International Journal of Cloud Computing and Services Science (IJ-CLOSER)
Vol.2, No.4, August 2013, pp. 226~248
ISSN: 2089-3337

Cloud Computing Effectiveness Assessment

Serdar Yarlikas*, Semih Bilgen**
* Department of Information Systems, ** Department of Electrical and Electronic Engineering,
Middle East Technical University, Ankara, Turkey

Article Info

Article history:

Received Jun 22th, 2013
Accepted Jul 13th, 2013

Keyword:

Technical Variables
Organizational Variables
Economical Variables
External Variables
Effectiveness Assessment

ABSTRACT

The first problem tackled in this study is identification of variables that effect cloud computing effectiveness. Besides, proposing an appropriate method for assessing effectiveness in terms of the variables identified is the second problem of this study. To solve these problems, we apply a four sequential step based approach (literature review-preliminary survey-cloud survey-qualitative exploratory case studies). In the research that led to the final model, after a detailed literature review, a large number of experts were interviewed and questionnaires were applied to construct the initial model. By applying factor and cluster analysis to the results of a cloud survey, the model was updated. Then, four qualitative exploratory case studies were carried out to finalize and validate the model. At the end of the study, we present a comprehensive model for cloud computing effectiveness assessment. The model consists of technical, organizational, economical and external dimensions and addresses providers of various levels of cloud computing service as well as users. Independent and dependent variables of effectiveness are identified. Generic measures of each of the four dimensions of the model are presented in the form of footprint diagrams.

Corresponding Author:

Serdar Yarlikas,
Department of Information Systems,
Informatics Institute,
Middle East Technical University,
METU Universiteler Mah. Dumlupinar Blv. No:1, 06800 Cankaya, Ankara/TURKEY
Email: yarlikas@metu.edu.tr

1. INTRODUCTION

Cloud computing is technically defined as "a computing capability that provides an abstraction between the computing resource and its underlying technical architecture (e.g., servers, storage, networks), enabling 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" [1]. This definition emphasizes five essential characteristics: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. Cloud computing is also a business model comprised of technical, economical, organizational and external dimensions. The term "effectiveness" refers to the level of achievement of desired effects. That is, in our context, the degree to which cloud computing objectives are achieved and the extent to which problems targeted in providing and/or receiving cloud computing service are solved.

The problems tackled in this study are:

(1) Identification of independent and dependent variables that effect cloud computing effectiveness; categorizing these variables according to their realm, as technical, organizational, economical and external.

(2) Proposing an appropriate method for assessing effectiveness in terms of the variables identified, for any service provider or cloud customer.

The rest of this paper consists of five sections. First the research method and phases are outlined. After that, case studies which constituted an essential phase of exploration and validation of the major contributions presented in the paper are discussed. Then the cloud computing assessment model is presented, followed by the generic measures. Then, validation of the model is discussed in the context of four case studies. The paper is concluded with a summary of the main results, perceived limitations of the study and suggestions for future work.

2. RESEARCH METHOD AND MATURATION OF THE MODEL

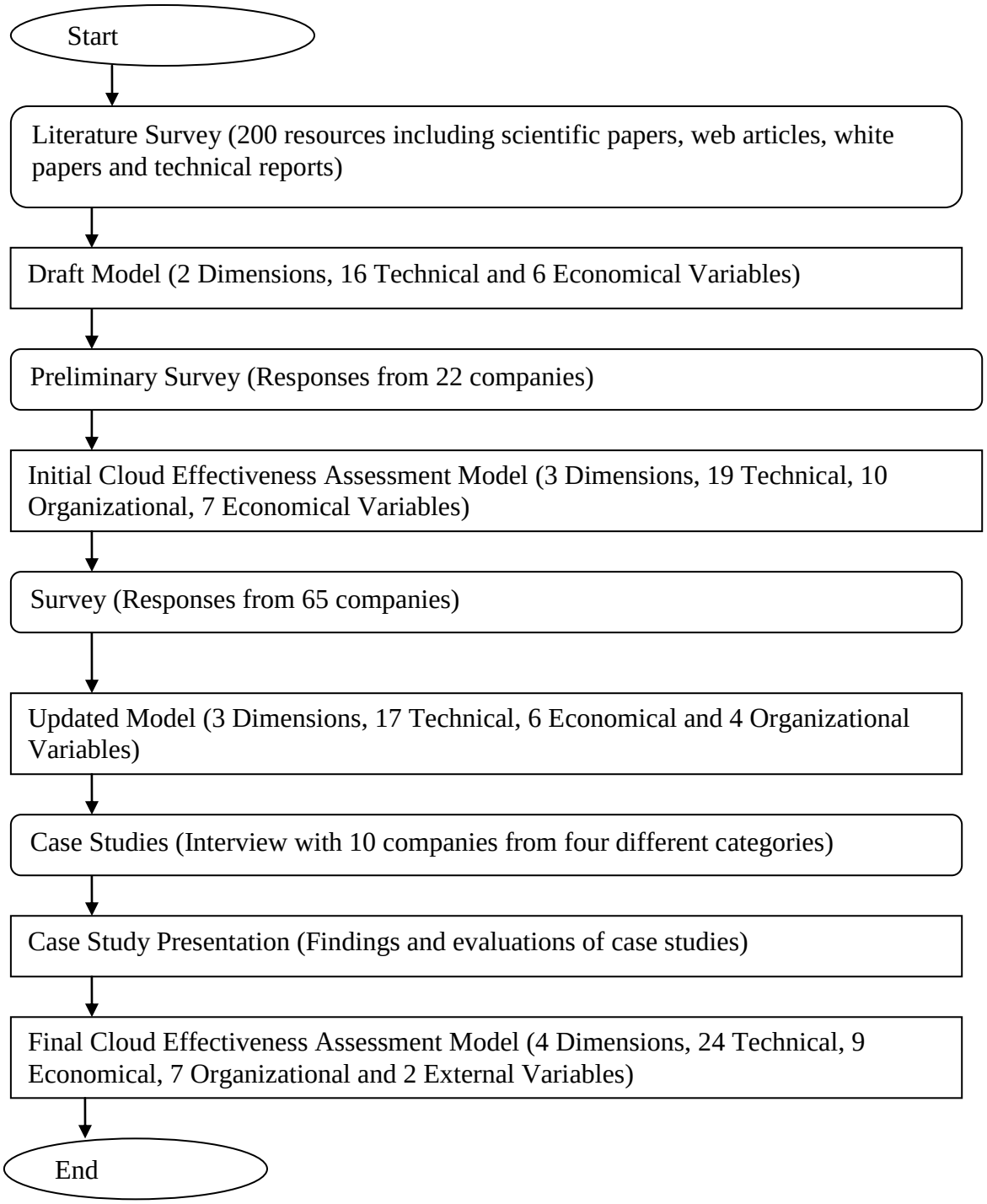

Figure 1. Research flow chart

Figure 1 summarizes the research process. First, we investigated approximately 200 resources including scientific papers, web articles, white papers and technical reports. In terms of cloud computing, economic challenges and technology related issues have long been under focus [3]-[5]. We also categorized factors and characteristics at this stage in the technical and economical dimensions.

Within the context of the draft model, technical variables were defined as the characteristics of cloud computing in a company in terms of:

- their ability to adapt cloud computing,
- the sufficiency level of cloud-based solutions they have adopted,
- the significance of risks originating from cloud computing,
- the feasibility of their cloud computing system,
- the levels of their computing resources,
- their cloud computing system continuity,
- the sufficiency of the level of agreement about meeting their expectations for the cloud computing system

On the other hand, economical variables consist of measures of cloud computing stated in terms of:

- the costs accruing for cloud computing usage,
- savings and benefits being achieved through cloud computing,
- the level of cloud-based revenue,
- their potential to invest on cloud infrastructure for future and the level of this investment.

