Costing of Cloud Computing Services: A Total Cost of Ownership Approach

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Abstract

The use of Cloud Computing Services appears to offer significant cost advantages. Particularly start-up companies benefit from these advantages, since frequently they do not operate an internal IT infrastructure. But are costs associated with Cloud Computing Services really that low? We found that particular cost types and factors are frequently underestimated by practitioners. In this paper we present a Total Cost of Ownership (TCO) approach for Cloud Computing Services. We applied a multi-method approach (systematic literature review, analysis of real Cloud Computing Services, expert interview, case study) for the development and evaluation of the formal mathematical model. We found that our model fits the practical requirements and supports decision-making in Cloud Computing.

1. Introduction

1.1. Motivation

According to Gartner's hype cycle of emerging technologies 2010, Cloud Computing has moved beyond the peak of inflated expectations and will be widely adopted by companies in about two to five years [17]. Due to the anticipated advantages of Cloud Computing, as e. g. high flexibility and low costs many companies do not analyze their decisions carefully [2]. This approach rises risk factors like for instance hidden costs or a vendor-lock-in [17] which discreate the pursued benefits. Thus, companies should conduct an ex ante analysis of direct and indirect costs to mitigate certain risk factors and to be aware of important cost types and factors.

In this paper we present a formal mathematical model for the calculation of the Total Cost of Ownership (TCO) of Cloud Computing Services. The TCO is one of the most important cost-oriented approach that is widely spread in both research and practice [22]. The main focus of our model lies in the identification and calculation of cost factors. More precisely, the model strongly support start-up companies that do not operate an internal IT infrastructure. The calculation results serve as decision support by evaluating Cloud Computing Services and providers on a cost basis. We based our model on the analysis of real Cloud Computing Services from our Cloud Computing research data base (www.CloudServiceMarket.info). Furthermore we conducted a systematic literature review with which we identified important cost types and factors. The TCO model is prototypically implemented on a website for further evaluation steps and is accessible for the general public. The software tool is able to analyze the cost structure of Cloud Computing Services and thus supports decision makers in validating Cloud Computing Services from a cost perspective. The presented multi-method approach extends the TCO theory and applies deductive and inductive methods to develop a theoretically and practically based model.

The paper is structured as follows. In the following section we define the term Cloud Computing and TCO. In Section 2 we discuss related work and the underlying research approach. Furthermore, Section 3 comprises the discussion of our model assumptions, the applied cost structure and the analysis of pricing schemes of real Cloud Computing Services. The mathematical TCO model is described in Section 4. The model is applied in a case study in Section 5 to show a practical example and to indicate possible values for the variables. A conceptual and technical evaluation is presented in Section 6 and we finally draw conclusions by means of limitations, implications and future research.

1.2. Defining Cloud Computing Services and Total Cost of Ownership

During the recent years the definition of the National Institute of Standards and Technology (NIST) became very popular in research and practice alike, since it provides a comprehensive overview: *"Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (for example, networks, servers, storage, applications, and services)* *that can be rapidly provisioned and released with minimal management effort or service-provider interaction."* [18]. The authors of this definition describe three service models in Cloud Computing: Infrastructure as a Service (IaaS), that include IT services as e. g. computing power and storage capacity; Platform as a Service (PaaS) that provide developer platforms and Software as a Service (SaaS), which include software services that are accessed through an internet browser [18].

To incorporate the majority of possible costs and cost categories of Cloud Computing Services we applied a Total Cost of Ownership (TCO) approach [22]. While traditional accounting approaches primarily aim at identifying the lowest possible costs, the benefits of the TCO approach lie in the improvement of customer-supplier communication and the analysis of the whole lifecycle of the IT artifact [7]. Furthermore, the TCO approach makes it possible to analyze the costs or individual cost components of an IT artifact by means of a predefined scheme. It virtually constitutes a mathematical representation of the "real world". However, it is not the purpose of TCO models (or of any model) to provide a 1:1 image of reality, but to deliver a simplified, abstract view [10]. Hence, instead of including all relevant costs into the TCO analysis, the complexity of reality can be reduced by working on the basis of assumptions and by including only a limited number of carefully selected cost factors. In spite of this limitation to selected cost factors the TCO model should be able to provide reliable decision support [6]. For a rigorous development of the TCO model we applied the following common requirements to TCO models [3,6,8,7]:

- *Transparency*: We provide an in-depth description of the model and the applied criteria.
- *Applicability*: The prototypical implemented software tool allows for an easy application of the TCO model with reasonable effort.
- *Variability*: The TCO model is standardized to a large extent, but central aspects are variable, so that desired changes or extensions of the model are possible.
- *Comparability*: The analysis results of the model are comparable to each other since we provide a predefined framework and transparency of the calculation scheme.
- *Decision Support*: Since calculated costs are structured according to cost types and factors, the model provides a sufficient basis for a comprehensive analysis. Decision-making processes are supported since the model provides significant information.
- *Status-Quo*: The formal model is based on current business practices (expert interview) and the state of the art of Cloud Computing (systematic literature review).

