DEDICATED VS. ON-DEMAND INFRASTRUCTURE COSTS IN COMMUNICATIONS-INTENSIVE APPLICATIONS

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Abstract: The deployment of cloud services promises companies a number of benefits, such as faster time to market, improved scalability, lower up-front costs, and lower IT management overhead, among others. However, deploying a cloud-based solution is a complex and often expensive process, which needs to be justified with a systematic analysis of the costs associated with alternative deployment options. This paper introduces a model for assessing the total costs of alternative software deployment options. Relevant cost factors for the model are identified based both on academic and practitioner literature. Assuming virtualized environment, the model employs the concept of a virtual central processing unit (vCPU) to represent a basic system construction block, to which different cost factors are allocated. By listing and aggregating relevant cost factors, the total costs are estimated and can be further used to compare the scenarios of shifting (elements of) software systems to a cloud. The analysis focuses on the case of communication-intensive services, where the network data transfer contributes the most to the overall service cost structure, whereas the contribution of other factors is assumed less significant. The cases of in-house, cloud-based and hybrid infrastructure deployment are compared. The results of the analysis suggest that in communication intensive applications, a single point of service is the most cost-effective, since it benefits from the economy of scale in purchasing communication capacity.

1 INTRODUCTION

As a part of vertical software industry evolution, a software industry is often transforming from in-house software development towards the acquisition of software products and services from independent software vendors (Tyrväinen et al. 2008; Mazhelis and Tyrväinen 2009). At the later stages of the evolution cycle, when the pressure to boost flexibility while minimizing the software-related costs increases, the traditional in-house software deployments are likely to be superseded by the on-demand software, provided as-a-service through cloud infrastructure (Luoma et al. 2010).

The deployment of cloud services promises companies a number of benefits, such as faster time to market and improved scalability (Youseff et al. 2008). The adoption of cloud is expected to provide also cost benefits in terms of lower start-up and/or operations costs (Weinman 2009a; Lee 2010).

However, contemporary services often rely on a highly complex infrastructure. Whether this infrastructure is deployed in-house, a cloud infrastructure is used, or a hybrid solution is adopted, it involves a number of inter-dependent elements. The resulting costs associated with alternative deployments depend on multiple, partially inter-dependent factors, making the comparison of these costs a non-trivial task. Therefore, a systematic analysis and comparison of the costs associated with alternative deployment options is needed, to justify the transition from a current deployment to a cloud-based one.

The outcome of such cost comparison may depend on multiple factors, such as:

- the computing requirements,
- the volume of network data transfer, and

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- the storage demands of the service.

Which of the factors affects the costs the most depends on the demands of a particular service. For computationally demanding services, the costs of computing are likely to become a decisive factor determining whether one or another alternative is the most cost-efficient. Similarly, for the services involving frequent and rich interaction with the customers, the bandwidth may become the critical decisive factors. For some services, the interplay of multiple factors needs to be taken into account when comparing the costs.

In this paper, we focus on the case when a single factor – namely, the volume of network data transfer – contributes the most to the overall service cost structure and therefore plays the major role in cost comparison, whereas the contribution of other factors to the overall costs is assumed less significant. The figure below provides a simplified outline of the service environment.

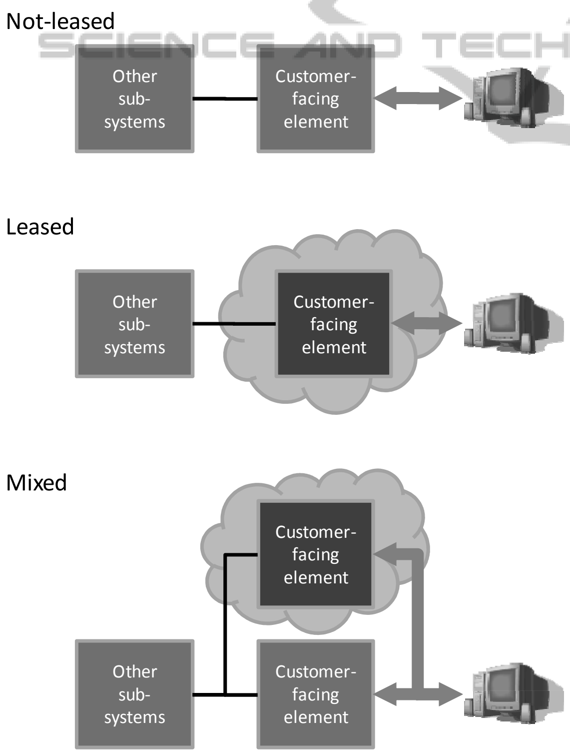


Figure 1: Alternative service deployment scenarios.

