 3</i>	Done	<i>Task 3</i>	Done
<i>Objective 4</i>	Done	<i>Task 4</i>	Done
<i>Objective 5</i>	Done	<i>Task 5</i>	Done
<i>Objective 6</i>	Done	<i>Task 6</i>	Pending

Appendix

```

globals [
  cout ;; Used as the xcor value for the first Mobile Service Provider.
  counter ;; Used to index the IDs of the clients. The value is set to 0 in
  setup.
  counter-DMSP-CMSP ;; Used to index the IDs of the Cloud-based Mobile Service
  Providers and Dominant Mobile Service Providers.
  General_Cost_DMSP ;; c = 1000
  General_Cost_CMSP ;; c = 200
  constant_a ;;market’s inverse demand function constant a
  constant_b ;;market’s inverse demand function constant b
  Number_of_active_CMSPs ;; n

  number_of_changes
  average_cost
  CMSP_count
  DMSP_count
  List_of_active_MSPs
  Number_of_active_MSPs

```

```

]

breed [clients client] ;; Breed of clients.
breed [CMSPs CMSP] ;; Breed of CMSPs.
breed [DMSPs DMSP] ;; Breed of CMSPs.

clients-own
[
  cost ;; Used to represent the cost the company is paying for its IT services
    that could be offloaded.
  id ;; Client's ID.
  connected_to ;; CMSP's OR DMSP's ID
  knowledge_list ;; list of CMSPs and DMSPs the user knows
]

CMSPs-own
[
  price ;; Used to represent the price the CMSP is offering its client. Price
    = ( general_cost * ( 1 + coefficient-of-price ) / (
      Number_of_active_CMSPs * CMSP_users ) )
  CMSP_users ;; Number of users connected to this CMSP
  id ;; CMSP's ID. Starts at 10.
  entry_period ;; When should enter business. Random number between 0 and 2*
    Average-entry-time
  in_business ;; Boolean value. If tick > entry_period and CMSP_users > 0
  Elasticity_starts ;; Before elasticity, CMSP_users will be Initial_momentum;
    Elasticity_starts = entry_period + Number-of-rounds-before-elasticity
  Good_Reputation ;; 1 is true, 0 is false
]

DMSPs-own
[

```


4.6. CONCLUSION AND FUTURE WORK

```
price ;; Initially it is set to Initial-price-of-DMSP; Used to represent the
    price the DMSP is offering its client.  $P = \text{general\_cost} / \text{DMSP\_capacity}$ 
DMSP_users ;; Number of users connected to this user
id ;; CMSP's ID. Starts at 1
in_business ;; Boolean value. If DMSP_users > 0
Good_Reputation ;; 1 is true, 0 is false
]

to fill_List_of_active_MSPs
;;
;; Identify the active MSPs so that a user can search for a suitable price
    between the active ones. It will decide the searched list based on the
    degree-of-knowledge
;;
set Number_of_active_MSPs 0
set List_of_active_MSPs []
ask DMSPs [if in_business = 1 [set Number_of_active_MSPs
    Number_of_active_MSPs + 1
set List_of_active_MSPs sentence List_of_active_MSPs id]]
ask CMSPs [if in_business = 1
    [set Number_of_active_MSPs Number_of_active_MSPs + 1
set List_of_active_MSPs sentence List_of_active_MSPs id]]
;;print "Number_of_active_MSPs"
;;print Number_of_active_MSPs
if Number_of_active_MSPs > 0
[
    let list1 [id] of DMSPs
let list2 [id] of CMSPs
let list_of_ids sentence list1 list2
;;
;; Fill a knowledge list i.e. the list of MSPs the user contact looking for
    the best offer. This is because of bounded rationality
```

```

;;
ask clients [
  ;;
  ;;Currently the user selects a new knowledge-list every tick, and the
  new knowledge-list may not include his current operator. The best way
  to be done is to keep the current operator in the list
  ;;since the user will cover all operators after certain number of ticks
  ;;
let start_of_knowledge random Number_of_active_MSPs
ifelse start_of_knowledge + ( Number_of_active_MSPs * Degree-of-knowledge)
  < ( Number_of_active_MSPs )
[set knowledge_list sublist List_of_active_MSPs start_of_knowledge ( round
  (start_of_knowledge + (Number_of_active_MSPs * Degree-of-knowledge)) )
]
[let subl1 sublist List_of_active_MSPs start_of_knowledge (
  Number_of_active_MSPs )
let subl2 sublist List_of_active_MSPs 0 (Number_of_active_MSPs * Degree-
  of-knowledge - (Number_of_active_MSPs - start_of_knowledge ) )
set knowledge_list sentence subl1 subl2
]
]]

end

to setup
  clear-all
  ;;ask patches [set pcolor white]
  set-default-shape clients "person"
  set-default-shape CMSPs "house"
  set-default-shape DMSPs "house"
  set cout (100 / (Number-of-CMSPs + Number-of-DMSPs + 1) ) ;; It is a dynamic
  value for ycor which is the position of the first CMSP. Other CMSPs will
  be shifted by a dynamic value called space