Our draft model thus consisted 16 technical and 6 economical variables. In the second phase of the research, responses to a questionnaire consisting of five questions were obtained from 22 companies based in 9 countries (England, USA, Ireland, China, Belgium, Sweden, Canada, France, Romania) participating in the Cloud Expo Europe 2012 conference. In addition to this, papers, interviews and presentations in Cloud Expo Europe 2012 and CLOSER 2012 were studied. By combining all of these findings, the components of the initial model were defined. The organizational dimension was incorporated to the model. The initial cloud effectiveness assessment model thus consisted of 3 dimensions, 19 technical, 10 organizational and 7 economical variables.

In the third phase, a questionnaire aiming to evaluate the initial model was administered to participants from 65 different companies, from 15 different countries, in the Cloud Computing World Forum 2012. A 5-point Likert scale was used in the questionnaire. According to the survey results, seven of the variables, the average Likert points of which were below 3.5, were excluded from the initial model. In addition to this, two of the variables were discarded from the model based on a factor analysis of the findings. Consequently, the model was updated to include 3 dimensions, 17 technical, 6 economical and 4 organizational variables.

To validate and further refine the assessment model, qualitative case study research was undertaken, investigating ten different cases, under four categories, as outlined in the next section. This last phase of the research led to the final Cloud Computing Effectiveness Assessment Model (CCEAM) consisting of 4 dimensions, 24 technical, 9 economical, 7 organizational and 2 external variables. Details of the research process and all findings, together with the dimensions and variables that constituted intermediate stages of the model have been documented in [2].

3. CASE STUDIES AND FINDINGS

The case studies carried out to further refine and finalize the CCEAM are reported below in conformance with the structure proposed in [6] for documenting qualitative research. Validity of the results of these studies is also discussed explicitly, considering possible threats and mitigation approaches.

3.1. Problem statement and research objectives

The literature consistently indicates that cloud computing effectiveness assessment has to consider (at least) the technical and economical dimensions. On the other hand, our survey results led to three dimensions. For that reason, the validity and sufficiency of these three dimensions and their constituent variables for assessment of the effectiveness of cloud computing had to be determined.

The first aim in the case studies was to determine whether the sub-variables associated with the 27 variables of the updated model were suitable for effectiveness assessment or not. The sub-variables determined to be valid in the scope of the case studies were adopted and later named as generic measures. The second aim was to determine the new variables to be added to the model. Yet another aim was to determine whether the three dimensions of model were valid and sufficient.

3.2. Context

The context of our case studies consisted of companies from the following four categories: (i) cloud service providers, (ii) companies that provide as well as receive cloud computing service, (iii) solution providers for cloud service providers, and (iv) cloud users. All companies were located in Turkey, where this research was undertaken. The companies who participated in the case studies are briefly described in Table 1. Their names are witheld due to reasons of corporate privacy.

3.3. Selection of cases and subjects

We undertook case studies in 10 firms collectively covering all four categories of companies stated above as service providers, service provider/receivers, solution providers, and users. Individual firms were selected on their accessibility and willingness to participate.

Table 1. Case study participants

Company name	Category	Number of employees	The sectors the company operates in	Contacted company staff	Marketplace of the company	Turnover for year 2012 (Million $)
A	Cloud Service Provider	700	• Finance • Telecom • Manufacturing and Services • Automotive	Senior Solutions Architect	Global	80
B	Cloud User	50-100	• Information Technology	General Manager	Domestic	2
C	Solution provider for cloud service providers	50	• Information Technology • Telecommunication	Business Service Management Consultant & System Administrator	Domestic	5
D	Cloud service provider and user	11-50	• Mobile Operators • Media and Entertainment • Education	Cloud Team Leader & Senior Software Architect	Domestic	2
E	Cloud service provider and user	11-50	• Information Technology and Services	Managing Director	Domestic	1-2
F	Cloud service provider and user	51-200	• Computer Software • Manufacturing • Automotive • Food • Chemicals • Construction • Retail • Textile • Tourism	Vice President of the Software Company	Domestic	22
G	Cloud service provider and user	51-200	• Information Technology	Data Center Services Manager	Domestic	50
H	Cloud service provider and user	51-200	• Information Technology	General Manager	Domestic	2
I	Cloud Service Provider	10001	• Information Technology and Services	Cloud Computing Expert & Sales Leader	Global	3,000
J	Solution provider for cloud service providers	51-200	• Information Technology and Services	Information Technology Manager	Domestic	6

3.4. Methodology

We preferred to apply a qualitative research methodology [6] based on case studies because cloud computing involves many different parameters and obtaining the new parameters and creating a final model with quantitative studies is statistically infeasible. Cloud computing is still a relatively new topic, so terminology problems abound. This is another reason for our preference for qualitative research. Since we have tried to support similar as well as contradictory results while constructing the effectiveness assessment model, a multiple-case design was needed.

For all of these reasons, carrying out case studies corresponding to the four categories of firms was suitable. We prepared open-ended interview questions to start interviews for each case. These questions were formulated based on our updated model based on the analysis of survey and literature search results. They included 20 major questions with numerous subordinate ones. Transcripts of all interviews are available in [7].

3.5. Data collection procedure

We performed face-to-face interviews and had e-mail contacts with the companies to collect data. The transcipt of interviews and the answers sent through e-mail by the companies were combined and analyzed in order to construct the CCEAM. A report documenting all of the results of analysis [7] was also prepared and shared with all participants.

3.6. Analysis procedure

In the first step, we evaluated the suitability of 27 variables constituting the updated model. If the suitability of a variable was supported according to the results of an open-ended interview question by most of the companies participating in the case studies, the related variable was incorporated in the final model. The sub-variables to be added and to be eliminated from the model were also determined in the same manner. The new variables to be added to the model were determined according to the inferences derived from case study interviews upon analyzing the interview transcripts. Besides, the suitability of model dimensions were evaluated. If most of the organizations participating in the case study supported the suitability of the three dimensions of the updated model, they would be accepted as the dimensions of the final CCEAM.

Finally, the new dimension(s) to be added to the model were determined by evaluating all dimension proposals. If a new dimension proposed by different companies implied the same concept in different terms, the related dimension was added to the model under a commonly acceptable name.

3.7. Description of cases

3.7.1. Category 1: Cloud service providers

We selected Company A and I as they are among the most influential cloud service providers in the information technology (IT) sector. Company A provides cloud services to their customers; they do not receive any cloud service because they had built their IT infrastructure before cloud computing was as popular as it has recently become. They provide such cloud services as cloud installation, cloud migration, application development (preparing applications for cloud or transforming applications for cloud compatibility), and cloud hosting. Besides, they provide SaaS solutions to the public sector as well as IaaS solutions to both private and public sectors.

On the other hand, Company I offers services in each of the cloud layers (Iaas-PaaS-SaaS-BPaaS) and in each of the service models (public, private and hybrid). They construct solutions according to the requests of customers.

3.7.2. Category 2: Companies that provide as well as receive cloud computing service

Company D offers SaaS and PaaS solutions. They provide SaaS solutions with the support of large scale enterprises. For IaaS and PaaS, they make use of Hypervisor, Xen Cloud and Vmware. They provide SaaS for mobile devices on which their own operating systems are installed. All of the assets of Company E are located on the cloud. They use Google e-mail services. Mainly, they use the following cloud services:

- CRM: Preliminary Sales (Pre-sale), Accounting and Support- Sales Force
- Project Management: Pivotal Tracker
- Integration: Informatica Cloud
- Collaboration: Chatter
- File hosting and content management: Box.com
- Social Media (Network) Tracking: Radian6

Except Pivotal, the services stated above are also offered by Company E. The main structure and the solution adopted by them is Salesforce.com. They realize implementations for organizations. This means they deal with the organizational side of cloud.

