Making the Cloud work for Software Producers: linking Architecture, Operating Cost and Revenue

Pierangelo Rosati[1], Frank Fowley[1], Claus Pahl[2], Davide Taibi[3], Theo Lynn[1]
[1]*Irish Centre for Cloud Computing and Commerce, Dublin City University, Dublin, Ireland.*
[2]*Faculty of Computer Science, Free University of Bozen-Bolzano, Bolzano, Italy.*
[2] *Laboratory of Pervasive Computing, Tampere University of Technology, Tampere, Finland.*
{pierangelo.rosati, frank.fowley, theo.lynn}@dcu.ie; claus.pahl@unibz.it; davide.taibi@tut.fi.

Keywords: Cloud migration, Total cost of ownership, Monetization, Architecture migration, Software producer.

Abstract: Cloud migration is concerned with moving an on-premise software system into the cloud. In this paper, we focus on software producers adopting the cloud to provide their solutions to enterprise customers. Their challenge is to migrate a software product, developed in-house and traditionally delivered on-premise, to an Infrastructure-as-a-Service or Platform-as-a-Service solution, while also mapping an existing traditional licensing model on to a cloud monetization model. The analysis of relevant cost types and factors of cloud computing generate relevant information for the software producers when deciding to adopt cloud computing, and defining software pricing. We present an integrated framework for informing cloud monetization based on operational cost factors for migrating to the cloud and test it in a real-life case study. Differences between basic virtualization of the software product and using fully cloud-native platform services for re-architecting the product in question are discussed.

1 INTRODUCTION

Cloud computing is increasingly the computing paradigm of choice for enterprises worldwide. Cloud computing is particularly attractive from a business perspective since it requires lower upfront capital expenditure, and improves operational and organizational efficiencies and agility (Armbrust et al., 2010; Leimbach et al., 2010; Marston et al., 2011; Berman et al., 2012). Similarly, from a technical perspective, the benefits of the cloud are well documented including on-demand, self-service, resource pooling and rapid elasticity (Armbrust et al., 2010).

Notwithstanding these benefits, cloud computing adoption also generates significant challenges for software producers (SPs), particularly for those offering a Software-as-a-Service (SaaS) model. SPs typically migrate their software to a third-party platform (Infrastructure-as-a-Service – IaaS – or Platform-as-a-Service – PaaS) and their customers access it from this new multi-tenant architecture. In a cloud environment both SPs and their customers are typically charged on a pay-per-use or subscription basis. Furthermore, SPs do not have control of customers' service usage; in such a context, it is crucial for SPs to identify the right architectural configuration to meet service level agreement (SLA) obligations at the minimum cost. Being charged on a per-use basis also represents a radical change in the producers' cost and revenue models and introduces additional uncertainty in cash flow forecasting (Dillon et al., 2010). Furthermore, the actual cost of the migration process might be substantial for SPs and for their legacy customers, while nonexistent for cloud-native SPs. According to the Cloud Native Computing Foundation, modern cloud-native systems have the following properties:

- container-packaged;
- dynamically managed by a central orchestrating process;
- microservice-oriented.

Cloud-native architectures have technical advantages in terms of isolation and reusability, thus reducing cost for maintenance and operations. PaaS clouds with their recent support for containerized microservice architectures are the ideal environments to create cloud-native systems.

While the service and payment/revenue model are the same in both scenarios, the total cost of ownership (TCO) is substantially different due to the migration costs. Rationally, SPs should offer their software at a higher price to compensate their migration costs, however this may not always be competitively feasible or desirable.

While architectural challenges in migration have been ad-dressed (Jamshidi et al., 2013; Pahl and Xiong, 2013), research exploring the link between cloud architecture and TCO, and therefore on pricing cloud services from an SP perspective is lacking.

The main objective of this paper is to explore the impact of two cloud architectural options, IaaS (basic virtualization) and PaaS (cloud-native), on SPs' operating costs. We present an initial framework for operating cost factors and dependencies, and a practical process for architecture-related cost estimation.

This paper is organized as follows. Section 2 reviews related work and presents the cloud migration context. Section 3 introduces the overall framework and process. Sections 4 and 5 focuses on the IaaS- and PaaS-based cost calculation respectively. In Section 6, we validate and illustrate our contribution using a case study. We end with some conclusions and observations for future research.

2 ARCHITECTURE MIGRATION CONTEXT

2.1 Context and Related Work

Traditionally, enterprise software was licensed under a packaged, perpetual or server license, and customers were typically required to purchase technical support and maintenance packages for a predefined period (Ferrante, 2006). The cost of software development, production and marketing was offset against the license fees, typically paid upfront by the customer.

The introduction of cloud computing accelerated the adoption of two new licensing models: subscription and utility-based licensing. The former involves an enterprise customer purchasing a license for a pre-defined time period whereas the latter involves charging the customer on a pay-per-use basis. Key advantages for the enterprise customer include (i) less upfront expenditure in licensing and (ii) no additional fees for fixes, upgrades or feature enhancements (Ferrante, 2006). The shift from a product orientation to a service orientation is a significant disruption for SPs, not only from a strategic perspective but also from a cost- and revenue- recognition perspective. Cost and revenues, indeed, are spread over time and producers do not receive additional fees for upgrades. This resulted in a significant business model readjustment (DaSilva et al., 2013). Such changes do not apply to cloud-native SPs such as start-ups. Giardino et al. (2015) observe that cloud computing is particularly beneficial for start-up companies since it significantly lowers the initial investment in IT infrastructure.