For simplicity, the service is decomposed only into two elements: the customer-facing element responsible for information exchange with the customers (e.g. a web-portal, a content-distribution server, etc.) and the other subsystems complementing the customer-facing element (e.g. business logics, databases, etc.). It is assumed that the interaction between the service side and the customer side requires substantial volume of data to be transferred, as depicted in the figure by using bold solid lines.

The question is formulated as: *Which of the three alternatives incurs the minimum overall costs to the provider of communication intensive services?*

In order to answer this question, the total costs of ownership (TCO) analysis is conducted. Namely, the cost structure of the service infrastructure is determined based on the available literature. After that, the cumulative costs of setting up and operating the service over the period of ownership are estimated, and the results of the estimation are used to compare alternatives.

The remainder of the paper is organized as follows. The details of the cost structure used in the TCO analysis are provided in Section 2. Section 3 describes how the individual cost factors can be estimated. In Section 4, a mixture of in-house (not-leased) and leased infrastructure is studied, in order to identify a combination with minimum TCO. The results of applying the model to assess the costs of a university content management system are reported in Section 5. Finally, concluding remarks are given in Section 6.

2 TOTAL COST OF OWNERSHIP

To confront the limitations of a simplistic costs analysis based on the acquisition price only, the total costs of ownership (TCO) analysis has been introduced as a systematic analytical tool for understanding the total costs associated with acquiring and using a good or service. The TCO analysis covers the key cost constituents of pre-acquisition, acquisition and possession, use, and disposal (Ellram 1993; Ellram 1995).

A number of cost-drivers can be potentially taken into account. For instance, Ferrin and Plank (2002) report 237 cost drivers grouped into 13 categories. The choice of cost factors to be considered depends on the particular industry: transportation costs, for example, are vital in logistics, whereas in the case of IT services these costs might be ignored as less important. According to David et al. (2002), the IT costs factors include the acquisition, operations, and control costs – with the latter being optional costs aimed at improving the IT centralization and standardization, which in turn results in reducing operations costs.

The costs relevant for the cloud-based services are listed below; these were identified based on

(David et al. 2002; Ferrin and Plank 2002; Murray 2007):

1. Pre-acquisition costs
   - Costs of evaluating features and gap analysis
   - SLA analysis, reviewing provider's security
2. Acquisition costs:
   a. Infrastructure, software
   - Hardware: servers, workstations, network and security infrastructure
   - Infrastructure and application software
   b. Integration and deployment
   - Requirements identification and software configuration
   - Integration software development or/and acquisition
   - Data conversion/migration
   - User training
3. Operations costs:
   a. External support
   - Hardware support and maintenance
   - Software support & maintenance
   b. Fees for using on-demand (cloud) services
   - Storage costs
   - Data transfer costs
   - Computing costs
   c. Others
   - Administering and operating the system
   - Power consumption costs
   - Facility (premises) maintenance and rent
   - Training, auditing, downtime, security incidents
4. Control costs (centralization and standardization)

Table 1: Cost factors.

Cost	Own deployment	Cloud deployment	Mixed
Acquisition costs			
Hardware	a_1	b_1	d_1
Software	a_2	b_2	d_2
Operations costs			
Hardware support & maintenance	a_3	b_3	d_3
Software support and maintenance	a_4	b_4	d_4
Storage	a_5	b_5	d_5
Data transfer	a_6	b_6	d_6
Computing	a_7	b_7	d_7
Administering & operating	a_8	b_8	d_8
Power consumption	a_9	b_9	d_9
Facility maintenance & rent	a_{10}	b_{10}	d_{10}

The premises are assumed to be leased rather then owned; therefore, the costs of facility maintenance and rent are estimated instead of the premise acquisition costs. For simplicity, in what follows, only acquisition and operations costs are considered, whereas the pre-acquisition and control costs are omitted. Furthermore, the integration and deployment costs (2b) as well as some other cost factors (namely, training, auditing, downtime, and security incidents) for the sake of simplicity are excluded from further consideration. The remaining ones are collected in Table 1. Along with the cost factors, the table contains the notations used for these factors in three deployment scenarios.