Company F has virtualized some of their servers. They manage all of their applications (including the operating systems of the virtualization servers) by themselves. They also offer corporate commercial applications to SME with a renting model on the cloud.

Company G offers IaaS to their customers. In the scope of this service, they use the existing infrastructures of the other service providers. Then, they add their own management services (operating system management, database management, etc.) to this service.

Company H provides IaaS. They provide this AWS-like service to their customers in accordance with the pay per use model with scalable, agile and flexible server resources. The customers of Company H can create a Company H account online. By using this account, they have the ability of using CPU, disk, bandwidth, and operating system resources through a web control panel, API and iOS in any combination as needed. In addition to server resources, they also provide the opportunity of using value added services such as storage, DNS and load balancing through web control panel, API and iOS.

3.7.3. Category 3: Solution providers for cloud service providers

Company C offers cloud computing life cycle management solution as a business partner of a large global company. Through this solution, cloud service provider firms can manage their cloud infrastructure over the cloud. Company J deals with virtualization, IT infrastructure and desktop virtualization. They offer services for the public sector.

3.7.4. Category 4: Cloud user

Company B uses the cloud together with their business partner companies on different projects. Their main aim is to reach a wider customer base. In their projects, they use SAP on the cloud. The benefit for their organization is the usage of cloud as a new technology in a data-intensive environment.

3.8. Case study findings

The main findings of the case studies can be classified as general and external dimension-based findings.

The general findings and achievements of the case studies were:

- The list of variables and their generic measures were finalized. Organizational, economical and technical dimensions proposed in the model were validated.
- Level of business ethics, legal environment of cloud computing, social and geographical factors, agility, and computer literacy rate had to be added to the CCEAM as new variables.

The external dimension-based findings are:

- An external dimension had to be added to the model as the fourth dimension with the variables: legal environment and social factors.
- Since computer literacy rate is associated with social factors, it had to be considered as a sub-variable of the social factor.

3.9. Limitations of the case studies

Feasibility assessment for full or partial migration to cloud is not possible with our model because potential users considering to migrate their operations fully or partially to the cloud were not included in the case studies. The model was finalized by studying cases from the four categories of companies stated in the subsection on selection of case and subjects. Future work will have to focus on potential cloud users and possibly other categories of companies that can be analyzed in the scope of cloud computing effectiveness assessment.

3.10. Validity of the case study results

The validity of a case study can be evaluated from two perspectives. First of all, to what extent the results are true must be evaluated. Secondly, the effects of subjective biases of researchers on the results of case studies must be assessed. The generally accepted categories [6] of validity threats to case studies are discussed below together with our respective mitigation remedies:

- **Construct validity**: The variables that we investigated in the scope of the case studies were determined and defined within the framework of both the literature and cloud surveys. As such, they were suitable for the problems tackled in this study. The interpretation of the interview questions were mostly identical between the researcher and interviewed persons. Representatives of 9 companies understood all the interview questions correctly. Only one company interpreted the cloud interoperability related question

in a different way from us. We made the necessary explanations about this question. Besides, due to the novelty of the area, in some of the interviews we observed that some interviewees interpreted some individual terms differently. To tackle with this threat, we explained these sub-variables with sample short cases including these sub-variables and their effects. Since we investigated four different categories of companies in the scope of this study, these short cases were adjusted and prepared specifically for the category of related company. So, the problem of interpreting some of the terms differently was solved. Besides, this enabled us to reach a common understanding on problematic terms.

- **Internal validity:** To overcome the possibility that some of the variables may be correlated to others, each one of the generic measures had to be defined independently of the others.
  For instance, considering data locality and data integration, in our model, effectiveness of data locality is measured with the generic measure "miss rate of cache", whereas effectiveness of data integration is assessed with the seven separate generic measures as denoted in Table 4, thus ensuring that different generic measures are used in order to evaluate the effectiveness of these two variables.
  The relationship between scalability and cloud performance can be considered as another example. As shown in Tables 6 and 7, their generic measures are also different.
  Another example is the relationship between level of virtualization and network virtualization. To assess the effectiveness of network virtualization, data confidentiality level, sensitivity of data and deployment situation inside network are measured, whereas two different ratios are investigated for the effectiveness of level of virtualization. So, it is ensured that these two variables are evaluated with different generic measures.
  Consequently, in CCEAM, different variables are assessed via distinct generic measures so that the threat of internal validity is alleviated.
- **External validity:** As outlined in Table 1, we were specifically cautious to select firms of both large as well as small size, from the described four categories. Their common characteristic was that they were all important players in the information technology sector and in the cloud computing field in Turkey. The literature survey and the earlier phases of the research involved direct contacts with and investigation of international firms. Hence, even though the case studies were carried out exclusively in Turkey, the national characteristics of the participants were neither relevant, nor were influential on case study outcomes. The combined results of these ten different case studies can thus be used by different researchers, as a wide coverage was achieved in terms of size as well as mode of participation in cloud computing. On the other hand, as with any instance of qualitative research, full generalizability is neither achieved, nor claimed.
- **Reliability:** In the scope of this research, a sequence of complementary phases were carried out, consisting of literature survey, a preliminary survey and a second focused survey, followed by direct qualitative study in 10 firms. The constructed model was updated after each phase as indicated. The questionnaires and interview questions applied in these steps were all clear and prepared in advance, based on the findings of the earlier phases, taking firms from a number of different countries as well as multi- and trans-national corporations into consideration. In the long-term, since major changes in all dimensions of cloud computing and information technology sector are inevitable, it is only to be expected that applicability of our findings will be reduced in time. But, in the short term, the adopted scope of the study as well as the applied steps have ensured repeatability of findings for any researcher.

4. CCEAM

This final model consists of a set of dimensions and variables to be used for cloud computing effectiveness assessment in the context of service providers and customers (Table 2). The variables and their generic measures are presented in Tables 3 to 12 in the next section. Table 2 presents a list of all variables of CCEAM.

4.1. Generic measures of CCEAM

This section presents the generic measures of the variables in the technical, economical, organizational and external dimensions of CCEAM. Ten separate tables have been constructed for these generic measures. Seven of them focus on the technical dimension since the variables of this dimension are categorized into seven major categories: technical cloud solutions, cloud adaptation, risk based issues, system technical feasibility, technical resources, cloud system continuity, technical agreement. Three tables present the variables of the other three dimensions. We present assessment results in the form of footprint diagrams [8], considered appropriate especially for comparative and improvement studies. In Tables 3 through 12, the generic measures for the four dimensions are presented together with their denotations used in the footprint

diagrams. The references to bibliography indicate fundamental sources related to individual variables and their relationships to cloud computing effectiveness.