Cost savings are a major factor in cloud adoption (CFO Research, 2012; Bain and Company, 2017), however ex-ante TCO estimation is not straightforward due to the presence of long-term and hidden costs of operating in the cloud which tend to be ignored or underestimated (ISACA, 2012). From an SP perspective, this represents a major concern since properly mapping the costs of the cloud represents the basis for adequate and effective pricing strategies. This process has become more and more important for SPs due to increasing competition in the cloud environment, where SPs are sometimes forced to deliver services whose costs exceed revenues (Durkee, 2010).

TCO is the most adopted costing model in both research and practice (Strebel and Stage, 2010) and has been defined as "a procedure that provides the means for determining the total economic value of an investment, including the initial capital expenditures (CapEx) and the operational expenditures (OpEx)" (Filiopoulou, 2015, p. 278). TCO estimation frameworks used for traditional on-premise infrastructure need to be adapted to the cloud world to reflect different cost drivers (Martens et al, 2012; Walterbusch et al, 2013).

Strebel and Stage (2010) applied a TCO-based decision model for business software application deployment, while running simulations on hybrid cloud environments. The decision model only included a comparison of operational IT costs, such as server and storage expenses and the external provisioning by means of cloud computing services. Reference (Li et al., 2009) formulated a TCO model and identified the factors involved in the utilization cost. This model consists of the total cost of all servers and resources used to provide the service. Cloud implementation and operating costs were divided into eight different categories that mainly represent fixed costs, such as setting-up and maintenance costs that providers need to bear during the whole lifecycle. Ilan (2011) presents a cost comparison between virtual managed nodes and local managed servers and storage, but neglects important cost components like licenses, training, licensing and maintenance. Finally, Walterbusch et al. (2013) presents a comprehensive TCO model for the three main cloud service models (i.e. IaaS, PaaS and SaaS), and map into their model different cost components across four phases of cloud computing, i.e., initiation, evaluation, transition, operation. Costs related to system failure and backsourcing or discarding are listed but not included in the model since they are, by their nature, contingent to situation contexts and therefore difficult to translate in a mathematical formula.

Despite the large number of studies on software architecture-related factors for consideration in migration, and, likewise, the large number of studies related to TCO for cloud computing, there is a lack of papers seeking to estimate the TCO for cloud migration in conjunction with architecture concerns. The extant literature is typically focused on ex-post calculation of costs and profits independently from the wider situational context, and typically considers only cloud operational cost. For example, Andrikopoulos et al. (2013) proposes a decision support system which includes a cost calculator based on per-use cost components only. Jinesh (2010) presents a TCO estimation of migrating to Amazon Web Services (AWS) that includes per-use charges only. Similarly, Anwar et al. (2015) examine cost-aware cloud metering for scalable services.

2.2 Two Migration Business Cases

Cloud computing adoption can dramatically change a company business model and internal organization, and requires investing a significant amount of resources in the migration process. In such a context, an ex-ante evaluation of costs and potential benefits that such an investment may generate is crucial for effective decision-making. In this paper, we consider two discernible migration business types:

- The migration of existing legacy customers with perpetual licenses;
- New customers with no existing economic relationship with the SP.

In the first case, there is a significant post-migration discontinuity in the vendor-customer relationship and the nature of the billing. From the customer perspective, the business case can be made by comparing the as-is and the to-be solution, however this is anything but a trivial process (ISACA, 2012). There may be time, effort and additional hidden costs related to the migration that need to be included in the ex-ante evaluation and recovered by both SPs and their customers (ISACA, 2012). In the second case, customers can make their choice on the basis of the perceived value of the service per se. In both cases a key consideration for SPs is the amount of cost they can sustain to generate a positive margin on their sale over a defined time period.

TCO is used to estimate the cost of cloud investments from the initial sourcing through to the end of the cloud usage, whether that is the backsourcing of information, or the client switching to other services or providers. While the measured nature of the cloud allows for a detailed ex-post cost analysis, ex-ante cost estimation can be complicated due to the uncertainty associated with multi-tenancy and resource pooling. Similarly, while there are clear cost savings in cloud computing there are also intangible cost components which are more difficult to estimate (ISACA, 2012).

By its very nature, cloud computing enables enterprise customer scale up and down on-demand without the ties associated with a substantial upfront investment. Thus, forecasting the customer lifetime (and associated value) for a cloud customer can be difficult. Suddenly, they can leave or radically modify their usage, since switching costs in the cloud are significantly lower than on-premise. Notwithstanding this, enterprise customers and SPs require a practical approach to measuring cloud TCO.

3 INTEGRATED MIGRATION FRAMEWORK AND PROCESS

Typically, a cloud migration is organized around an architectural transformation of the legacy system, independent of cost and pricing considerations. We propose an integrated process for migration planning:

- Analyze and model: use a set of migration patterns to determine structural cloud architecture aspects;
- Right-scaling: conduct a feasibility study to validate quality requirements such as scalability;
- Right-pricing: determine pricing for the software service based on analysis of direct operational costs driven by predicted usage and experimental consumption figures generated from the feasibility study.