2. Theoretical Background

2.1. Related Work

To build this paper on a solid base, we applied the method of a concept-centric systematic literature review [24]. As a first step we define the review scope and concentrate on TCO and cost accounting in Cloud Computing. Key words for the search belong to the realm of Cloud Computing and include terms like "total cost", account*, combined with "cloud computing" and "as a Service". The applied wildcard assures the identification of related, conjugated terms. Next we applied these key words to scientific databases like EBSCO, Science Direct, SpringerLink and AISeL to receive scientific, peer-reviewed papers. To enlarge the number of papers we used forward (review of reference lists) and backward search (author-centric review).

Strebel and Stage [22] developed an economic decision model that compares costs for the internal IT infrastructure (server and storage expenses) and the external provisioning by means of Cloud Computing Services (fees for CPU hour, time contingent, storage, internet service provider costs and inbound and outbound data transfer costs). They present a formal cost model, an optimization model and a regression model that focus on the hybrid usage of internal and external infrastructure sources. Simulation runs are conducted with data from a case study. Their first finding is that Cloud Computing is more cost-effective the more business applications and processes are ready to source via a Cloud Computing Service. In contrast they find that the cost-effectiveness decreases with the number of virtualized applications, since internal servers can be used more effectively. However, they conclude that the application of Cloud Computing Services is beneficial for high storage requirements.

A cost-benefit analysis is applied by Kondo et al. [14] that focuses on IaaS. They compare Cloud Computing Services to volunteer computing applications like SETI@home and XtremLab. The benefit analysis concentrates on the system performance. Their overall finding is that in the long run volunteer computing is economically more beneficial but requires high start-up investments. For short and high performance tasks it is recommendable to apply a commercial Cloud Computing Service. Also, they just concentrate on particular cost factors (salaries, electricity, network, hardware, data storage and queries) in their approach.

While Strebel and Stage [22] as well as Kondo et al. [14] applied the company perspective on TCO in Cloud Computing Li et al. [16] focus on the provider perspective. They developed a software tool to calculate setting-up and maintenance costs for a Cloud (costs of hardware, software, power, cooling, staff and real-estate). Instead of focusing on physical hardware they concentrate on maximum virtual machines that can be deployed within a datacenter to react more flexible on customer demands. Moreover they emphasize the importance of fixed costs that providers need to bear during the whole lifecycle.

The results of the systematic literature review indicate that the topic of TCO in Cloud Computing has not been discussed extensively. For instance, several authors in this field argue that a rigorous and comprehensive TCO approach for Cloud Computing is important, since it can significantly lower the TCOs and corresponding risk factors [4]. However, they do not provide further information on how to develop such a model or tool. Furthermore, results from the field of Grid Computing that shares several features with the Cloud Computing paradigm focus on resource providers, omit storage costs and are scenario-specific (not generally applicable) [22]. To the best of our knowledge, we are the first one who develop a comprehensive TCO model that applies for IaaS, PaaS and SaaS, focuses on the particular features of these service models and include a wide range of cost types and factors.

2.2. Research Approach

The TCO model underwent several cycles of development. Figure 1 illustrates the process of development.

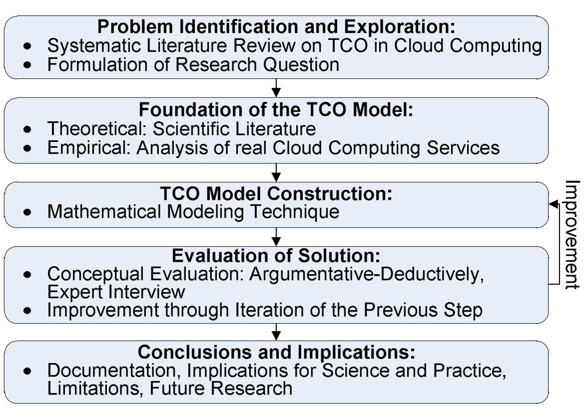

Figure 1. Underlying research approach for the construction of the reference model

It is based on a combination of deductive and inductive elements and draws on our own preliminary considerations, the results of the systematic literature review and the final iterative improvements by means of an expert interview [23]. At present, our research project passed the complete process. However further improvements for instance by means of model extensions and improvements will be conducted in additional iterations.

3. Preliminary Considerations for the Model Construction

3.1. Assumptions and Applied Cost Structure

For the further model development it is required to state some model assumptions. They simplify the model construction to meet the requirement of *applicability* and to focus on significant information and cost types.

1. Internal IT infrastructure for the internet connection as well as client PCs are available: Every employee has a computer connected to the internet. Thus, the costs of purchasing and operating the client PCs, as well as the cost of the network (e. g. routers, switches, network security) are not attributed to the TCO of a Cloud Computing Service.

2. A server infrastructure in the user company is not required: The focus of the analysis lies in the cost comparison of different Cloud Computing Services and service models. As a result, purchasing costs for servers are not considered in the model.