Table 2. Variables of CCEAM

Technical dimension	Organizational dimension	Economical dimension	External dimension
1. Cloud Applications 2. Network Virtualization 3. Cloud Performance 4. Cloud Delivery Models 5. Scalability 6. Reliability 7. Multiplicity 8. Data Integration 9. Data Locality 10. Resilience (Fault Tolerance) 11. Application Integration 12. Cloud Security 13. Distance 14. Computing Capacity 15. Flexibility as a Technical Dimension 16. Availability 17. Isolation Failure 18. Cloud Deployment Type 19. Cloud Application Migration 20. Cloud Response Time 21. Agility 22. Service Level Agreement (SLA) as a Technical Dimension 23. Cloud Interoperability 24. Level of Virtualization	1. Administration 2. Innovation 3. Cloud Strategy 4. Cloud Supplier Selection 5. Manageability 6. Level of Business Ethics 7. Vendor Lock-in Degree	1 Cloud Application Migration Cost 2. Flexibility as an Economic Dimension 3. Cost-Benefit Analysis 4. Revenue 5. Total Cost of Ownership of each of the Cloud Applications 6. Operational Efficiency 7. Outage Duration Cost 8. Future Major Cloud Infrastructure Cost 9. Service Level Agreement (SLA) as an Economic Dimension	1. Legal Environment of Cloud Computing 2. Social Factor

Table 3. Technical dimension-generic measures-category1-technical cloud solutions

Major Category	Variable Name	Generic Measures
Technical Cloud Solutions	Cloud delivery models	Level of data security (Cdm1) The effects of back-up data (Cdm2) Level of data migration ability (Cdm3) Level of (Price/Performance) ratio (Cdm4) Level of compatibility with consumer rights (Cdm5)
	Cloud deployment type [16].	Satisfactory level of the cloud deployment type (private/public/hybrid/community) used as a solution in the cloud customer company (Cdt1)
	Network virtualization [17]-[20].	Data confidentiality level (Nv1) Sensitivity of data (Nv2) Deployment situation of cloud applications (Nv3)
	Level of virtualization [17]-[20].	Level of the ratio of (The number of total Virtual Host / the number of total Physical Server)*100 (Lv1)) Level of the ratio of (The number of total Virtual Operating System / the number of total virtual host) (Lv2)

Table 4. Technical dimension-generic measures-category2-cloud adaptation

Major Category	Variable Name	Generic Measures
Cloud Adaptation	Cloud applications	Level of architectural compatibility of applications with cloud (Cla1) Level of average usage period of cloud based desktop-applications (Cla2) Satisfaction level about cloud friendly components (Cla3) Level of cloud applications support (Cla4)
	Data integration [9]-[10].	Level of control difficulties in the scope of access rights (Di1) Risk level of integration for cloud customer company (Di2) Data quality of the integrated applications (Di3) Sufficiency level of technical infrastructure of the integrated applications (Di4) Level of data management provided by cloud service provider (Di5) Data speed level (Di6) Ease of deployment (Di7)
	Application integration	Level of Service Oriented Architecture (Aint1) Level of centralized authorization (Aint2) Level of data integration inside application integration (Aint3)
	Flexibility as a technical dimension	Level of flexible application architectures (Flt1) Dependency level on external systems (Flt2) Level of cloud computing vulnerabilities (Flt3)
	Cloud application migration [11]-[12].	Bandwidth level (Clam1) Wide area network latency (Clam2) Level of synchronization ability (Clam3) Level of mass conversion (Clam4) Level of back up ability (Clam5) Level of cultural readiness to cloud system inside the company (Clam6) Strategic importance level of cloud application migration for organization (Clam7)
	Cloud interoperability [13].	Variety of ready-made integrated solutions (Cli1) Level of possibility of programming applications in the cloud environment (Cli2) Level of applicability of different application usage scenarios (Cli3) Level of heterogeneity of data produced in the cloud environment (Cli4) Data replication ability level in cloud (Cli5) Ability level of moving data inside cloud correctly (Cli6) Possibility level of managing workflows and distributed databases inside cloud (Cli7)
	Agility [14]-[15].	Effects of archival strategy (Ag1) Database size (Ag2) The effects of the kind of interfaces the system supports (Ag3) Infrastructure utilization (the adaptation level of infrastructure to the changes) (Ag4) Level of services reuse (Ag5)

Table 5. Technical dimension-generic measures-category3-risk-based issues

Major Category	Variable Name	Generic Measures
Risk-Based Issues	Reliability	Protection level of corporate identity of cloud customer company (Re1) Preparation ability of cloud service provider for disaster scenarios (Re2) Effectiveness of backup and recovery facilitated by redundancy (Re3)
	Cloud security [11], [21], [22].	The level of changes on technical functions in the system in terms of security after migrating to cloud (Cs1) The level of infringements that have originated from the cloud system (Cs2) The effects of availability of security certifications (Cs3) Frequency of client access to the system (Cs4) The level of usage ability of data isolation methods for cloud security (Cs5) Security level of cloud staff, cloud partner company and hosting environment (Cs6) Ability level of applying security audits (Cs7) Level of data security (Cs8)
	Isolation failure [23].	Level of amount of financial losses originated from data loss (Isf1) The effects of commercial results including prestige and competitive power (Isf2) Level of legal results including legal action (penal charge) and penalty (Amount of penalty) (Isf3)

Table 6. Technical dimension-generic measures-category4-system technical feasibility

Major Category	Variable Name	Generic Measures
System Technical Feasibility	Distance [24].	Relative location of the system of cloud customer to system of cloud service provider (Dis1)
	Cloud performance [25]-[29].	Speed of internet connections (Cp1) Speed of external applications (Cp2) Level of dependency on external applications for cloud customer company (Cp3) Accessibility ratio of cloud applications and system (Cp4) Uptime for cloud applications and system (Cp5) Efficiency of cloud computing arrays, indexes and algorithms used for developing cloud applications and system (Cp6) Data accuracy (Cp7)
	Multiplicity	The effects of multiplicity in cloud environment (M1)
	Data locality [30]-[31].	Level of miss rate of cache (Dl1)
	Cloud response time [32]-[33].	Level of system connection quality (Crt1) Level of cloud service lead time (Crt2)

Table 7. Technical dimension-generic measures-category5-technical resources

Major Category	Variable Name	Generic Measures
Technical Resources	Scalability [3], [34], [35], [36], [37].	Level of capacity increase in terms of transactions per request (Sc1) Level of amount of resources (CPU, RAM and disk) (Sc2)
	Computing capacity	The probabilities of occurrence of bottleneck, contention and congestion situations inside the cloud system (Cc1) Sufficiency level of the growth plan of cloud service provider for computing capacity (Cc2) Level of cloud service provider readiness for disaster recovery (Cc3) Level of installed capacity (CPU, ram, disk size) (Cc4) Level of expandable capacity (Cc5)

Table 8. Technical dimension-generic measures-category6-cloud system continuity

Major Category	Variable Name	Generic Measures
Cloud System Continuity	Availability [3], [38], [39].	Level of accessibility ratio for cloud system and applications (Av1) Level of the ratio of cloud system speed/ cloud performance (Av2) Accessibility level of back-up infrastructure from every environment (Av3) Level of continuous infrastructure for services (Av4)
	Resilience (Fault tolerance) [40]-[41].	Level of mean time to failure (Rs1) Level of mean time to recover (Rs2) Level of buffering capacity (Rs3) Level of tolerance of connection losses (Rs4)

Table 9. Technical dimension-generic measures-category7-technical agreement

Major Category	Variable Name	Generic Measures
Technical Agreement	Service level agreement (SLA) as a technical dimension [42].	Level (amount) of availability and uptime measures definitions in the agreement (Slt1) Frequency of realistic targets included in the specifications (Slt2) Differentiation of service levels (Slt3) Level of precautions (measures) taken for continuity of performance criteria stated in SLA (Slt4) Level of methods followed for continuity of performance criteria stated in SLA (Slt5)

Table 10. External dimension-generic measures

Variable Name	Generic Measures
Legal environment of cloud computing	The level of maturity of cloud-specific legislation (LEGENV1)
Social factor	Level of computer literacy rate inside the cloud-related company (SOCF1)

Table 11. Organizational dimension-generic measures

Variable Name	Generic Measures
Administration [11], [12], [29].	Level of automated resource management through cloud (ADM1) Ability level of adjusting the schedule of administrative tasks through cloud (ADM2) The functionality of cloud administration tools (ADM3) Variety of regular reports about each of the cloud services (ADM4) Level of detail on service interruptions (ADM5) Level of detail on solution durations (ADM6) Level of detail on interventions to services (ADM7) Level of detail on data accessibility statistics of cloud customers (ADM8) Level of detail on data migration (data move) (ADM9)
Innovation [43].	The level of effects of availability of sub-strategies of the product (INV1)