While a comprehensive discussion of cloud migration patterns, processes and issues are presented in Jamshidi et al. (2014) and Taibi et al. (2017), right-scaling and pricing need further discussion.

3.1 Problem 1: Right-Scaling of SaaS Software

SPs seeking to migrate to the cloud need to find the right architectural configuration to meet the necessary service level agreement (SLA) obligations at the minimum cost. Therefore, a key question for a decision maker is: how many components can I host on a fixed cloud compute resource with a pre-defined latency performance target for a forecasted number of users of a particular application with a forecasted mix of application operation usage?

Changes in usage require changes in the number and/or configuration of cloud resources used, which may result in additional costs. Estimation of the expected usage level or patterns is needed to predict when scaling, and related additional costs, may occur. Furthermore, storage and networking charges are akin to commodities that can be consumed on a per-unit of usage basis. The compute costs are more difficult to predict since they are determined by the users' use of the application. In this paper, we consider a virtual SLA-backed service that is not entirely fixed in terms of computational and storage resources allocated. Finally, the actual capacity of the offered cloud service may fluctuate over time affecting potential economies of scale and application performance. Only the cloud service provider, and not the SP, can monitor the underlying service availability thus, the first problem is right-scaling i.e., to size a predicted workload to a machine (configuration) profile. This requires usage prediction to configure IaaS or PaaS through an experimental pre-migration feasibility study, and represents the basis for an accurate estimation of operational costs. For SPs, right-scaling reduces overprovisioning and therefore usage cost of their cloud infrastructure.

3.2 Problem 2: Right-Pricing of SaaS-delivered Products

Monetization refers to how organizations capture value i.e. when, what and how value is converted into money (Baden-Fuller and Haefliger 2013). Despite the fact that how SPs price and monetize their cloud offering is beyond the scope of the TCO framework adopted in this paper, it is important to understand as the TCO represents a critical component of SPs' pricing decision. A monetization framework for SPs usually comprise three models, namely:

- Architecture model: the source and target architecture need to be considered together with planned changes in functional or non-functional properties;
- Cost model: the expected direct operational costs need to be estimated including basic infrastructure and platform costs, additional features for external access and networking, internal quality management, and development and testing costs, and mapped into the TCO estimation;
- Revenue model: expected revenues based on a selected pay-per-use or subscription model.

From an SP perspective, the relationship between cloud cost and price (P) can represented as follows:

$$P = TCO \times (1 + \mu) \quad (1)$$

Where μ represents the percentage of profit the producer aims to obtain. Understanding how SaaS usage translates in to IaaS costs is of primary importance for SPs since the SaaS income should cover the corresponding infrastructure costs. The interplay between these three models ultimately determines the attractiveness of the cloud offering of an SP in the marketplace.

Relevant questions are: (a) which factors are static and might be considered as a baseline for the cost calculation? (b) What are the additional costs for scaling up beyond the baseline? And (c) what is the best combination of cost and revenue model that maximize profit in the short- and long-term?

3.3 Total Cost of Ownership and Cost Factors

TCO in a strict sense, is the sum of the initial investment required to purchase an asset (*CapEx*) plus the operating costs that the cloud generates (*OpEx*). When choosing among alternatives, SPs should look at both components of TCO to evaluate the investment properly. Migration costs tend to be omitted in cloud TCO estimations even though they can be substantial and change the overall return on investment. TCO calculation can be formalized as follows:

$$TCO = CapEx + OpEx \quad (2)$$

In the context of our study, *OpEx* includes fixed (e.g. location and size) and variable (i.e., usage) IaaS Cost components while *CapEx* includes migration and implementation costs (e.g. development and testing, project management etc.). Walterbusch et al. (2013) provide a comprehensive list of cost components that may be considered for estimating TCO of SP cloud migration.

In order to estimate the cost associated with the expected SaaS usage, we consider costs at the SP level. In terms of IaaS operational costs for an SP we focus on compute, storage and network resources since they usually represent the most significant cost components. IaaS costs can be categorized as (i) fixed (size, availability, location, and other supplemental and/or premium services), or (ii) variable (i.e., usage of all respective IaaS resources). Like other fixed cost factors, reconfiguration is possible, but not considered in this paper. Availability is considered as a contractually guaranteed property and it is assumed to be fixed.

4 IAAS COST CALCULATION PROCESS

The nature of the cloud makes it difficult to determine the input variables of the TCO model, but, we will see, architecture quality concerns such as performance and availability can drive this process. Cloud architecture qualities, and corresponding costs, can be influenced by compute, storage and network resources. Figure 1 summarizes the cost estimation process that we will now apply.

Figure 1 Costing SaaS Usage - Estimation Process

4.1 Cost Estimation Process

In a cloud migration scenario, an SP needs to migrate the system architecture of the product and change the corresponding cost and revenue models at the same time. As highlighted before, the new models heavily depend on expected or predicted usage, both of which are difficult to estimate. In fact, any estimation of SaaS usage volumes will determine IaaS usage requirements but customers' usage can be subject to temporary peaks that might generate spikes in costs due to ineffective IaaS usage.