3. A change of a service provider corresponds to the first adoption of a Cloud Computing Service: If a provider change is taking place, it should be considered as a deployment of a new Cloud Computing Service. The reason for this is that the steps for the initial deployment of a Cloud Computing Service are the same as that of a change.

The cost structure and identification of cost types have been initially created on the basis of real Cloud Computing Services and the identified literature. Finally the results of the expert interview approved and extended our model. The identification approach follows a typical decision-making process starting with a strategic decision to source a Cloud Computing Service and ending with the backsourcing or discarding of a Cloud Computing Service [13]. Table 1 shows an overview of the different identified cost types, representing the single phases of the decision-making process, and corresponding cost factors, which are unique by item or cost type [9].

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Table 1. Cost types and descriptions

Cost Type	Description
Strategic Decision, Selection of Cloud Computing Services and Cloud Types [9,1,16,3] (str)	Strategic decision on sourcing a Cloud Computing Service: as-is analysis of the IT infrastructure and business applications, analysis of performance indicators, application of decision tools; choice of Cloud Computing Service type (IaaS, PaaS, SaaS or combinations); choice of Cloud type (Public, Private or Hybrid Cloud); definition of service requirements (as e. g. hardware configuration for IaaS, programming language support for PaaS and functionalities for SaaS).
Evaluation and Selection of Service Provider [14,9,1,3,5] (eva)	Search process for providers offering the desired service based on the previously defined requirements.
	Service evaluation and analysis: evaluation of the functionalities of Cloud Computing Services; identification of the best alternative.
	Evaluation of the provider and SLA analysis: determining the provider's reputation, analysis of the SLAs (quality of service) and of the security requirements (e. g. data recovery)
Service Charge [9,1,16,3] (char)	Pricing schemes vary depending on the service type and the provider. The service charge can be calculated on the basis of the pricing schemes.
Implementation, Configuration, Integration and Migration [5,1,9] (imp)	Implementation and configuration of the service, including, for example, access authorizations (creating groups and users including their specific rights).
	Integration into or merging with other systems and business processes. This includes the option of merging two Clouds into a hybrid Cloud.
	Migration of the system (porting of data)
Support [5,7,1,16] (sup)	Phone, email and ticket support and/or support via chat (instant messaging)
Initial and permanent training [5,8,7,1,14] (train)	Internal (by own employees) or external training (by third-party providers): User training and administrative training
Maintenance and Modification [14,16,22,7] (maint)	Modifying the service to guarantee operability
	Testing the service operability; configuration of settings; tariff changes
	Monitoring and Reporting: Performance and Cost management
	Service Level Management: testing whether the provider fulfills contractual obligations (aspects of service quality, as e. g. availability)
System Failure [9,5](fail)	Lost working time
	Contract penalty for non-delivery of services
	Loss of reputation
Backsourcing or Discarding [9,16,22] (bs)	Porting of data from the Cloud
	Reestablishment

3.2. Pricing Schemes of Cloud Computing Services

To construct a realistic and Cloud Computing specific model we conducted several analyses of Cloud Computing Service pricing schemes and distinguish between the IaaS, PaaS and SaaS service models. The selection of services for our analysis is based on our Cloud Computing Service data base which is publicly available on www.CloudServiceMarket.info and currently includes about 170 Cloud Computing Services. Additionally, we consulted several literature sources which list providers [15,20,21] and describes important cost factors [14,11,22]. For the construction of the model we identified and analyzed 15 services that appropriately describe the Cloud Computing market. The purpose of this analysis is to include a wide range of different pricing schemes which enables us to posit a general statement of pricing in Cloud Computing.

Starting with *IaaS*, it becomes evident that a wide range of different pricing schemes exist on the market. A list of the analyzed services is presented in Table 2.

Table 2. IaaS pricing schemes

Description (Provider, Cloud Computing Service Name and Characteristics of the Pricing Scheme)
Amazon Web Services: Elastic Compute Cloud (EC2) - Price per hour depending on RAM in GB, processing units, storage space in GB and platform (32-bit or 64-bit) - Optional reservation of further units - Price per transferred GB (outbound and inside to another Amazon Web Service)
Amazon Web Services: Simple Storage Service (S3) - Price per GB - Price per transferred GB (outbound); Inbound data transfer is free of charge - Price per 1,000 or 10,000 queries, respectively (PUT, COPY, POST or LIST)
AppNexus: AppNexus Cloud - Support provided at an hourly charge - Charges for the provision of a domain
Dropbox: Dropbox Cloud Storage Charges for stored GB only; inbound and outbound data transfer is irrelevant
EU Reservoir project: Open Nebula Open Source (Private Cloud or Hybrid Cloud)
FlexiScale: FlexiScale public cloud Purchase of so-called „units" which pay for computing power (depending on storage and number of CPUs), storage capacity and transferred GB (distinguishing between inbound and outbound data transfer); if MS Windows is installed on the server, further "units" are charged; for Linux there is no extra charge
Joyent: SmartMachines - Basic monthly price for a complete package (for example, 4 GB RAM, 50 GB storage capacity, 10 TB of outbound data transfer) - As soon as the maximum amount of transferred data is exceeded, charges are per GB - Extra storage capacity is available at an extra charge per GB and day - An SSL certificate is offered at an annual charge
Rackspace: cloudfiles Basic price per saved GB; price per transferred GB (inbound and outbound); price per query depending on the size of the file