	The frequency of reference customers of cloud service providers that will develop the innovative cloud product (INV2) Accessibility level of innovative cloud product in different architectures (INV3) Ease of deployment of innovative product (INV4) Level of readiness for disaster recovery in terms of product (INV5) Contingency frequency of product (INV6) Cloud-based automatization level of business processes (INV7) Agility level for the adaptation to the changes through the cloud product (INV8) Level of resource usage and sharing (INV9)
Cloud strategy [44].	The level of effects of cloud strategies (CLSTR1)
Cloud supplier selection [44].	Level of the number of current customers and references of cloud supplier (CLSUPSEL1)
Vendor lock-in degree [3], [45].	Level of the number of cloud vendor and/or cloud service providers that the cloud customer takes the same services and/or products from (VLID1) Level of usage period of the cloud product and/or service from the same vendor and/or provider (VLID2)
Level of business ethics	The satisfaction level about the behavior of cloud vendor and provider firm in product and service quality (LOBETH1) The satisfaction level about the behavior of cloud vendor and provider firm in treatment of customers (LOBETH2) The satisfaction level about the behavior of cloud vendor and provider firm in fair market practices (LOBETH3) The satisfaction level about the behavior of cloud vendor and provider firm in terms of community responsibility (LOBETH4)
Manageability [14], [46], [47], [48].	The level of detail of checklist of manageability functions adjusted for cloud environment (MNG1) Level of number of steps to manage towards desired state in cloud environment for each of the cloud components (MNG2) Level of time to manage tasks (MNG3) Documentability level (MNG4) Elasticity of management (MNG5) Availability and continuity of management (MNG6) Ease of use in cloud computing systems and services (MNG7) Level of ability to have visibility and control over cloud services and cloud usage (MNG8)

Table 12. Economical dimension-generic measures

Variable Name	Generic Measures
Cloud application migration cost [45], [49].	Level of the value of electricity (power) expenses (CLAMIGCOS1) Amount of turnover generated through innovation by migrating one application or some of the applications of company to cloud (CLAMIGCOS2) Level of Return on Investment (ROI) through migrating one application and/ or some of the applications of company to the cloud (CLAMIGCOS3)
Revenue	Amount of cloud product and/or services sold (REV1) Unit price of each of the cloud product and/or services sold (REV2)
Flexibility as an economic dimension	The economical value of cloud application and system (FECD1) The qualitative value of cloud application and system- The strategic importance level of cloud application and/or system for the core business of company (FECD2) Variety of pricing and billing mechanisms (FECD3)
Future major cloud infrastructure cost [50].	The level of future major cloud infrastructure cost (FMCICOS1)
Cost-benefit analysis [33].	Level of deployment based costs (CBA1) Level of virtualization based costs (CBA2)

	Level of service based costs (CBA3) Level of total cost of ownership of the complete cloud computing system (CBA4) Level of total initial investment for cloud products and services (CBA5) Level of net present value of cloud system (CBA6) Level of estimated ROI over predetermined number of years by cloud customer through the complete cloud computing system(CBA7) Level of average annual ROI for company through the complete cloud computing system (CBA8) Level of percentage of hardware savings through cloud per year (CBA9) Level of percentage of software savings through cloud per year (CBA10) Level of percentage of system administration cost savings through cloud per year (CBA11) Level of percentage of testing and productivity savings through cloud per year (CBA12) Level of percentage of provisioning cost savings through cloud per year (CBA13)
Service level agreement (SLA) as an economic dimension [42].	Level of amount of penalties (SLAEC1) Level of amount of investment costs (SLAEC2) The effects of operating costs (SLAEC3) Variety of service charges (SLAEC4)
Total cost of ownership of each of the cloud applications [45], [51].	Level of the value of total cost of ownership of applications (TCO1)
Outage duration cost [3], [52], [53], [54].	Level of length of outage duration hours (ODC1) Level of amount of money lost per hour in case of outage duration (ODC2)
Operational efficiency [55].	Cost level of applications (OEF1) Quality level of applications (OEF2)

5. CASE STUDIES

As described above in Section 3, we carried out case studies in four different categories of companies with the aim of validating the finalized CCEAM. All generic measures of CCEAM correspond to a 5-level Likert Scale (Very High=5; High=4; Medium=3; Low=2; Very Low=1). Footprint diagrams display the generic measures for each of the four dimensions.This section is also presented in conformance with the structure proposed in [6] for documenting qualitative research.

5.1. Relation of case study results to CCEAM

Since all of the companies included in the four categories use each of the generic measures of external variables for effectiveness assessment, it has been accepted that the generic measures of external variables proposed in the assessment are valid and suitable. Generic measures used by cloud service providers and cloud users are different, except those in the external dimension. Hence, the generic measures that will be used in effectiveness assessment will be selected according to the company category.

5.2. Case study results specific to four cases

For the sake of brevity, the detailed case study results specific to four cases shall be discussed with one company per category because the companies in the same category have similar features and have led to similar results.

5.3. Case study 1: CompanyA-cloud service provider

Technical, organizational and economical footprints of Company A are presented in Figures 2, 3 and 4, respectively. For this company, 52 generic measures of 19 technical variables were found to be relevant. Whereas some variables are irrelevant for this specific firm, some others, e.g. “dependence on external systems” are not relevant for any service provider.

Upon inspection of the footprints of the technical dimension for CompanyA, the following observations can be made:

- The computing capacity variable indicates low probabilities of occurrence of bottleneck, contention and congestion inside the cloud system of Company A.
- Resilience is evaluated differently than the other technical variables because it has generic measures with both positive and negative effects. For instance, high value of mean time to recover has negative effects on companies since it implies that the system returns to its running mode through recovery in a long period. The results denote that Company A can return to its running mode quickly.
- Most of the technical variables evaluated for Company A indicate either high or very high effectiveness.

In the scope of the effectiveness assessment of the organizational dimension of a cloud service provider company, the variables cloud supplier selection, vendor lock-in degree, level of business ethics and manageability are not relevant because they are associated with cloud customer /user companies.

Inspecting the footprint of the remaining three variables of the organizational dimension of Company A, the following observations can be made:

- The effects of cloud strategy on Company A are high because they have two specific cloud strategies defined as cloud enablement and transparency. Thanks to the cloud enablement strategy, they provide support to cloud customer companies in terms of financial, technical, cultural issues that may be encountered in case of migration to the cloud. On the other hand, with the transparency strategy, they sell the cloud product by emphasizing its benefits.
- The innovation variable is not effective for Company A because they do not develop many innovative products specific to cloud. They also declared that they will not deal with the task of developing cloud based innovative products in the near future.

In the effectiveness assessment of the economical dimension of a cloud service provider company, the generic measures, cloud application migration cost, cost and benefit analysis and total cost of ownership of each of the cloud applications are excluded because they are associated with cloud customer companies.

Assessment of the remaining six variables lead to the following inferences:

- The company will increase their investment on cloud infrastructure in the future because they expect increased earnings from cloud computing.
- The company has the ability of selling a high amount of cloud products and services with high prices.
- They provide a wide variety of pricing and billing mechanisms to their customers. This reflects on the increase on their. revenues.
- Since they obey all of the rules of service level agreement, they do not experience high penalty costs. Hence, they are considered to be trustful in terms of cloud services according to their cloud customers.