Estimation complexity varies between the two business cases identified earlier, i.e., migrated or cloud-native application. Usage patterns of the existing customer base can be determined with reasonably high accuracy, as opposed to an expansion into a new a customer base with unknown behavior.

process for costing a SaaS service from an SP perspective. The initial two phases are about usage estimation at both the SaaS and IaaS level. SaaS usage can be mapped onto IaaS by experimental means using feasibility studies or other mechanisms. A third phase is concerned with IaaS cost estimation, which is driven by the usage estimation and SLA obligations. IaaS configuration heuristics can be used to identify the most efficient infrastructure configuration. The fourth and final phase is related to pricing the SaaS service based on the outcome of the previous stages.

4.2 Architecture Selection and Cost/Revenue Prediction

From an SP perspective, the selection criteria of a cloud provider include fees and billing model. Many IaaS providers offer monthly basic subscription fees with additional fees for premium services such as scalability, access (e.g., IP endpoint, network bandwidth) or monitoring and advanced self-management. An SP requires a clear comparison of costs and revenues resulting from the cloud adoption. This has to be an "apples to apples" comparison (ISACA, 2012). Even though we primarily discuss IaaS, similar assumptions can be made for PaaS services. PaaS-level costs need to address both development and deployment and need to be aligned with SaaS-level income.

4.3 Heuristics – Resource Cost Modeling and Right-scaling

In order to make this more practically relevant, we can look at the different resource types and compare them in terms of utilization and cost fluctuations in common deployments (and resulting impact on cost estimation).

Cost modeling for compute versus storage services are fundamentally different. Storage is more predictable and current cloud service pricing models support a commodity-style costing. Compute cost is more complicated to predict and contributes disproportionately to the achievement of economies of scale. SPs need to make configuration assumptions which may or may not prove to be accurate. Scenario analysis may help to achieve better estimation.

For illustration purposes, a simple initial configuration of IaaS resources could be based on 80 percent reserved and 20 percent on-demand instances. This combines reliable core provisioning without overprovisioning for extra demand (in which case on-demand instances are acquired). The benefits of this strategy are:

- 60-80 percent utilization of used instances is achievable if the reserved instances deal with peak demand;
- Up to 50 percent cost reduction compared to on-demand instances only.

Another factor impacting resource requirement is the nature of the architecture. Stateless, loosely-coupled architectures help accommodate extra demand and enable scalability by just using additional resources on-demand without much start-up costs (transfer of state to other resources).

4.4 An Exemplar Pricing Model

In order to understand pricing models of IaaS and PaaS providers, we report exemplar categories and common pricing models (Table 1). This is largely built on Azure pricing information, but is typical of other providers.

Relevant pricing models focus primarily on storage in GB and transactions (read/write). A proper estimation of IaaS costs associated with a SaaS application provisioning is needed in order to (i) select the technically best option, and (ii) estimate the costs for hosting the SaaS application, for example, in a PaaS cloud. Quality concerns other than the expected workload (e.g. availability expectations, failover strategy etc.) have to be considered in the process as well. Effectively, the estimation process needs to include the number of storage units and total size as an input, and the costs, estimated over a defined period, with predicted growth, and for different replication options as an output.

Table 1: Storage Cost Component

Component	Description
Region	Slightly different rates might apply per region (relevant if data location regulations apply).
Replication	It is a mechanism to deal with down-time and increase reliability. Sample configurations: Local Redundant – a number of copies of data, all in the same data-center and region of the storage account, across different fault or upgrade domains. Zone Redundant – a number of copies of data, all in different data-centers, which has slightly less throughput than Local redundancy. Geo Redundant – a number of copies of data, all in different data-centers, with a back-up, separate multiple saves in a specific secondary region to allow to recover from Region failure. Read-Only Geo Redundant – the same as geo redundancy with read access to secondary data. All replication operations are done asynchronously.
Size	It depends on actual amount of Gbytes stored.
Transactions	Number of Read/Write Blob Operations.
Data Transfer	It is measured. Sample costing: Data Ingress Network Data Transfer is free. Data Egress Network Data Transfer is free if in the same region. Data Egress Data Transfer between regions or out of a region is charged.

A further complication is that pricing models between platform providers are difficult to compare due to different definitions of price components. Consequently, a formal and clear estimation framework for an economic evaluation of different solutions to deliver a SaaS service is needed.

5 CLOUD-NATIVE PAAS ARCHITECTURE MAPPING

In the previous section, we discussed the implementation of a SaaS product on an IaaS set of services. Now we consider the adoption of PaaS to provision a SaaS product. We assume here a migration to a PaaS architecture to be cloud-native in style, i.e., platform services, such as databases, are provided as packaged services in a microservice style. The migration to PaaS is more demanding particularly where many native PaaS services are used. Notwithstanding this, the cost estimation may be easier. This will also further clarify the impact of cloud software architecture on costs and revenues.

5.1 PaaS Migration

From an SP perspective, a PaaS solution has two main benefits: (i) development costs can be mapped and associated with the migration, and (ii) more accurate estimation of deployment costs.

An important consideration for SPs is whether to fully adopt the cloud as both a delivery and a development platform. While moving software development to a PaaS cloud allows software producers to further reduce upfront capital expenditure, it may limit technical options in the future. Another important consideration is whether to have a staged migration. Through basic virtualization, a simple VM-based IaaS solution might emerge. The ultimate objective would be to move from VMs to so-called cloud-native applications at the platform level that utilize fully cloud-based services for development and deployment. Consequently, this provides a more metered and granular cost model.