Most providers offer hourly (usage-dependent), component-based rates. Some try to attract customers by a low price per GB of storage while charging hidden costs for inbound and/or outbound data transfer or even for data transfer within the provider's infrastructure. The approach of the provider FlexiScale is clearly different from those of the other providers looked at: here, so-called "units" serve as a currency in exchange for computing power etc. Particularly many providers offer basic packages at a fixed price which can be extended according to the user's needs (variable, usage-dependent costs in case the limits of the basic package are exceeded). It is also possible to pay a fixed price in order to get discounts on usage-dependent prices.

The results of Cloud Computing Services that can be assigned to *PaaS* are presented in Table 3. Basically, three different pricing schemes are distinguishable: free of charge services, complete packages and usage-dependent pricing. Furthermore, the category of usage-dependent pricing can be subdivided into pricing per user and component-based pricing. The type of service access is also subject to the provider's pricing policy.

Table 3. PaaS pricing schemes

Description (Provider, Cloud Computing Service Name and Characteristics of the Pricing Scheme)
Google: App Engine - Price per user - Maximum charge per month - Maximum amount of provided storage, data transfer, computing power and emails to customers; in case of limit extension or at request o additional storage, price per GB o increased data transfer, price per GB, distinguishing between inbound and outbound transfer o computing power, price per hour o emails to customers, price per recipient
LongJump: LongJump Platform - Monthly charge per user distinguishing between: data storage space per user and document storage space per user; gradual extension per user and month possible - There are extra charges for queries to the API in case the fixed amount of free queries is extended (charge per 1,000 queries) - Extra charge for every 30 minutes of telephone support
Microsoft: Azure - Price per processing hour - Price per GB of storage - Monthly charge per 100,000 transactions - Monthly charge per database, as distinguished by size of the database in GB - Transfer price per GB (inbound and outbound) - Monthly charge for connections to applications from different hosts - Monthly charge per 100,000 logins (secure access)
Zoho: Zoho Creator Complete packages, monthly charge (dependent on the number of users, number of database entries, backup function etc.)

Finally, the SaaS pricing schemes can be subdivided into the categories "free of charge" (non-binding and with obligatory registration) and "complete package at a fixed monthly charge". Compared to IaaS and PaaS the pricing schemes of the SaaS model are quite simple. The price of a complete package depends on the scope of services it includes and/or the number of users. Several services provided by Google are free of charge.

Table 4. SaaS pricing schemes

Description (Provider, Cloud Computing Service Name and Characteristics of the Pricing Scheme)
Google: Google Maps API Free of charge (after registration; in order to receive the API key)
MEEZA: Cloud Services Complete package (dependent on scope of services), monthly charge
Salesforce: Salesforce.com Complete package (dependent on scope of services), monthly charge per user

A closer look at the different types of Clouds shows that for the usage of services from a *Public Cloud* the service provider delivers the necessary resources [2]. The costs incurred depend on the particular pricing scheme. Their customers do not have any insight into the underlying IT infrastructure and have restrictive administrative rights. Hence, in case the hardware requirements are not sufficiently specified, the user needs to contact the provider's technical support before closing a contract. On the opposite and not in the focus of this study, a Cloud Computing Service can be defined to be delivered via a *Private Cloud* if the user and the provider of the service belong to the same organization or if a third party provides the service exclusively [2]. The former (same organization) is only the case if the service is implemented into an existing IT infrastructure, i. e. if an existing infrastructure – in a rented or a company-internal data center – is transformed to a Cloud Computing Service delivery environment. The costs incurred in the course of this process include the license costs of the implemented software as well as the costs of the underlying IT infrastructure that the user must provide for. The latter case (third-party provider) resembles the Public Cloud variety of IaaS in the sense that the user procures the resources from an IaaS provider. However, the provider does not administrate the data in a Public Cloud, but in an exclusive Private Cloud. Lastly, h*ybrid solutions* can be described as an aggregation of Public and/or Private Cloud varieties [2]. The total cost of a Hybrid Cloud equals the total or at least proportionate costs incurred by each individual solution that is associated to it. Also, the monetary expenses of aggregating the individual solutions need to be considered (provided the applied software enables the creation of a Hybrid Cloud).

4. Description of the Total Cost of Ownership Model

4.1. Basic Mathematical Approach

To fulfill the requirement of *transparency* of a TCO model, we start with a description of the general model design. This means that we firstly assign cost factors that influence the cost types and then present the general underlying formula design that is applied for each cost type. The assignment of the cost factors f to the identified cost types t is represented in Table 5.