```

```
set counter 0 ;; Used to index the IDs of the clients
set counter-DMSP-CMSP 1 ;; Used to index the IDs of the DMSPs and CMSPs

set Number_of_active_CMSPs 0
set General_Cost_DMSP 1000
set General_Cost_CMSP 200
set constant_a 1000
set constant_b 20

create-DMSPs Number-of-DMSPs [
  let space ( 90 / ( Number-of-CMSPs + Number-of-DMSPs ) ) ;; Dynamic value
    for CMSP locations
  set size 5

  set price Initial-price-of-DMSP
  set DMSP_users 0
  set in_business 1

  let reputation random 100
    set Good_Reputation 0

  if reputation < 100 * PoP
    [set Good_Reputation 1]

  set xcor 70
  set ycor cout
  set cout cout + space
  set id counter-DMSP-CMSP
  set counter-DMSP-CMSP counter-DMSP-CMSP + 1
  set number_of_changes 1
]
```

```

set DMSP_count 0
ask DMSPs with [ in_business = 1 ] [ set DMSP_count DMSP_count + 1 ]

create-CMSPs Number-of-CMSPs [
let space ( 90 / ( Number-of-CMSPs + Number-of-DMSPs ) ) ;; Dynamic value
for CMSP locations
set size 1

set entry_period random ( 2 * Average-entry-time )
set in_business 0
set Elasticity_starts ( entry_period + Number-of-rounds-before-elasticity
)
set CMSP_users Initial_momentum

set price 0

let reputation random 100
set Good_Reputation 0

if reputation < 100 * PoP
[set Good_Reputation 1]

set xcor 70
set ycor cout
set cout cout + space
set id counter-DMSP-CMSP
set counter-DMSP-CMSP counter-DMSP-CMSP + 1
set number_of_changes 1
]

set Number_of_active_CMSPs 0

```

```
ask CMSPs with [ in_business = 1 ] [ set Number_of_active_CMSPs
    Number_of_active_CMSPs + 1 ]

set cout (100 / (number-of-Clients + 1) )
let list1 [id] of DMSPs
let list2 [id] of CMSPs
let list_of_ids sentence list1 list2
;;print list_of_ids

fill_List_of_active_MSPs
;;print List_of_active_MSPs

create-clients number-of-Clients [
    set size ceiling ( 20 / number-of-Clients) ;; be easier to see
    let space (90 / number-of-Clients)

    set cost 100000
    set id counter
    set counter counter + 1

    set connected_to -1
    set xcor 20
    set ycor cout
    set cout cout + space

;;
;; Fill a knowledge list i.e. the list of MSPs the user contact looking for
    the best offer. This is because of bounded rationality
;;
ask clients [
let start_of_knowledge random Number_of_active_MSPs
```

```

ifelse start_of_knowledge + ( Number_of_active_MSPs * Degree-of-knowledge)
  < ( Number_of_active_MSPs )
[set knowledge_list sublist List_of_active_MSPs start_of_knowledge ( round
  (start_of_knowledge + (Number_of_active_MSPs * Degree-of-knowledge)) )
]
[let subl1 sublist List_of_active_MSPs start_of_knowledge (
  Number_of_active_MSPs )
let subl2 sublist List_of_active_MSPs 0 (Number_of_active_MSPs * Degree-
of-knowledge - (Number_of_active_MSPs - start_of_knowledge ) )
set knowledge_list sentence subl1 subl2
]
]]

ask CMSPs [ set plabel (word (precision price 2) "□-□" Good_Reputation)]
ask DMSPs [ set plabel (word (precision price 2) "□-□" Good_Reputation)]
ask clients [ set plabel precision cost 2 ]
reset-ticks
end
to exiting_business

if ( ticks > 3 ) [

ask DMSPs [ set in_business 0 ]

set DMSP_count 0

foreach sort-on [id] Clients
  [ ?1 ->
let DMSP_connected_to [connected_to] of ?1
ask DMSPs with [id = DMSP_connected_to][set in_business 1]
]