5.2 Staged Migration towards Cloud-Native

For illustration purposes, we assume that the SP wishes to migrate a traditional stacked application with application, middleware, DBMS and disk storage support that runs in an on-premise setting, to the cloud. A stepwise migration from on-premise via IaaS into a PaaS cloud can happen as follows:

- Phase 1 – IaaS Compute Architecture: The application can be packaged into VMs. License fees for components of the application are incurred as usual. The business problem is scaling out; adding more VMs means adding more license fees for every replicated component. From a technical point of view, multiple copies of data storage that are not in sync might cause integrity problems.

- Phase 2 – DaaS Storage: Refactor and extract storage i.e. use a virtual data-as-a-service (DaaS) solution for storage needs. This alleviates the technical integrity problem cited above.
- Phase 3 – PaaS Cloud Data Storage: Package the whole DBMS into single virtual machine. This alleviates the business license fee problem for the DBMS and simplifies data management, but other license fees may still occur.
- Phase 4 – Full Application Migration: Migrate to a PaaS service. Apart from solving technical problems, this significantly mitigates the licensing fees issue.

This process results in a so-called cloud-native application, which is scalable/elastic, clusterable, multi-tenancy, pay-per-use, and self-service.

6 ILLUSTRATION AND VALIDATION – CASE STUDY

We now illustrate the estimation process presented in Section V using a case study. The estimation process was applied to an SP migrating a legacy client-server on-premise single-tenant enterprise application to the cloud by re-designing, re-engineering and recoding the system as a cloud application. The SP is a small-medium enterprise which provides a document management application. Its application has over 1,000 existing client installs and in this case study, we present the TCO estimation of migrating 240 of these to the new cloud platform over a 3-year period. The main business requirements for the SP to adopt the cloud were (i) to pursue flexibility across different devices and situational contexts, and (ii) to increase the customer base through new market entries. The solution requires meeting high-volume data storage and processing needs.

6.1 Application Overview

The application is a Document Management System (DMS), which enables a user to scan paper documents from enterprise-grade scanners and save them on a cloud store as electronic images. Documents are classified under custom types, such as invoice or delivery docket, and specific metadata templates are used to store searchable tagged data against the documents for future retrieval and reporting. The application has been designed and coded specifically to run as a cloud application on the Microsoft Azure public cloud platform.

6.2 TCO Calculation

The TCO is made up of the implementation costs of the new cloud application and the cloud charges incurred in running the new system on Microsoft Azure.

Estimated implementation costs (CapEx) were classified into seven implementation phases: Business Analysis, Cloud Architecture Design, Data Design, Security Framework Design, Development and Test, Performance and Costs Analysis. It should be noted that the calculations do not include the operational costs of migrating the customers to the new cloud web application.

The application is a multi-process system since it comprises a web server compute resource and a separate image processing compute resource. However, the functional dependency between these do not need to be considered in the TCO analysis since the image processing worker VM acts completely asynchronously to the web server role web requests which continue regardless of the state of the image processor. Therefore, we have calculated the multi-tenant VM requirements based on a simple linear multiplication of the CPU load per tenant.

IaaS usage charges (OpEx) are estimated considering the two most relevant cost components:

- A cloud data store – made up of a NoSQL Table structure (using the Azure Table service) and an object store (using the Azure Blob Storage service). Table and blob storage are platform services that allow a more fine-grained costing. As such, these need to be considered on an individual service base.
- A cloud compute architecture – made up of a separate compute resource for the web server of the web application (Web Role Virtual Machine), and a separate compute component for carrying out the image processing functions, such as barcode reading (Worker Role Virtual Machine).

Our calculation is based on the Azure services pricing reported in Tables 2, 3, and 4. In order to forecast the usage of cloud storage resources, we used actual historical data over an eleven-month period from an existing average-sized tenant with a typical application usage pattern. To estimate the computing resources required, we monitored the usage and performance statistics during a snapshot of the operational use of the application by the same typical user. Tables 5, 6, and 7 summarize the usage profile adopted in the calculation.

Table 2: Blob Storage Prices

Service	Redundancy	Cool Tier	General Purpose
Price per GB/Month space	Local	€ 0.013	€ 0.020
	Geo	€ 0.025	€ 0.041
Price per 10,000 transactions	Local	€ 0.084	€ 0.003
	Geo	€ 0.169	€ 0.003
Price per GB data access write	Local	€ 0.002	-
	Geo	€ 0.004	-

Table 3: Table Storage Prices

Price per Entity/GB/Month	Local Redundant	€ 0.059
	Geo Redundant	€ 0.085
Price per 10,000 transactions (PUT)	Local Redundant	€ 0.003
	Geo Redundant	€ 0.003

Table 4: Compute Prices

VM Type	No. of CPU Cores	Annual cost Azure VM (€)	VM Type	No. of CPU Cores	Annual cost Azure VM (€)
a1	1	602.4	d4	8	8,937.00
a2	2	1,204.68	d1 v2	1	1,114.32
a3	4	2,409.36	d2 v2	2	2,236.20
a4	8	4,818.60	d3 v2	4	4,464.72
d1	1	1,114.32	d4 v2	8	8,937.00
d2	2	2,236.20	d5 v2	16	17,873.88
d3	4	4,464.72			

Table 5 Usage Profile of a Typical Tenant

Total Number of Scanned Documents per annum	145,853
Average Document Table Entities per Month	14,675
Peak Entities per Day	3,551
Peak Entities per Hour	1,137
Average Table Entity Size in Bytes	2,160
Average Scanned Image File Size in KB	666
Average Template File Size in Bytes	2,200