Table 5. Cost types and related cost factors

Cost Type	Cost Factors
Strategic Decision, Selection of Cloud Computing Services and Cloud Types (str)	expenditure of time (eot), consulting services (cons), information for decision-making (inf)
Evaluation and Selection of Service Provider (eva)	expenditure of time (eot), consulting services (cons), information for decision-making (inf)
Service Charge *IaaS* (charIaaS)	computing power (cp), storage capacity (sto), inbound data transfer (inb), outbound data transfer (outb), provider internal data transfer (intdt), number of queries (que), domain (dom), SSL certificate (ssl), licence (lic), basic service charge (bsc)
Service Charge *PaaS* (charPaaS)	user-dependent basic charges (use), storage capacity [for the developer team] (sto), inbound data transfer (inb), outbound data transfer (outb), provider internal data transfer (intdt), extra user data storage capacity (udats), extra user document storage capacity (udocs), queries to the Application Programming Interface (api), sent emails (email), database (db), secured logins (seclog), connections with other providers' applications (con)
Service Charge *SaaS* (charSaaS)	access to the service system (acc), user (use)
Implementation, Configuration, Integration and Migration (imp)	expenditure of time (eot), porting process (port)
Support (sup)	expenditure of time (eot), support costs (sc), problem solving (ps)
Initial and permanent training (train)	preparation time of internal employees (prept), participating time of internal employees (part), instruction material (mat), external consulting services (cons)
Maintenance and Modification (maint)	expenditure of time (eot)
System Failure (fail)	loss per period (loss)
Backsourcing or Discarding (bs)	expenditure of time (eot), porting process (port)

The abbreviations of the cost factors are also applied within the mathematical model. To transform this result into a mathematical representation we define that the cost type $t \in T$ is subject to set T={str, eva, char, imp, sup, train, maint, fail, bs}. Additionally, cost factor $f \in F$ is subject to set F={eot, cons, inf, sto, cp, inb, outb, intdt, que, dom, ssl, bsc, udats, udocs, api, email, seclog, db, con, acc, port, sc, ps, prept, part, mat, loss}.

For our model we assume that the TCO of a Cloud Computing Service equals the sum total of all cost types: $\mathrm{TCO_{CCS}} = \sum \mathrm{C^t}$ (cf. Table 6, G.1). In the following, the total amount of a cost type t (shown in the exponent) equals the sum total of all involved cost factors f (shown in the index) (cf. Table 6, G.2). We consider the complete period of time during which a Cloud Computing Service has been used or is going to be used respectively. This period is subdivided into several (accounting) periods i. As a general rule, each period comprises one month, since this time period is mostly predetermined by the provider. The entire time period consists of n periods (cf. Table 6, G.3). Additionally, we introduce variable $a_{f,i}^t$ that represents the variable for consumed or required quantity in period i and $\mathrm{p_{f,i}^t}$ that characterizes unit costs or prices (cf. Table 6, G.4).

Table 6. General formulas

#	Formula
G.1	$TCO_{CCS} = \sum C^t$ with $t \in T$
G.2	$C^t = \sum C_f^t$ with $t \in T, f \in F$
G.3	$C_f^t = \sum_i^n C_{f,i}^t$ with $i = \{1, \dots, n\}, t \in T$ and $f \in F$
G.4	$C_{f,i}^t = a_{f,i}^t * \mathrm{p_{f,i}^t}$

4.2. Mathematical Modeling of Cost Types

Strategic Decision, Selection of Cloud Computing Services and Cloud Types (str)*:* The costs of strategic decisions and the selection of suitable Cloud Computing Services are made dependent on the expenditure of time (eot) necessary for decision-making (expressed in monetary terms). The expenses for information on which the decision may be based (inf), as e. g. scientific literature or market studies, as well as costs of external consulting services (cons). The total costs of the expenditure of time result from the total expenditure of time of all involved employees. It is determined by multiplying the employee's hourly salary $\mathrm{p_{eot,m}^{str}}$ by the expenditure of time $\mathrm{a_{eot,m}^{str}}$ and add up for all involved employees m: $\mathrm{C_{eot}^{str}} = \sum \mathrm{p_{eot,m}^{str}} * \mathrm{a_{eot,m}^{str}}$. Costs for decision-making incur in periods $\mathrm{i} < 1$. Furthermore, the total cost of purchased information materials (inf) can be described as the sum total of the prices of all purchased materials. Lastly, the costs of consulting services $\mathrm{C_{cons}^{str}}$ are summarized into a total, as illustrated in formula G.3 in Table 6. The cost factors of cost type str are finally add up: $\mathrm{C^{str}} = \mathrm{C_{eot}^{str}} + \mathrm{C_{cons}^{str}} + \mathrm{C_{inf}^{str}}$.

Evaluation and Selection of Service Provider (eva): The costs induced by the process of evaluating and selecting service providers depend on the amount of time that employees invest in this process (eot) and on the costs of external consultants that support this process (cons). The calculations for C_{eot}^{eva} and C_{cons}^{eva} are analogously conducted to C_{eot}^{str} and C_{cons}^{str}.