```

```
ask DMSPs
[
  if in_business = 1
  [
    set DMSP_count DMSP_count + 1
  ]
]

set DMSP_count 0
ask DMSPs with [ in_business = 1 ] [ set DMSP_count DMSP_count + 1 ]
end

to Join_business
ask CMSPs
[
  if ( ticks > entry_period - 1 ) AND ( ticks < Elasticity_starts )
  [
    set in_business 1
    print id
    set price initial_momentum
  ]
]
end

to update_pricing
set Number_of_active_CMSPs 0
set Number_of_active_MSPs 0
ask CMSPs with [ in_business = 1 ] [ set Number_of_active_CMSPs
  Number_of_active_CMSPs + 1 ]
ask DMSPs with [ in_business = 1 ] [ set Number_of_active_MSPs
  Number_of_active_MSPs + 1 ]
```

```

;;Every operator in business has to check whether increasing his price or
  decreasing it up to 100 units would increase his profits assuming all other
  operators are constant.
;;The price should be based on the old prices.

let Total_Q 0
ask clients [ set Total_Q (Total_Q + 1) ]

ask CMSPS with [in_business = 1]
[
  let q 0
  ask clients with [ connected_to = id ] [ set q q + 1 ]
  set CMSP_users q
  print q
  ifelse CMSP_users > 0
  [
    ifelse ticks < Elasticity_starts [set price initial_momentum]
    [
      ifelse (constant_a - constant_b * (q + Total_Q + 1) - General_Cost_CMSP
        ) > 0
      [set price ( constant_a - constant_b * ( Total_Q + 1 ))]
      [ ifelse (constant_a - constant_b * (q + Total_Q - 1) +
        General_Cost_CMSP) > 0
        [set price ( constant_a - constant_b * ( Total_Q - 1 ))]
        [set price ( constant_a - constant_b * ( Total_Q ))]]
    ]
  ]
  [
    ifelse ticks < Elasticity_starts [set price initial_momentum]
    [
      ifelse (constant_a - constant_b * (q + Total_Q + 1) - General_Cost_CMSP
        ) > 0

```



```

    [set price ( constant_a - constant_b * ( Total_Q + 1 ))]
    [set price ( constant_a - constant_b * ( Total_Q ))]
  ]]]

ask DMSPs with [in_business = 1]
[
  let DID id
  let q 0
  ask clients with [ connected_to = DID ] [ set q q + 1 ]
  set DMSP_users q
  print q
  ifelse DMSP_users > 0
  [ifelse (constant_a - constant_b * (q + Total_Q + 1) ) > 0
    [set price ( constant_a - constant_b * ( Total_Q + 1 ))]
    [ ifelse (constant_a - constant_b * (q + Total_Q - 1)) > 0
      [set price ( constant_a - constant_b * ( Total_Q - 1 ))]
      [set price ( constant_a - constant_b * ( Total_Q ))]]]
  [ifelse (constant_a - constant_b * (q + Total_Q + 1) - General_Cost_CMSP)
    > 0
    [set price ( constant_a - constant_b * ( Total_Q + 1 ))]
    [set price ( constant_a - constant_b * ( Total_Q ))] ]
  ]
end
to go

;;Update list of active MSPs
fill_List_of_active_MSPs
;;Linking users
dynamic-revised-pricing
;;Update pricing
update_pricing
;;Linking users

```

```

dynamic-revised-pricing

;;Anybody wants to go out of business
exiting_business

;;Anybody to join the market
Join_business

ask CMSPs [set plabel (word (precision price 2) "_-" Good_Reputation)]
ask DMSPs [ ifelse in_business = 1 [ set plabel (word id "-" (DMSP_users) "
    _-" price)] [set plabel "" ] ]
ask clients [ set plabel ( word (precision cost 2 ) "_-" connected_to )]
tick
end
to dynamic-revised-pricing ; Business Model

let read_CMSP_price 0
let read_CMSP_id 0
let read_DMSP_price 0
let read_DMSP_id 0

ask clients[

let read_client_connected_to connected_to
let read_client_id id
let read_client_cost cost
;;let read_client_client_capacity 1
let klist knowledge_list
;let node1 end1

let node1 one-of clients with [ id = read_client_id]
let minimum_price 0
;;let Reputation_of_the_CMSP_offering_minimum_price 0