Table 6: Forecasted Input Parameters

Per Tenant	End of Year		
	1	2	3
No. of documents	176,105	352,210	528,314
Document table size (GB)	0.380	0.761	1.141
No. of image blobs	176,105	352,210	528,314
Image blobs size (GB)	117	235	352
Document Template File Blobs	2	3	6
Total Template blob storage (bytes)	4,400	8,800	13,200

Table 7: Summary Parameter Values

Web Role Peak CPU Load	67.1%
Web Role Average CPU Load	31.5%
Worker Role Peak CPU Load	24.3%
Worker Role Average CPU Load	10.4%

6.3 Experimentation – Usage and Cost

Table 8 summarizes the estimated implementation and migration costs for the SP (€168,647). The most significant cost component, which represents 47.83% of the overall migration costs, is by far consultancy costs for design and development, followed by security design (16.15%). Such a significant amount of upfront migration costs further highlights the need to include such costs into TCO estimation to inform both adoption and pricing decisions.

Table 8 Migration and Implementation Costs

Implementation Phase	Cost (€)
Implementation Consultancy Costs – Business Analysis (Contract hours)	16,078
Implementation Consultancy Costs – Security Design (Contract hours)	27,237
Implementation Consultancy Costs – Design and Development (Contract hours)	80,662
Project Management and Implementation Design (Staff Salaries)	16,265
Development and Testing (Staff Salaries)	17,465
Non-Staff or Non-Contractor Costs (Cloud Testbed subscription, test equipment, travel)	10,940
Total	168,647

Tables 9, 10, and 11 summarize IaaS usage costs estimated as a linear combination of usage parameters and price of each service.

Table 9: Blob Storage Costs

Costs per tenant	Space Cost (€)		Transactions Cost (€)	
Redundancy	Local	Geo	Local	Geo
End year 1	8.87	17.80	1.48	2.97
End year 2	26.60	53.41	1.48	2.97
End year 3	44.33	89.02	1.48	2.97
	Data Access Write Cost (€)		Total Cost (€)	
Redundancy	Local	Geo	Local	Geo
End year 1	1.48	2.96	11.83	23.73
End year 2	4.43	8.87	32.52	65.25
End year 3	7.39	14.78	53.21	106.77

Note: Blob storage costs for template files were ignored due to their negligible amount.

Table 10: Table Storage Costs

Costs per tenant	Space Cost (€)		Transactions Cost (€)		Total Cost (€)	
Redund.	LR	GR	LR	GR	LR	GR
End year 1	0.13	0.19	0.05	0.05	0.19	0.25
End year 2	0.40	0.58	0.05	0.05	0.46	0.63
End year 3	0.67	0.97	0.05	0.05	0.73	1.02

Note: LR (Local Redundant); GR (Geo Redundant); Redund.(Redundancy)

Table 11: Compute Costs

End year	Clients migrated	Number of VMs (WeR)	Number of VMs (WoR)	Storage Costs (LR) (€)
1	80	5	2	946
2	80	14	5	3,548
3	80	24	8	7,805
		Storage Costs (GR) (€)	Compute Costs (WS) (€)	Compute Costs (IP) (€)
1	80	1,898	11,181	4,473
2	80	7,118	31,307	11,181
3	80	15,660	53,669	17,890

Note: WeR (Web Role); WoR (Worker Role); LR (Local Redundant); GR (Geo Redundant); WS (Web Server VMs);IP (Image Processing VMs).

The use case we present in this paper involves a significant image-processing component resulting in high upload- and download- volumes and the in-cloud processing of images. The most critical challenge at the architectural level was to select the optimal Virtual Machine type from the available types on the Azure platform; we carried out a benchmark study of the performance of the different "flavors" of the role VMs, when running the data layer functions of the new application. The costs presented in Tables 9, 10, and 11 are based on the D2-v2 VM type which represented the best trade-off between TCO and SLA requirements on the basis of the average tenant usage. Among different TCO components, compute is by far the most significant (€129,701), and also the most fluctuating resource (see Figure 2). As such, its efficient and effective usage should be the main concern of the SP. Storage, as predicted, is relatively stable and predictable with essentially fixed costs (see Figure 3), and accounts for a very tiny portion of the TCO (€293.31 – 0.001%).

The heavy image processing, results in higher-than-normal network bandwidth and storage requirements. As a consequence, the observations should also hold for applications with less data volume and would thus cover the majority of typical transactional business applications.

Note that these pragmatic/empirical observations stem from experiments in a live feasibility study, and have been implemented on the basis of the following assumptions:

- The existing deployment does not include any data caching which would obviously reduce the CPU overhead and data storage access costs.
- No optimization of the queries to the table service to optimize CPU load over the TCO estimation period.
- No performance tuning on the application and/or on the platform during the TCO estimation period.
- There is no smoothing effect of multiple tenants sharing the same application compute resources.