Service Charge for IaaS (charIaaS): For IaaS the service charge depends on the cost factors f that are presented in Table 5. The period-specific costs for used computing power are calculated by multiplying the number of used processing units $a_{cp,i}^{serIaaS}$ per period i by the price of one computing unit $p_{cp,i}^{serIaaS}$ within period i. The price varies according to the specific characteristics of the system, as e. g. RAM, the number of computing units, storage capacity (in GB), the used operating system (Linux or Windows) and the platform (32-bit or 64-bit). The total costs of this cost factor result from the addition of all induced costs during all periods n: $C_{cp}^{charIaaS} = \sum_{i=1}^{n} a_{cp,i}^{charIaaS} * p_{cp,i}^{charIaaS}$. This calculation scheme is also applied for storage capacity costs (sto), inbound (inb), outbound (outb) and internal data transfer (intdt) to other web services by the same provider and query costs (que). The total costs of a domain (dom), an SSL certificate (ssl), software license (lic) and basic service charges (bsc) are determined by multiplying the number of used periods n by the respective price p_f^t of the cost factor f of the respective cost type t: $C_{dom}^{charIaaS} = n * p_{dom}^{charIaaS}$.

Service Charge for PaaS (charPaaS): Again, we applied the cost factors listed in Table 5 for charPaaS. Firstly, service prices are regularly user-dependent basic charges and incur in period i. However, these costs frequently cannot exceed a maximum value $C_{useMAX}^{charPaaS}$ per period i: $C_{use}^{charPaaS} = \sum_{i=1}^{n} C_{use,i}^{charPaaS} = a_{use,i}^{charPaaS} * p_{use,i}^{charPaaS}$ with $(C_{use,i}^{charPaaS} \leq C_{useMAX}^{charPaaS})$. Storage capacity for the whole developer team is determined by $C_{sto,i}^{charPaaS}$ and calculated in the same way as for IaaS: $C_{sto,i}^{charPaaS} = a_{sto,i}^{charPaaS} * p_{sto,i}^{charPaaS}$. The same goes for the costs incurred by inbound and outbound data transfer. The basic service charge $C_{use,i}^{charPaaS}$ entitles every user to a certain amount of data and document storage that is user-dependent. This user storage may be increased for an extra charge per period i: $C_{udats}^{charPaaS} = \sum_{t=1}^{n} a_{use,i}^{charPaaS} * p_{udats,i}^{charPaaS}$. The costs of queries to the API can be determined by means of the following formula: $C_{api,i}^{charPaaS} = a_{api,i}^{charPaaS} * p_{api,i}^{charPaaS}$. The formula for the calculation of the overall costs of the cost factor computing power is the same for PaaS and IaaS. Furthermore, some providers charge a fee for sent emails whose amount depends on the number of messages: $C_{email}^{charPaaS} = \sum_{t=1}^{n} a_{email,i}^{charPaaS} * p_{email,i}^{charPaaS}$. The costs for databases (db), secured logins (seclog) and connections (con) to other providers' applications can be calculated by multiplying the number of occurrences of each cost factor f during period i by the respective price $p_{f,i}^{t}$: $C_{db}^{charPaaS} = \sum_{t=0}^{n} a_{db,i}^{charPaaS} * p_{db,i}^{charPaaS}$.

Service Charge for SaaS (charSaaS): Service charges for SaaS are often determined on the basis of an access price per period $p_{acc,t}^{serSaaS}$. Additionally they may also be dependent on the number of users $a_{acc,t}^{serSaaS}$. If this is not the case, this factor takes a value of 1 in our approach. The total costs of the period-dependent cost factor acc equals the sum total of all costs caused by this factor during all periods n: $C_{acc}^{charSaaS} = \sum_{i=0}^{n} a_{use,i}^{charSaaS} * p_{acc,i}^{charSaaS}$. Finally, the overall costs of the service charge for SaaS equal the sum of the total costs of all individual cost factors f. Due to the fact that the cost type charSaaS is dependent on one cost factor only, the total costs of the service charge for SaaS can be defined as: $C^{charSaaS} = \sum C_f^{charSaaS} = C_{use}^{charSaaS}$.

Implementation, Configuration, Integration and Migration (imp): The total costs of this cost type are dependent on the expenditure of time (eot) to fulfill the required tasks as e. g. implementation, configuration, integration and migration of services and data. An important cost factor in this category is the need of data porting from the customer to the provider (port). As mentioned, the providers charge their customers for inbound data transfer. The costs of the *initial* transfer of data to the Cloud for the purpose of system migration belong to this cost type. They are calculated by multiplying the data volume per unit (i. e. gigabyte) by the price of one unit. Some providers offer hard disk shipping services to input the customer's data. However, this approach does not focus on data volume but rather on the number of hard drives and data loading time. The cost factor "porting" is not made dependent on temporal price shifts because it is assumed that the data porting process can be completed within one period t: $C_{port}^{imp} = a_{port}^{imp} * p_{port}^{imp}$. The expenditure of time C_{eot}^{imp} is determined in the same way as C_{eot}^{str} (cf. G.3 in Table 6).