```

```
let id_of_CMSP-with_minimum_price 0
;;let Reputation_of_the_CMSP_connected_to 0

foreach sort-on [id] CMSPs
[ ?1 ->
  set read_CMSP_price [price] of ?1
  set read_CMSP_id [id] of ?1
  ;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1

  if read_client_connected_to = read_CMSP_id ; Updating the cost
  [
    ;;set Reputation_of_the_CMSP_connected_to read_CMSP_Good_Reputation

    set read_client_cost read_CMSP_price ; the client has to pay for
      his resourcesBased on the new price the CMSP is offering
    set cost read_CMSP_price ; Both increasing and decreasing costs
  ]
]
foreach sort-on [id] DMSPs
[ ?1 ->
  set read_DMSP_price [price] of ?1
  set read_DMSP_id [id] of ?1
  ;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1

  if read_client_connected_to = read_DMSP_id ; Updating the cost
  [
    ;;set Reputation_of_the_CMSP_connected_to read_CMSP_Good_Reputation

    set read_client_cost read_DMSP_price ; the client has to pay for
      his resourcesBased on the new price the CMSP is offering
```

```

        set cost read_DMSP_price ; Both increasing and decreasing costs
    ]
]

set minimum_price read_client_cost
set id_of_CMSP-with_minimum_price -1
;;set Reputation_of_the_CMSP_offering_minimum_price
    Reputation_of_the_CMSP_connected_to

ifelse ticks = 1 [
    ask CMSPs
    [
        set read_CMSP_price price
        set read_CMSP_id id

    foreach klist
    [
        ?2 ->
        if(read_CMSP_id = ?2)
        [
            if (read_CMSP_price < minimum_price )
                [ set id_of_CMSP-with_minimum_price read_CMSP_id ]
        ] ] ]

    ask DMSPs
    [
        set read_CMSP_price price
        set read_CMSP_id id

    foreach klist
    [

```

```

?2 ->
  if(read_CMSP_id = ?2)
  [
  if (read_CMSP_price < minimum_price )
    [ set id_of_CMSP-with_minimum_price read_CMSP_id ]
  ]
]
]
]
[
ask CMSPs
[
  set read_CMSP_price price
  set read_CMSP_id id
  ;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1
  ;;set read_CMSP_capacity [CMSP_users] of ?1

  if (minimum_price * (1 - RaS) * (RoM) > read_CMSP_price)
  [
    foreach klist
    [ ??1 ->
      let xid ??1
      if read_CMSP_id = xid
      [
        set minimum_price read_CMSP_price
        set id_of_CMSP-with_minimum_price read_CMSP_id
        ;;set Reputation_of_the_CMSP_offering_minimum_price
          read_CMSP_Good_Reputation
      ]]]
    ask DMSPs
  [
    set read_DMSP_price price

```

```

set read_DMSP_id id
;;set read_CMSP_Good_Reputation [Good_Reputation] of ?1
;;set read_CMSP_capacity [CMSP_users] of ?1

if (minimum_price * (1 - RaS) * (RoM) > read_DMSP_price)
[
  foreach klist
  [ ??1 ->
    let xid ??1
    if read_DMSP_id = xid
    [
      set minimum_price read_DMSP_price
      set id_of_CMSP-with_minimum_price read_DMSP_id
      ;;set Reputation_of_the_CMSP_offering_minimum_price
        read_CMSP_Good_Reputation
    ]]]]

foreach sort-on [id] CMSPs
[ ?1 ->
  set read_CMSP_price [price] of ?1
  set read_CMSP_id [id] of ?1
  ;;set read_CMSP_capacity [CMSP_users] of ?1

  if (id_of_CMSP-with_minimum_price = read_CMSP_id) ; User found
    better price
  [
    ;show connected_to
    let was_connected_to connected_to

    if connected_to > -1 ; If not first round
    [

```

```
ask links with [ color = 12 + read_client_id] [die] ; Disabling the
    connection with the old CMSP

]

set connected_to read_CMSP_id ; Connecting to the new CMSP
set cost read_CMSP_price
let node2 one-of CMSPs with [ id = read_CMSP_id]
ask node1 [ create-link-with node2 [ set color 12 + read_client_id] ]

;ask CMSPs with [id = iCMSP] [ create-link-with end1 [set color 12 +
    idinput + idinput]]
]
]

foreach sort-on [id] DMSPs
[ ?1 ->
set read_DMSP_price [price] of ?1
set read_DMSP_id [id] of ?1
;;set read_DMSP_capacity [DMSP_users] of ?1

    if (id_of_CMSP-with_minimum_price = read_DMSP_id) ; User found
        better price
[
;show connected_to
let was_connected_to connected_to

    if connected_to > -1 ; If not first round
    [

ask links with [ color = 12 + read_client_id] [die] ; Disabling the
    connection with the old CMSP
```

```
    ]
    set connected_to read_DMSP_id ; Connecting to the new CMSP
    set cost read_DMSP_price
    let node2 one-of DMSPs with [ id = read_DMSP_id]
    ask node1 [ create-link-with node2 [ set color 12 + read_client_id] ]

    ;ask CMSPs with [id = iCMSP] [ create-link-with end1 [set color 12 +
        idinput + idinput]]
    ]
    ]
    ]
end
```