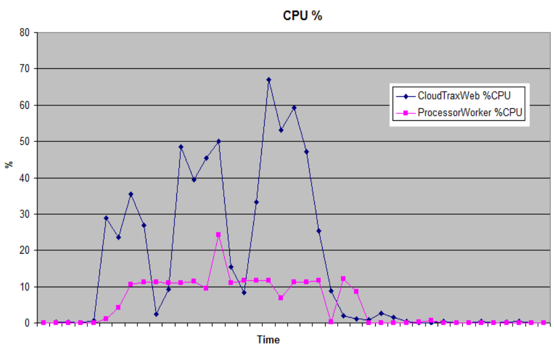

Figure 2 Compute Usage Over a Twenty-Minute Monitoring Period

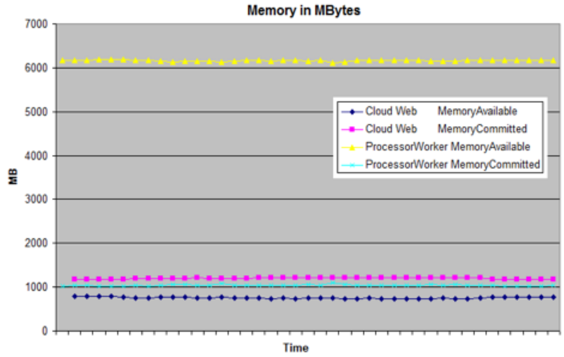

Figure 3 Storage Usage Over a Twenty-Minute Monitoring Period

7 CONCLUSIONS AND FUTURE DEVELOPMENTS

Research has covered costing and migration separately. Our literature review did not identify a detailed framework that integrated both costing and software architecture within a cloud migration scenario. An investigation linking architectural decisions and the impact on costing in cloud migration is therefore important and this paper makes an initial contribution in this context (Li et al., 2011). We have identified the major components and integrated them into an integrated framework to estimate the cost of hosting a SaaS application on an IaaS or PaaS platform, and to use this as the basis of a SaaS licensing model. As a generic, formalized model cannot exist due to the differences in factors and account types between the IaaS/PaaS providers, our aim was to identify the factors influencing this calculation and to illustrate this through a real case study.

No single formula, which allows right-scaling and right-pricing to be easily determined, was identified in our literature review. In this paper, we propose:

- An approach for cost estimations in cloud migration.
- Heuristics for providing better estimation accuracy.
- An experimental determination of usage and cost patterns for reliable cost.

We have focused on a business-to-business SP thus our conclusion is not directly generalizable to business-to-consumer SPs and consumer buyers. Similarly, we have focused on migration and operational costs as the primary cost unit and fees paid as the main components of the cost of ownership. Cloud adoption, like all IT investments, results in direct tangible costs such as cloud resources but also in intangible costs, e.g., change management, vendor management, risk mitigation etc. (Misran and Mondal, 2011). We sought to explore and illustrate a relatively simple but practical process for cost estimation in cloud migration targeting small and medium enterprises. Further studies may account for more complex models suitable for larger and more mature organizations. Similarly, we limited our case study to one cloud service provider and a small number of services. Future studies may seek to compare functionality, quality and costs, but this stage has been neglected in the literature (Gilia and S. Sood, 2013).

From an architecture perspective, container technology and micro-service style architectures are an increasing feature in the enterprise cloud and are impacting cloud-native architectures. New provisioning and payment models moving away from pay-per-hour models towards payment by business cycles are emerging in PaaS, linking the SaaS provisioning costs for the software producer with the platform.

Cloud service providers are also innovating in ways that will impact how software producers conceptualize costs and pricing. For example, AWS Lambda is a compute service where code is uploaded and the Lambda service executes the code using the AWS infrastructure. The uploaded code is used to create a so-called Lambda function. The AWS Lambda service then handles provisioning and managing the servers to run the code. The charging model is innovative in that the user is charged based on the number of requests for the software producers functions and the time the software producer code executes. Google has recently announced a similar Cloud Functions model. These initiatives are too recent to allow a deeper analysis of concerns. However, they are worthwhile future research.

Our work shows that an integrated perspective accommodating architecture, cost and revenue is needed and that the traditional TCO approaches cannot be applied without adaptation. Our paper highlights the need for collaboration between business, accounting and computer science researchers in order to understand the implications for costing, pricing and software design in the cloud computing context. This may require not only adaptation in common activity-based and resource-based costing methodologies but also in software and systems design.

ACKNOWLEDGEMENTS

The research work described in this paper was supported by the Irish Centre for Cloud Computing and Commerce, an Irish National Technology Centre funded by Enterprise Ireland and the Irish Industrial Development Authority.

REFERENCES

Andrikopoulos, V., Song, Z. and Leymann, F., 2013. Supporting the migration of applications to the cloud through a decision support system. *IEEE Sixth International Conference on Cloud Computing*.

Anwar, A., Sailer, A., Kochut, A., Schulz, C.O., Segal, A. and Butt, A.R., 2015. Cost-Aware Cloud Metering with Scalable Service Management Infrastructure. *CLOUD*, IEEE, pp. 285-292.

Armbrust, M., Fox, A., Griffith, R., Joseph, A.D., Katz, R., Konwinski, A., Lee, G. Patterson, D., Rabkin, A., Stoica, I. and Zaharia, M., 2010. A view of cloud computing. *Communications of the ACM*, Vol. 53, No. 4, 2010, pp.50-58.

Baden-Fuller, C. and Haefliger, S., 2013. Business models and techno-logical innovation. *Long range planning*, Vol. 46, No. 6, 2013, pp.419-426.