Support (sup): The cost type „Support" depends on the costs of support services via telephone, email, ticket systems or chat. It is assumed that the customer has access to the internet for reasons other than technical support (cf. assumption 1). Therefore this type of costs depends on the expenditure of time (eot) required for interactions with support personnel, as well as on occurred costs. However, some providers charge users on the basis of the time needed for problem solving and support. The cost factor C_{eot}^{sup} is calculated as described in the general formula G.3 in Table 6. The total support costs can be determined by multiplying the price of one unit by the total number of units required ($C_{sc}^{sup} = p_{sc}^{sup} * a_{sc}^{sup}$). Also, the problem solving costs depend on the number of units consumed and the price per unit ($C_{ps}^{sup} = p_{ps}^{sup} * a_{ps}^{sup}$).

Initial and Permanent Training (train): The total costs of the cost type „initial and permanent training" can be subdivided into internal training (staff members as coaches) and external training (third party coaches from outside the company). There can be several internal and external trainings. The costs of an internal training depend on the amount of preparation time invested by one or more employees (prept), the amount of time invested by participating employees (part) and the costs of instruction material (mat): $C_{int}^{train} = \sum C_{prept,m}^{train} + \sum C_{part,m}^{train} + C_{mat,m}^{train} = \sum(p_{prept,m}^{train} * a_{prept,m}^{train}) + \sum(p_{part,m}^{train} * a_{part,m}^{train}) + C_{mat}^{train}$. The total costs of an external training can be calculated by adding the costs of consultants who organize the training (cons), the amount of time that all employees invest in participating in the training (part) and the costs of instruction material (mat): $C_{ext}^{train} = \sum C_{cons}^{train} + \sum C_{part}^{train} + C_{mat,m}^{train} = \sum(p_{cons}^{train} * a_{cons}^{train}) + \sum(p_{part,m}^{train} * a_{part,m}^{train}) + C_{mat}^{train}$.

Maintenance and Modification (maint): This cost type depends on the expenditure of time (eot) for the general maintenance and for modifications made to the service implementation (C_{eot}^{maint}). The cost factor "tariff switch" is included here as well. If the prices have changed due to a tariff switch the new values for $p_{f,i}^{char*}$ need to be modified for this cost type and the relevant time periods i. A change of provider is defined as analogous to the implementation of a new Cloud Computing Service (cf. assumption 3) and is therefore not included in the formal model. The calculation of expenditure of time (eot) for the respective tasks is based on formula G.4 in Table 6.

System Failure (fail): The consequences of a system failure strongly depend on the interdependencies of services and business processes and their relevance to the business goals. Hence, the total costs of a system failure need to be stated for each company individually. Possible cost factors are, for example, loss of productive working time, contract penalties for delays or damage to the company's reputation which is hard to evaluate. Thus, we just introduce a general formula that represents the loss per period i (loss): $C_{loss}^{fail} = \sum_{i=0}^{n} a_{loss,i}^{fail} * p_{loss,i}^{fail}$.

Backsourcing or Discarding of the System (bs): The backsourcing of the system involves costs for the porting of data from the Cloud (port), as well as a certain expenditure of time (eot). However, the costs caused by the porting of data to another Cloud or by the migration to a different system are part of the TCO of the new service system, not of the TCO of the withdrawn Cloud Computing Service. The costs are determined in the same way as the costs for the porting of data to the Cloud ($C_{port}^{bs} = a_{port}^{bs} * p_{port}^{bs}$) and are also dependent on the necessary expenditure of time for the strategic decision to do so: $C_{eot}^{bs} = \sum p_{eot,m}^{bs} * a_{eot,m}^{bs}$.

5. Case Study

To illustrate the application of the presented TCO model, we introduce an example that deals with the provisioning of a public IaaS Cloud Computing Service. A start-up company that develops web platforms and services decides to source infrastructure services like computing, power and storage capacity from a Cloud Computing Provider. The advantages for the customer lie in the flexible cost accounting of Cloud Computing Services. For instance, in periods with low market demand for his services he can scale down the required systems.

Table 7. Cost types and related cost factors

Cost Type	Costs
Strategic Decision, Selection of Cloud Computing Services and Cloud Types (str)	Expenditure of time (eot): 16h * \$112 = \$1,792 Information for decision-making (inf): \$140
Evaluation and Selection of Service Provider (eva)	Expenditure of time (eot): 20h * \$112 = \$2,240
Service Charge *IaaS* (charIaaS)	Computing power (cp): 10mo * \$0.14 * 720h + 2mo * \$0.48 * 720h = \$1,412.6 Storage capacity (sto): 1,000GB * \$0.14 * 12mo = \$1,680 Outbound data transfer (outb): 199GB * \$0.12 * 12mo = \$286.56
Implementation, Configuration, Integration and Migration (imp)	Expenditure of time (eot): 50h * \$112 = \$5,600
Maintenance and Modification (maint)	Expenditure of time (eot): 2h * \$112 * 12mo = \$2,688
System Failure (fail)	Loss per period (loss): \$50 * 12mo = \$600
Sum per 12 month	*\$16,439.16*