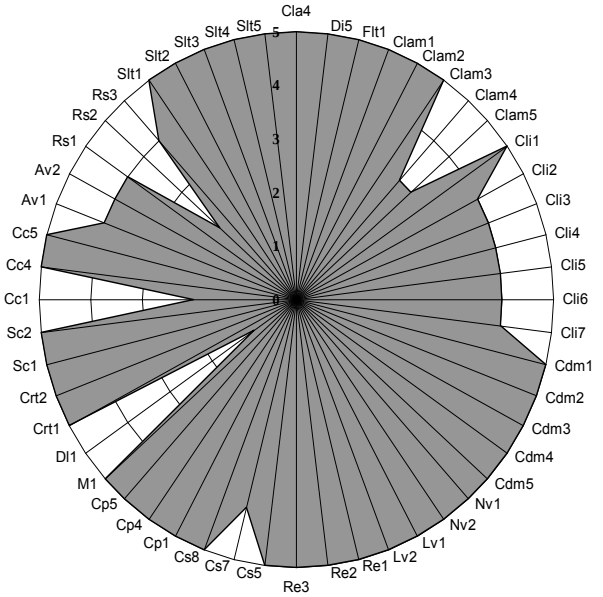

Figure 2. Technical dimension footprint of Company A

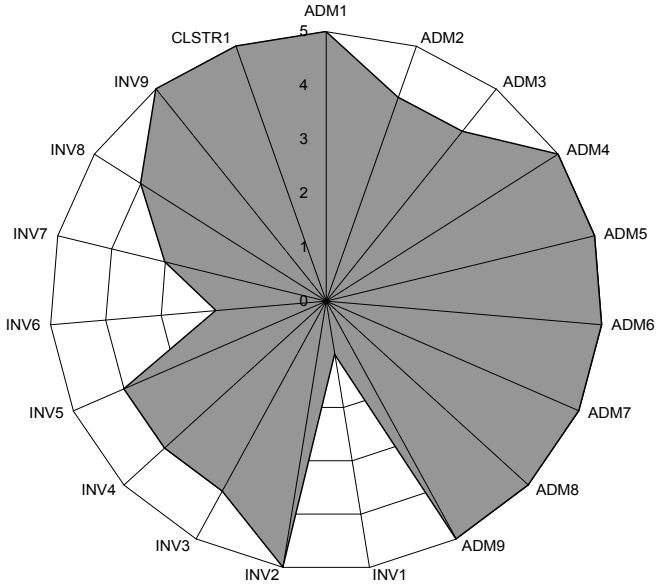

Figure 3. Organizational dimension footprint of Company A

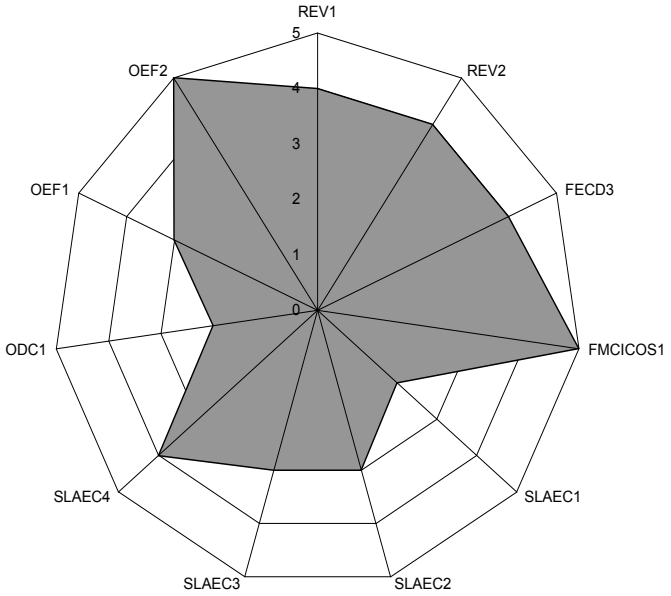

Figure 4. Economical dimension footprint of Company A

5.4. Case study 2: CompanyB-cloud user

Technical, organizational and economical footprints of Company B are provided in Figures 5, 6 and 7. Slt1, Slt2 and Slt3 are the common generic measures that apply both to cloud service providers and to users. There are not any other common generic measures for these two categories of companies. 29 generic measures in 13 technical variables were found to be relevant for Company B. The following observations can be made:

- They are satisfied with the private cloud provided to them by their cloud service providers.
- Dependency on external systems does not cause any problems in terms of cloud performance for them.

Assessment of the organizational dimension of Company B indicates that:

- Company B uses cloud services of a low number of cloud service providers with long periods. This means that vendor-lock in degree is an important issue for them.

- They do not spend more time to carry out their tasks with cloud compared to their previous system. This means that time effectiveness has been achieved through migrating to the cloud.
- Suppliers of Company B boast a large number of customers and references, indicating their overall reliability.

According to the economical dimension evaluation results of Company B, it is observed that cloud computing provides more benefits to Company B compared to the costs.