Chapter 5

General Discussion

Contents

5.1 Introduction	167
5.2 Impact on Literature	169
5.3 Impact on Managerial Practices	171
5.4 Future Research Design	173
5.4.1 Simulation using system dynamics	173
5.4.2 Optimizing the recommender system	173
5.4.3 Investment and time series	174
5.4.4 Oligopoly models	174

5.1 Introduction

Organization's success is based on the correctness of its decisions. Correct decisions require accurate and relevant information. Too much data and the decision-maker will fail to detect relevant information and thus take a mal-informed decision.

Technology is a driving force for current businesses and is among the key decisions and investments directly supervised by senior executives. Large organizations are

searching the industry for technologies developed by startups and small companies that can complement their arsenal of services and technologies. Those startups and small companies receive generous offers for acquisition in the hope that their technologies offer market superiority for the buyer. Selecting winner technologies is a tedious task, contains many ambiguities and variables, and is relatively not very accurate.

Epistemologically, the organization cannot know a winner technology ahead of time but can use existing evidence, predictions, statistics, surveys, and other techniques to justify its belief in the correctness of its decision. Due to the sheer number of emerging technologies, Business executives try to assess hyped emerging technologies, they sometimes overlook disruptive technologies.

Cloud computing is typically one of those disruptive technologies that divide the market between adopters vs. non-adopters. Choosing whether to adopt cloud computing must consider its impact on the organization's success which, in turn, depends on internal and external factors to the organization. The existing literature addressed organizational cloud computing adoption using two distinct approaches. The first one considered the internal factors to help an organization select the most suitable type of cloud computing, while the second approach took into account the external factors that set the market price and service standard. This thesis provides in-depth coverage of both approaches.

In this thesis, we tried to generate automated tools that help decision-makers decide on the adoption of disruptive technologies and more specifically cloud computing. The generated tools offer two portals, the first portal hides the organization's internal factors, shows the most relevant information, and recommends decisions based on the organization's needs. The second portal hides the external (economic) factors, shows the most relevant information, and recommends decisions based on the predicted economic trend.

This work was intentionally designed to be modular and applicable to other disruptive and emerging technologies. As shown in Section 1.3 of Chapter 1 (general discussion), the need for studying the corporate adoption of blockchain is very relevant and is expected to be in high demand next year. The contributions of this work can be easily migrated to the blockchain which makes this work very relevant and one of the very first, the first to

the best of our knowledge, to cover the economic factors of blockchain adoption.

This work has yielded the first open-source DSS, to the best of our knowledge, to study the economic factors affecting cloud computing adoption and predicted its economic trend. Additionally, this work is the first to use a collaborative filtering recommender system to match experts' answers concerning cloud computing adoption. This approach yields considerable accuracy enhancement compared to the approaches found in the literature.

This work is also the first to study the market risks resulting from the introduction of multitenancy in 5G mobile networks. It also paved the way for policy studies regulating incoming 5G networks.

This chapter rediscusses the main findings and contributions of this work in a more general context and transversally summarizes them as follows. Section 5.2 analyzes how this contribution adds to the literature. Section 5.3 analyzes how this contribution adds to managerial practices. Lastly, Section 5.4 describes some operational future research directions.

5.2 Impact on Literature

Cloud computing can be represented by a three-layer business model framework. Each layer is related to one of its core services which are SaaS, PaaS, and IaaS. More advanced and complex business models evolved to respond to the new features of cloud computing. Like all disruptive technologies, it is susceptible to failures and downtime. Thus, considering adopting it involves risks, sophisticated contracts, and complex decision-making processes. Adopting cloud computing or other disruptive technologies is a core decision that should be taken at the highest corporate levels because it can lead to unexpected losses, if not bankruptcy. The severity of the decision's consequences and the value-at-risk motivated researchers to help decision-makers select the suitable technology.

The literature is divided into two distinct methodologies for deciding on the adoption

of cloud computing. The first methodology relies on questionnaires sent to experts and decision-makers to extract a set of determinants for cloud computing adoption. The second methodology relies on modeling the market dynamics and predicting the success of the adoption.