In this case study the chosen Cloud Computing Provider (Amazon Web Services) has been identified in previews periods and the decision-maker wants to calculate the TCO of this particular provider. The strategic decision required 16 hours of work (average wages per hour for decision-maker and IT personnel: \$112) plus costs for information material amounting to \$140. Consulting services are to be omitted since costs should be kept down. Since the business processes are strongly dependent on the provider's performance the availability of the service is very important and was set to 99.99%. For the identification of a suitable provider he assumes 20 hours. Since the company is quite young the planning period just covers 12 month. Two month during this year are assumed to require a high level of computing power. Thus the provider charges 10 times a regular rate for two windows instances of $0.14 per hour and twice $0.48 per hour for peaks. In the first year 1 TB of storage capacity is required that costs $0.14 per GB. The data transfer will be 200GB per month ($0.12, charged by the second GB of data transfer). Since the company did not realize a Cloud Computing project yet, implementation efforts are quite high and estimated to 50 hours. Costs for inbound data transfer are not charged by the provider. Since support information for the provider's services are available in many internet forums the company subscribes to the lowest level of support that cost $50 per month. Costs for trainings are not accounted, for the new infrastructure will not change the business processes. The maintenance and modification efforts are estimated to be 2 hour per month. For the assessment of the system failure we assume a loss of $50 per month. The results of this case study are presented in Table 7.

6. Conceptual and Technical Evaluation

The conceptual evaluation of the cost model is based on an expert interview [23] and supported by the case study. The interviewee is experienced practitioner and academic with 5 years of work experience in the field of Cloud Computing. He managed a project for the implementation of a private Cloud that internally offers IaaS, PaaS and SaaS to their employees and customers. The required server infrastructure (150 physical server machines) is rented by means of a traditional IT outsourcing contract. Before starting the interview we briefly outlined the objective of our research. Following that, our developed artifact was discussed with a particular focus on completeness of cost types and factors, suitability and improvements. The results of the interview were documented and analyzed, and the model was refined and improved accordingly. The interviewee stated that the major issue of the TCO model is the disregard of a differentiation between private, public and hybrid Cloud. Since we focus exclusively on the calculation of TCOs for start-up companies we did not include this kind of differentiation. However, we are planning to include costs of existing IT infrastructure in future versions of the model. Furthermore, a general problem of TCO models is the pure cost perspective. The interviewee explicated that even in decisions on generic services like IaaS a quality check is important. Extensions of the model have been seen in costs for personal training. His advice aimed at including initial and permanent as well as internal and external training.

Since we based our model on related work and include insights from real Cloud Computing Service, we further approved the model conceptually by means of taxonomies of Cloud Computing Services [19,21,12] and an ontology [25]. The balance of the cost model with the aforementioned literature showed that all cost types included in the model were also mentioned in the literature.

For the purpose of technical evaluation a web-based, system-independent TCO software tool has been implemented, which makes the formal model of the TCO of Cloud Computing Services easy applicable. The software tool can be found on www.CloudServiceMarket.info/tools/tco.aspx.

7. Conclusions

In this paper we argue that the analysis of relevant cost types and factors of Cloud Computing Services is an important pillar of decision-making in Cloud Computing management. The IT artifact is presented in the form of a mathematical model and implemented on a website that is open for the general public. The TCO model has been evaluated by means of an expert interview, the result of the analysis of real Cloud Computing Services, a case study as well as scientific taxonomies and ontologies. During our research process we found that the evaluation and selection process of Cloud Computing Services is frequently conducted ad-hoc and lacks systematic methods to approach this topic. The presented method rises the awareness of indirect as well as hidden costs in Cloud Computing. Nevertheless, the TCO approach should be regarded as one part of a comprehensive IT cost management and as an additional method to evaluate a Cloud Computing Service.

Every mathematical approach has some limitations that need to be considered for its practical application. First, we made some restrictive assumptions that support us in taking a particular focus on Cloud Computing Services. Thus, we hide cost types that focus for instance on an existing internal IT infrastructure and their cost factors (cf. assumption 1 and 2). If a company plans to implement a private Cloud these additional cost types are necessary for a complete evaluation. Since our approach focuses strongly on the evaluation of Cloud Computing Services that are frequently provided externally, we feel that these assumptions simplify the cost evaluation approach and its applicability. Furthermore, we do not consider quality or functional aspects of Cloud Computing Services within our method.

Implications for the scientific community are aiming at several new fields that have not been discussed extensively in the scientific literature on Cloud Computing yet. For instance, we found that current work strongly focuses on risk and security aspects of Cloud Computing. However, we did not find an approach that combines risk and security aspects by means of an TCO approach. Additionally, benefits management in Cloud Computing is another new research field that can for instance be explored by means of cost-benefit analyses [14] in real world scenarios that reveal more insights on economic and managerial success factors in Cloud Computing. Additionally, further research can tackle some of the stated limitations. With regard to our TCO model we are planning to anonymously collect and store data that has been applied to the software tool. They can be statistically analyzed to better understand decision-making in Cloud Computing. Moreover, it is possible to include an AHP process for the evaluation of quality of service compared to the results of the TCO model.

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