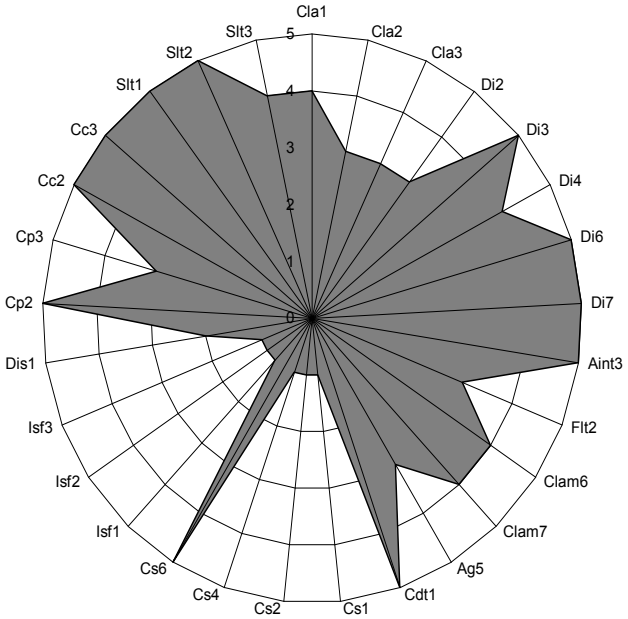

Figure 5. Technical dimension footprint of Company B

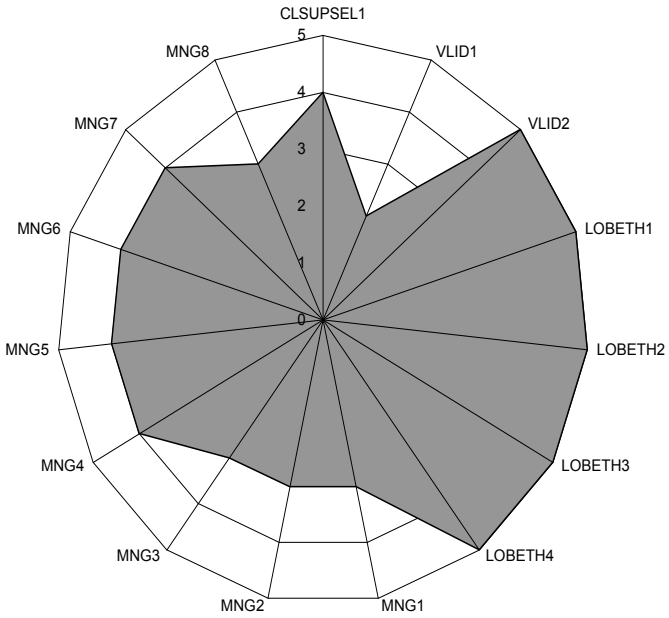

Figure 6. Organizational dimension footprint of Company B

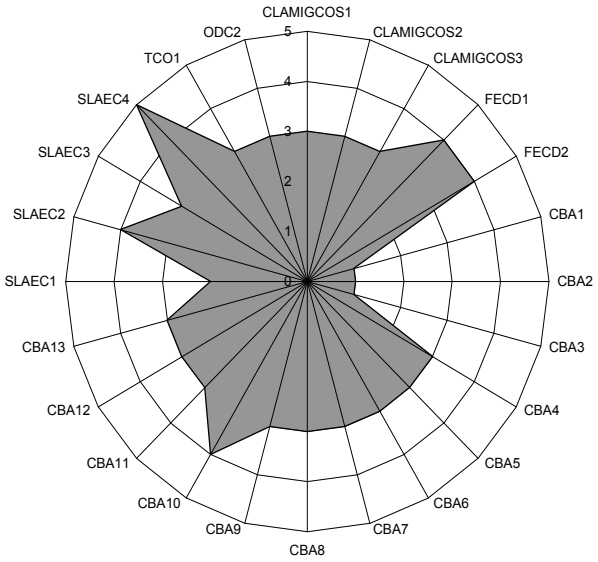

Figure 7. Economical dimension footprint of Company B

5.5. Case study3: CompanyC-solution provider for cloud service providers

Technical, organizational and economical footprints of Company C are given in Figures 8, 9 and 10. 9 variables including 19 generic measures are evaluated for this company in the technical dimension. The following observations are made:

- Cloud response time is not satisfactory for Company C. The level of system connection quality is very high, but the level of cloud service lead time is also high. For that reason, cloud response time seems to be problematic.
- Company C has a medium level of dependency on external systems and low level of cloud computing vulnerabilities. These results are not sufficient to decide on their effectiveness in terms of technical flexibility.

The assessment results associated with the economical dimension for Company C are as follows:

- They supply a high volume of cloud solutions with medium level of unit prices to cloud service providers. Company C provides solutions to the key and big cloud service providers in the sector. Since these service providers can access many competing solution providers, prices are determined competitively.
- Company C provides a high variety of pricing and billing mechanisms to the service providers, which helps them to increase their market potential.

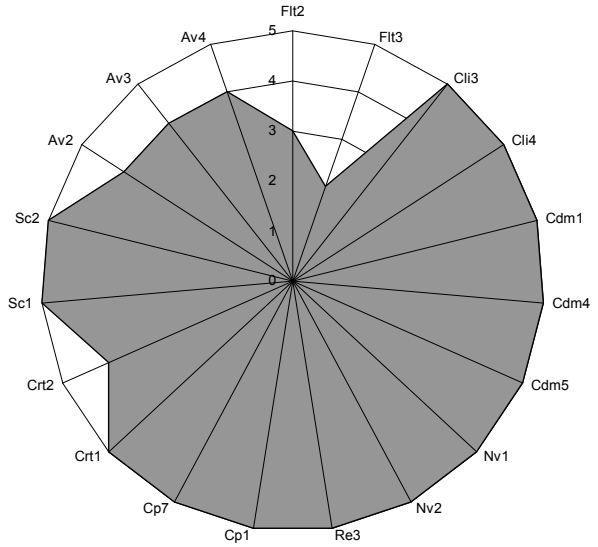

Figure 8. Technical dimension footprint of Company C

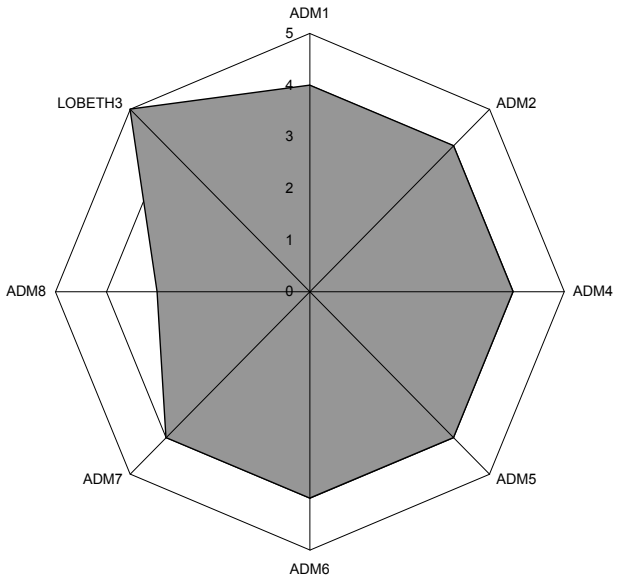

Figure 9. Organizational dimension footprint of Company C

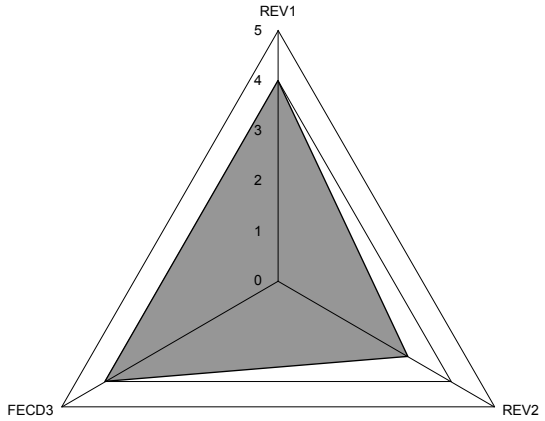

Figure 10. Economical dimension footprint of Company C

5.6. Case study4: CompanyF-cloud user and service provider

Technical, organizational and economical footprints of Company F are given in Figures 11, 12 and 13. 15 variables including 53 generic measures are evaluated for this company in the technical dimension. The following results are obtained for this dimension:

- The level of system connection quality is very high, but the level of cloud service lead time is also high. For that reason, cloud response time is higher in Company F.
- They provide a high level of flexible application architectures to their customers. For that reason, their customers do not meet with the issue of adapting their applications to cloud.
- They have a growth plan for computing capacity, but it does not include detailed estimations and analysis about computing capacity.

The assessment results of Company F in the organizational dimension show that:

- Company F spends less time to carry out their tasks with cloud compared to their previous system.
- Vendor lock-in degree is an important issue for Company F.
- Company F has a cloud strategy, but this strategy is not sufficiently mature to guide them while carrying out their focus on core businesses.

The assessment results associated with the economical dimension for Company F lead to the following observations:

- The sales of cloud solutions with medium level of unit prices to cloud service providers attains a high volume.
- The costs accrued in Company F exceed the benefits.