In the first methodology, researchers tried to identify all the determinants that affect the cloud's business models in order to design a realistic model for a viable process. Including all the determinants in a business model is not a guarantee for success. The second methodology considers that strategies and clients' business models, suppliers, and competitors' processes are very important in deciding the success of the user's strategy. For this reason, simulating the interaction between business models is important to fine-tune the designed model and decrease failure risk by preventing any miscalculated behavior.

As shown in Figure 1.1 (Cloud adoption literature), the first approach reached a maturity level without being able to overcome its weaknesses which are implementation weaknesses due to limitations in the determinant's selection, questionnaire distribution and rigidity of the outcomes and Conceptual weaknesses due to the nature of the methodology such as: experts' biased recommendations, decision-makers' biased answers and corporate officials' biased perception to the used adoption model or determinants.

Biases influence the experts' recommendations, decision-makers' answers, and corporate officials' perception of the used adoption model or determinants. We next provide a couple of examples that highlight the different factors at play for choosing the right IT-based strategy for a business. For instance, CEOs with fixed salaries have less tendency to migrate to the cloud while CEOs with shares have a higher tendency to adopt this technology. In other circumstances, we notice that Strategic IT Alignment's (SITA) interaction with IT Investment (ITI) is negative. SITA's unmalleability lowers the good influence of ITI on firm performance in stable, uncomplicated, and abundant surroundings. Based on the abovementioned concerns, the second methodology is becoming dominant since 2017.

The second methodology considers that strategies and clients' business models, suppliers, and competitors' processes are very important in deciding the success of the

user's strategy. For this reason, simulating the interaction between business models is important to fine-tune the designed model and decrease failure risk. Several approaches were proposed to study the interaction between processes and to predict the success rate under different environments, such as mathematically modeling the optimal pricing strategies of a cloud service provider, studying the mathematical equilibrium in a market for data-based services, or using game theory to compare different selling strategies under monopolistic and competitive environments.

This work contributed to the literature by solving the implementation weakness of the first methodology by using a collaborative filtering recommender system. It also contributed to the expansion of the second methodology by being the first to introduce Agent-Based Modeling to simulate the market behavior for cloud computing. Additionally, this work is the first to discuss oligopolistic behavior in cloud computing markets.

5.3 Impact on Managerial Practices

The aim of this work, first and above all, is increasing the manager's awareness of his corporation's capabilities and needs and making sense of the surrounding environment in terms of cloud computing technologies and capabilities offers.

The decision-making process for selecting a technology to adopt is very complex since it requires information from different departments and different skillsets. The decision-maker has to have the solid technical mastery to be able to fully understand an incoming technology and assess its suitability. He also has to have an economics skillset and accurate forecasts and analytics on the market to be able to assess the market's readiness for the new technology. He also has to have finance exposure and accurate predictions on the corporation's finances to be able to decide whether the corporation can afford it. The decision-making process is a multi-party process, and any inaccurate information or calculation will result in damaging consequences. Additionally, the decision requires skillsets unavailable in many SMEs. This work offers managers with limited technical or economic exposure the ability to decide on the adoption of cloud computing

and other emerging technologies.

The commercial approach in existing ‘Cloud Decision Engines’ found in literature and market may include deliberate and indeliberate biases. Those biases affect the correctness and fairness of the decisions by favoring one solution over the other or faithfully holding optimistic expectations. As long as the managers are concerned, our work provides DSS tools that are open-source, vendor-neutral, and free. Our designed tools save managers from the subjective evaluation of individual experts/consultants and replace their subjective evaluations with normalized subjective evaluations that can be considered objective. Using those tools, the consultants’ role changes from providing subjective expert (sometimes biased) opinion into helping extend the capabilities of the tools by adding additional factors, technologies, and features.

The DSS tools provided in this work are transparent, i.e. the logic behind the decision-making process can be traced and investigated. Consequently, managers can now take informed decisions powered by the dynamic logic generated in both tools. Transparency is legally required [270] for autonomous systems and shareholders required in corporate environments.

In addition to transparency, we offer accountability, a feature predicting our confidence in the recommended decision. None of the experts or DSS can confidently recommend technologies /architectures/systems for every faced scenario. Although consultants are esteemed to be experts and express confidence in their recommendations as a sales tactic, it is very important to keep the managers aware of the fact that emerging technologies introduce high margins of uncertainty due to a plethora of technical and economic factors. Accountability benefits the managers by providing them with indicators to assess the reliability of a recommendation and the need for additional opinion.