Bain and Company, 2017. The Changing Faces of the Cloud. Available from: http://www.bain.com/publications/articles/the-changing-faces-of-the-cloud.aspx [January 25, 2017].

Berman, S.J., Kesterson-Townes, L., Marshall, A. and Srivathsa, R., 2012. How cloud computing enables process and business model innovation. *Strategy & Leadership,* Vol. 40, No. 4, pp.27-35.

CFO Research, 2012. The Business Value of Cloud Computing: A Survey of Senior Finance Executives. CFO Publishing. Available from: http://lp.google-mkto.com/rs/google/images/CFO%2520Research-Google_research%2520report_061512.pdf [June, 2012].

DaSilva, C.M., Trkman, P., Desouza, K. and Lindic, J., 2013. Disruptive technologies: a business model perspective on cloud computing. *Technology Analysis & Strategic Management*, Vol. 25, No. 10, pp. 1161-1173.

Dillon, T., Wu, C. and Chang, E., 2010. Cloud computing: issues and challenges. *IEEE international conference on advanced information networking and applications*, pp. 27-33.

Durkee, D., 2010. Why Cloud computing Will Never Be Free. *Communications of the ACM*, Vol. 53, No. 5, 2010, pp. 62-69.

Ferrante, D., 2006. Software Licensing Models: What's Out There?. *IT Professional*, Vol. 8, No. 6, pp.24-29.

Filiopoulou, E., Mitropoulo, P. and Tsadimas, A., 2015. Integrating cost analysis in the cloud: A SoS approach. *11th International Conference on Innovations in Information Technology (IIT)*.

Giardino, C., Bajwa, S.S., Wang X. and Abrahamsson, P., 2015. Key Challenges in Early-Stage Software Startups. *XP Conference 2015*.

Gilia, P. and Sood, S., 2013. Automatic Selection and Ranking of Cloud Providers using Service Level Agreements. *International Journal of Computer Applications*, Vol. 72, No. 11, pp. 45-52.

Han, Y., 2011. Cloud computing: case studies and total costs of ownership. *Information technology and libraries*, Vol. 30, No. 4, pp. 198-206.

ISACA, 2012. Calculating Cloud ROI: From the Customer Perspective. Available from: https://www.isaca.org/knowledge-center/research/researchdeliverables/pages/calculating-cloud-roi-from-the-customer-perspective.aspx.

Jamshidi, P., Ahmad, A. and Pahl, C., 2013. Cloud Migration Research: A Systematic Review. *IEEE Transactions on Cloud Computing*, Vol. 1, No. 2, pp. 142-157.

Jamshidi, P., Pahl, C., Chinenyeze, S. and Liu, X., 2014. Cloud Migration Patterns: A Multi-Cloud Service Architecture Perspective. *International Workshop on Engineering Service Oriented Applications* - WESOA14.

Jinesh, V., 2010. Migrating your existing applications to the aws cloud. A Phase-driven Approach to Cloud Migration. Available from: http://docs.huihoo.com/amazon/aws/whitepapers/Migrating-your-Existing-Applications-to-the-AWS-Cloud-October-2010.pdf.

Leimbach, T., Hallinan, D., Bachlechner, D., Weber, A., Jaglo, M., Hennen, L., Nielsen, R.Ø., Nentwich, M., Strauß, S., Lynn, T. and Hunt, G., 2016. Potential and Impacts of Cloud Computing Services and Social Network Websites. Science and Technology Options Assessment (STOA). Available from: http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/513546/IPOL-JOIN_ET(2014)513546_EN.pdf. [15 August 2016].

Li, X., Li, Y., Liu, T. Qiu, J. and Wang, F., 2009. The Method and Tool of Cost Analysis for Cloud Computing. *2009 IEEE International Conference on Cloud Computing*, pp. 93-100.

Li, H., Zhong, L., Liu, J., Li, B. and Xu, K., 2011. Cost-effective partial migration of VoD services to content clouds. *IEEE International Conference on Cloud Computing*, pp. 203-210.

Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J. and Ghalsasi, A, 1999. Cloud computing The business perspective. *Decision support systems*, Vol. 51, No. 1, pp.176-189.

Martens, B., Walterbusch, M. and Teuteberg, F., 2012. Costing of cloud computing services: A total cost of ownership approach. *45th Hawaii International Conference on System Science (HICSS)*.

Misra, S.C. and Mondal, A., 2011. Identification of a company's suitability for the adoption of cloud computing and modelling its corresponding Return on

Investment. *Mathematical and Computer Modelling*, Vol. 53, No. 3, pp. 504-521.
Pahl, C. and Xiong, H., 2013. Migration to PaaS Clouds - Migration Process and Architectural Concerns. *IEEE International Symposium on the Maintenance and Evolution of Service-Oriented and Cloud-Based Systems*, pp. 86-91.
Strebel, J. and Stage, A., 2010. An economic decision model for business software application deployment on hybrid cloud environments. *Multikonferenz Wirtschaftsinformatik, MKWI 2010*.
Taibi, D., Lenarduzzi, V. and Pahl, C., 2017. Processes, Motivations and Issues for Migrating to Microservices Architectures: An Empirical Investigation. *IEEE Cloud 2017*.
Walterbusch, M., Martens, B. and Teuteberg, F., 2013. Evaluating cloud computing services from a total cost of ownership perspective. *Management Research Review*, Vol. 36, No. 6.

View publication stats