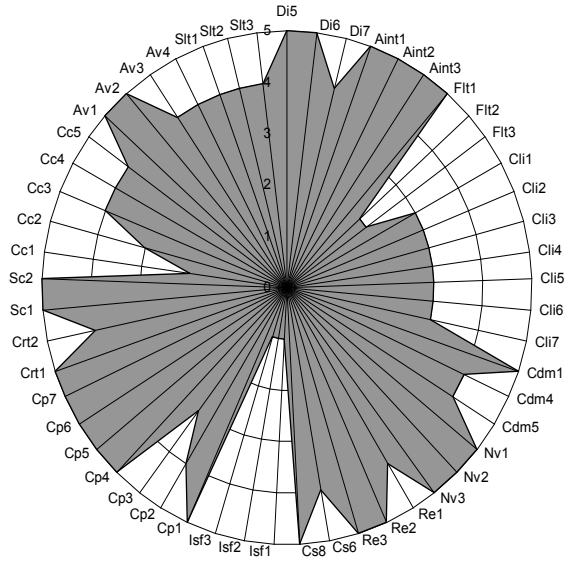

Figure 11. Technical dimension footprint of Company F

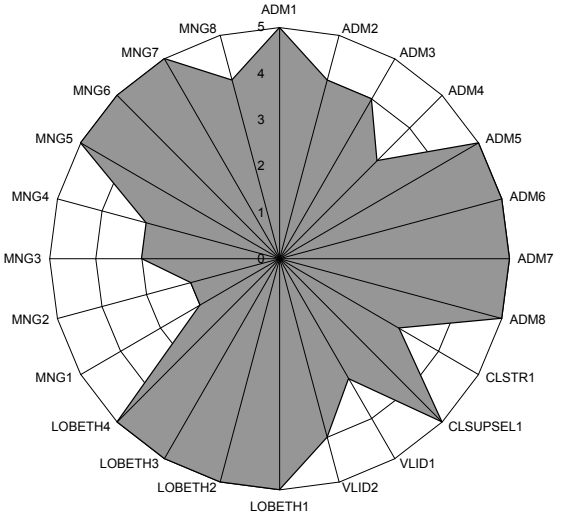

Figure 12. Organizational dimension footprint of Company F

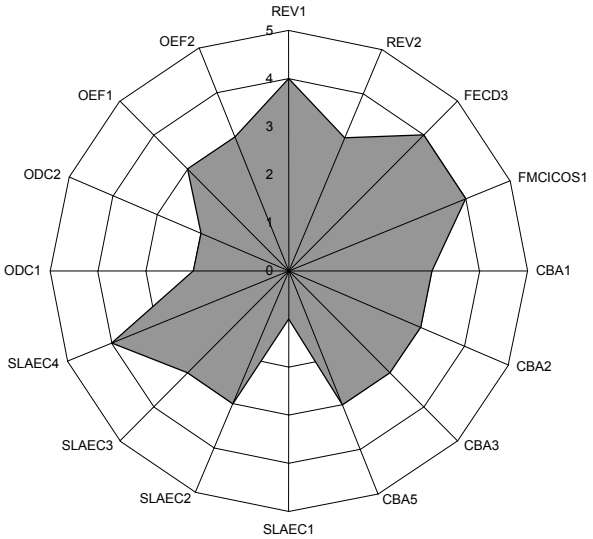

Figure 13. Economical dimension footprint of Company F

5.7. External dimension results for these four companies

As the external dimension consists only of two variables, rather than footprint diagrams, we compare the four companies in two bar charts, presented in Figures 14 and 15, one corresponding to each variable.

Investigation of these bar charts lead to the following observations:

- The variable of computer literacy rate is more effective than the variable of cloud-specific legislation for these four companies. This means that computer literacy can not be considered as significant an issue as cloud-specific legislation for them.
- Cloud service provider (Company A) is more effective than the other companies in terms of cloud-specific legislation because it gives consultancy support to their customers about cloud computing laws and regulations.

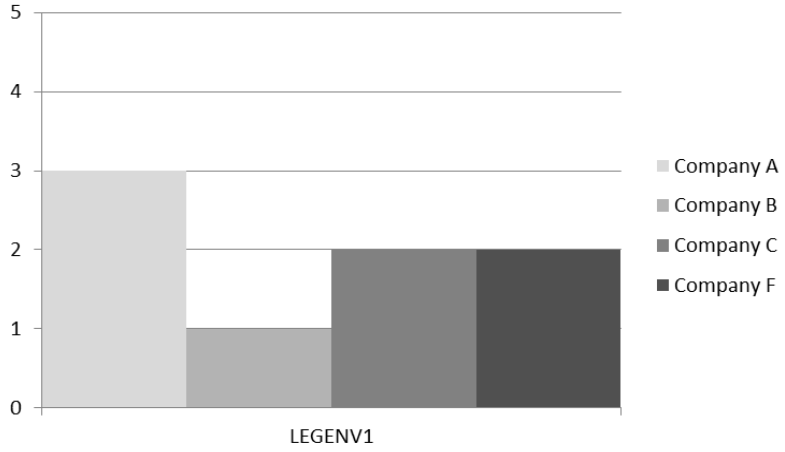

Figure 14. Cloud-specific legislation

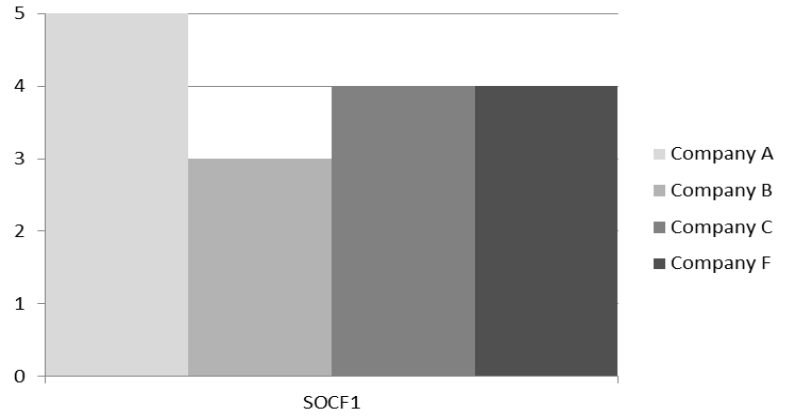

Figure 15. Computer literacy rate

6. CONCLUSION

Through this study, the variables that effect cloud computing effectiveness are obtained, so an effectiveness assessment model for cloud computing consisting of the technical, economical, organizational and external dimensions is proposed. The model and research carried out in the scope of this study has been validated for cloud computing service providers, service provider/receivers, solution providers, and users. Effectiveness assessment results obtained in four case studies are presented in the form of footprint diagrams, pointing out some interpretations. Each of the variables of the model have at least one generic measures. Besides, the applicability of all generic measures are denoted through the case studies. The model can be used for benchmarking and comparing different organizations, as well as a possible starting point for improvement. The model provides to assess the effectiveness of cloud computing, in terms of four separate dimensions, which may be more useful for companies that will make comparisons. This means that rather than assessing the effectiveness with two dimensions as economical and technical, including four dimensions as stated in our model provides the companies a more comprehensive view on cloud computing effectiveness.

There are two noteworthy limitations of this study: The first limitation has originated from having a large number of open-ended interview questions. For that reason, some of the invited companies did not participate in our case study application, hence generalizability of the results, even though still sufficiently strong, has not been achieved at the level originally aimed for. The second limitation is related to the deficiency of cloud experts having comprehensive knowledge of each of the technical, organizational, economical and external dimensions. While each one possessed expertise on some aspects of the evaluation, not all were equally qualified to respond to all interview questions. Hence, to ensure validity, multiple interviewees with different organizational roles were selected and approached in most cases.

Our future work will focus on the construction of an improvement strategy and method based on this assessment model, to assist companies in enhancing their cloud computing effectiveness. There is a necessity for an improvement proposal formulation algorithm/approach based on CCEAM. Companies may want to observe their effectiveness assessment in order to reach the weaknesses and strengths of their companies through applying CCEAM. But, besides, they also want to learn how they can enhance their effectiveness by eliminating these weaknesses. For these reasons, proposals for enhancements have to be constructed in a structured way.

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BIOGRAPHY OF AUTHORS

Serdar Yarlikas holds a BS degree in Econometrics from Dokuz Eylul University, Turkey. He received MS degree in Information Systems from Middle East Technical University, Turkey, in 2007. He is a Research Assistant and PhD Student at Middle East Technical University (METU), Department of Information Systems in Informatics Institute in Ankara, Turkey. His areas of interest are Management Information Systems, Information Systems Outsourcing, Cloud Computing, Human Computer Interaction, e-learning, Statistical Analysis, Econometric Modeling, and Operations Research.

Semih Bilgen graduated from the Middle East Technical University in 1973. His MSc is from Rensselaer Polytechnic Institute (1976) and PhD from the University of Manitoba, (1982). He has been with the Middle East Technical University since 1976. His main research areas are Computer Networking, Software Engineering and Information Systems.