Ambiguity resulting from low-confidence recommendations or conflicting ones should automatically flag the need for deep investigation. Such case usually happens because of wrong evaluation of organizational needs. It is well-known that technologies and architectures provide a compromise between different needs. Overdemanding can confuse the consultants and DSS alike. In the case of low-confidence recommendations, the investigation should start with ensuring the correctness of the organizational needs. As

highlighted earlier, a major contribution to the proposed tools is increasing the manager's awareness of his corporation's capabilities and needs and making sense of the surrounding environment. Finally, low-confidence recommendations can pinpoint errors in reports generated by different teams in the organization.

5.4 Future Research Design

The contributions of this manuscript can still be developed in multiple directions and we are planning to pursue the following:

5.4.1 Simulation using system dynamics

We modeled the market using Agent-Based Modeling which is very efficient in representing the interactions between agents. Complementing this work with a system dynamics simulation would allow us to build a much better understanding of market behavior.

5.4.2 Optimizing the recommender system

As discussed in the limitations, the proposed recommender system satisfies the requirements we set in Chapter 2, but it hasn't been evaluated for accuracy against other recommender systems. We are planning to work on optimizing the design of the used algorithm and hopefully overcome the cold-start problem even with small datasets.

5.4.3 Investment and time series

We are planning to mathematically study the emergence of new suppliers over time using time series instead of evaluating the market as a closed network of suppliers and customers.

5.4.4 Oligopoly models

In this work, we only considered Cournot's oligopoly model although not very suitable for representing our use case. Other models are available, such as Bertrand's duopoly model. It would be much more enriching if other models are considered and benchmarked against the Agent-based modeling and System dynamics simulations.

Chapter 6

Conclusion

Contents

6.1 Contributions	178
6.1.1 Generic and vendor-neutral decision support solution for cloud computing adoption	178
6.1.2 Modeling 5G networks under perfect competition conditions	178
6.1.3 Modeling 5G networks under oligopolistic conditions	179
6.2 Limitations	179
6.2.1 Cold-Start problem	179
6.2.2 Recommender system	180
6.2.3 Parameter fine-tuning	180

Disruptive technologies, including cloud computing, are double-edge swords. Many organizations adopted the new disruptive technologies to boost their revenues and succeeded such as Amazon’s cloud services and Kaspersky Lab’s Next Generation Anti-Virus. Others failed to adopt and lost market share such as Nokia’s failure to adopt smartphone technology and finally some organizations adopted disruptive technologies that turned out to be a bubble such as solar cars.

The common factor between all the above examples is that they all considered their organizational factors when deciding on the adoption of the respective disruptive technology. The factors deciding the decision’s success or failure were outside the organizational

boundaries especially that all the above names are major players in their respective markets. Based on this observation, we studied in this dissertation the organizational as well as the economic factors affecting cloud computing's corporate adoption.

Selecting winner technologies is a tedious task, contains many ambiguities and variables, and is relatively not very accurate. The literature still misses a successful formula for predicting the future of a technology and organizational learning leads to organization-specific decision schemes which lack community testing and evaluation and thus potentially not very accurate. Epistemologically, the organization cannot know a winner technology ahead of time, but can use existing evidence, predictions, statistics, surveys, and other techniques to justify its belief in the correctness of its decision. Very successful corporations, such as Google and Microsoft, invested in and developed multiple services and technologies that turned to be a complete failure and later ended in suspension.

Almost all emerging technologies will not endure time and market competition. Their impact and market penetration will be marginal and will eventually fade away. Unlike lawmakers, business leaders must assess all emerging technologies and devote their very limited resources to study any potential technology. Since early adopters achieve the highest revenue rate, managers can be overwhelmed with the new technologies and this can lead them to neglect real disruptive technologies, and therefore, to become late adopters. While late adoption of emerging technologies removes many of the inherent risks associated with them, a significant part of the profit margin will also be eliminated.

Cloud computing is a distinctive disruptive technology that divides the market into two parts: adopters and non-adopters. Depending on the type of cloud used, the adopters themselves can be evenly divided. This important division is success versus failure. The decision of an organization to adopt or not to adopt cloud computing should be based on the impact of this technology on the success of that organization. Several internal and external factors influence this success, therefore, adopting a specific technology is not a trivial decision, it depends on future opportunities and market dynamics, and not just on the internal state of the organization.

The impact of economic factors on the success of corporate decisions is consistent

across all emerging technologies, thus corporations should follow an exocentric approach to decision-making. Exocentric approach is more difficult than endocentric because the latter relies on internal historical data, internal processes, and internal needs. Corporations are usually very efficient in accessing and analyzing internal factors. Exocentric approach requires external historical data, knowledge of competitors' intentions, new player's intentions and most importantly suppliers' plans. Corporations usually find the analysis and extraction of complicated trends from external data difficult, resource consuming and very sensitive to random factors not included in the observations.

Missed factors, even negligible, can lead to radical changes in the predictions following the butterfly effect. This makes any designed model in a continuous enhancement loop. Artificial Intelligence (AI) and Machine Learning (ML) gained momentum in nearly every field, but not in our case. Training effective AI and ML models require a relatively large training dataset which we miss in this case. For this reason, we decided to design a parameterized model relying Agent-Based Modelling and economics equations. Each decision maker can insert the parameters representing the market situation he is facing.

The designed model definitely requires loops of enhancement to become more accurate as will be shown next.

This chapter recapitulates the main findings and contributions and is organized as follows. Section 6.1 indicates the important contributions and relevant implications of this thesis, while Section 6.2 lists some of this work's limitations.

It also acts as the result summarization and dissemination as requested in CBOD task 6. The updated project status is shown in table 6.1.

TABLE 6.1 – Chapter 5 contributions to CBOD objectives and tasks

	Status		Status
<i>Objective 1</i>	Done	<i>Task 1</i>	Done
<i>Objective 2</i>	Done	<i>Task 2</i>	Done
<i>Objective 3</i>	Done	<i>Task 3</i>	Done
<i>Objective 4</i>	Done	<i>Task 4</i>	Done
<i>Objective 5</i>	Done	<i>Task 5</i>	Done
<i>Objective 6</i>	Done	<i>Task 6</i>	Done

6.1 Contributions

6.1.1 Generic and vendor-neutral decision support solution for cloud computing adoption

Considering both organizational and economic factors in a corporate decision is not a trivial task especially that market trends differ from our mental models. We solved this challenge by proposing an RS based DSS since one of RS's strength is extracting trends from datasets and user interactions. These trends are very important for providing decision-makers with an insight into the external factors. Interestingly enough, Collaborative Filtering Recommender Systems profile similar organizations and utilize the trends only from the coherent group. We consider this DSS to be the first generic and vendor-neutral decision support solution for cloud computing adoption.

6.1.2 Modeling 5G networks under perfect competition conditions

In this contribution, we simulated two categories of organizations, one didn't adopt cloud computing (legacy mobile operators), and the second adopted cloud technology (cloud-based mobile operators). The adoption decision is not related to internal organizational factors. The simulation showed that the market behavior (outcome) could result in:

1. All legacy mobile operators driven out of the market with the final user cost exceeding the initial cost.
2. All legacy mobile operators driven out of business with the final user cost less than the initial cost.
3. Co-existence between legacy and cloud-based mobile operators. Some of the legacy and cloud-based operators left the market.

4. Cloud-based mobile operators join the market and leave later because of the competition from the legacy mobile operators.

More important than the number of possible outcomes is that we were able to prove that economic factors decide whether cloud adoption is beneficial or not. This proof reinforces our decision of using RS as the engine inside DSS that we designed in this manuscript.

6.1.3 Modeling 5G networks under oligopolistic conditions

In this contribution, we evaluated the transition phase from a stable market (in oligopoly terms) into a disrupted market (when disruptive technologies emerge). We considered two cases: elastic and inelastic demands for cloud services. For the first case, the market stability was modeled mathematically where legacy mobile operators have a limited capacity inherited from the nature of their infrastructures; while cloud-based mobile operators are free from this constraint. The market behavior of the second case was modeled using Agent-Based-Modeling. In addition to the outcomes of the previous contribution, we concluded that Businesses' actions towards cloud computing are active during the cloud's first stages, but become reactive with its introduction to the market.

6.2 Limitations

6.2.1 Cold-Start problem

Collaborative Filtering has a well-known problem called the cold-start problem that affects the accuracy of the recommender system when having a very small dataset. This problem is automatically overcome as the dataset grows. For this case, the DSS has to go through a test phase for collecting answers from practitioners.

6.2.2 Recommender system

The proposed recommender system is not necessarily the best algorithm available, but it has been developed to cover the requirements of the DSS. Further investigation in the computer science discipline can help develop a more optimized algorithm.

6.2.3 Parameter fine-tuning

The ABM simulation is not benchmarked with valid data because the data aren't available yet and the simulation's role is to predict the future market behavior. More investigation is required to calibrate the simulator equipped with market data.

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