3 COST FACTOR ESTIMATION

Ellram (1995) describes two approaches to TCO evaluation: dollar-based and value-based approaches. In dollar-based approach, either actual cost of TCO constituents are used, or a formula is applied to estimate the costs of each activity. Dollar-based TCO analysis may be also based on formal analytical models of pre- and post-acquisition costs: mixed integer linear programming model (Degraeve and Roodhooft, 1999); data envelope analysis (Garfamy, 2006; Ramanathan, 2007). These analytical models are particularly useful in supplier selection for tangible assets, while their application in the context of software products and services appears challenging. The value-based approach is used when costs cannot be directly quantified. In this approach, costs are complemented with qualitative performance indicators which are transformed to quantitative values. Such transformation takes into account weights of variables and requires significant efforts for fine-tuning.

In this work, the dollar-based approach is followed. Thus, for the purposes of the analysis, the values of the factors should be either:

- estimated based on the real expenses as incurred in the organization;
- approximated based on expert knowledge; or
- approximated based on the trends and reference values reported in the literature.

Below, the cost estimation for the customer-facing element of the service is discussed for all three deployment scenarios. No cost estimation is done for the rest of the service infrastructure, since it is assumed to remain constant in all three scenarios and hence will not affect the results of the comparison.

3.1 "Own" Deployment Scenario

Let us assume that the "own" deployment is either currently state-of-the-art, or are extensively described in literature. Therefore, for this scenario, a majority of variables can be estimated based on the real expenses or based on the estimates found in the literature.

It should be noted that storage fee (a_5) and computing fee (a_7) are likely to be zero in this scenario. Furthermore, hardware and software maintenance costs can be approximated as a percentage of the hardware and software maintenance costs. For instance, yearly hardware support costs can be assumed to be 20% of the hardware acquisition costs (Murray 2007).

Thus, the variables to be assigned based on real expenses/literature include the costs of hardware and software acquisition (a_1, a_2), data transfer (a_6), as well as the costs of administration/operating, power, and facility costs (a_8, a_9, a_{10}). It should be noted that the data transfer costs (a_6) reflect the charges paid to a communication service provider for allocated bandwidth, i.e. the high-bandwidth last-mile access is assumed to be available.

Hardware acquisition costs (a_1). Nowadays, many organizations utilize a virtualized environment, wherein servers are implemented as *server instances* running on virtual CPUs (vCPUs). In such environment, multiple servers are sharing the same underlying hardware, thus making it difficult to estimate the costs of individual instances directly. In order to address this problem, the vCPU costs can be estimated as follows.

For each instance, its hardware requirements are stated, and the number of vCPUs to fulfill these requirements is estimated. Assuming homogeneous vCPU, the number of vCPUs can be estimated as

$$n_{\mathrm{vCPU}} = \left\lceil \max\left(\frac{r_{\mathrm{m}}}{v_{\mathrm{m}}}, \frac{r_{\mathrm{d}}}{v_{\mathrm{d}}}, \frac{r_{\mathrm{c}}}{v_{\mathrm{c}}}\right) \right\rceil, \quad (1)$$

Where v_{m}, v_{d}, and v_{c} are memory, disc space, and computing resources of a single vCPU, and r_{m}, r_{d}, and r_{c} are the requirements of an instance.

The cost of a single vCPU is estimated, by aggregating the costs of virtualized hardware and dividing it by the total number of virtual machines. Finally, the server instance costs are estimated as a product of the number of vCPUs needed and the vCPU cost.

Software acquisition costs (a_2). Once the number of vCPU is known, the costs of software licenses per vCPU can be estimated. The total software acquisitions costs are then a product of per-vCPU software licenses costs and the number of vCPUs. It should be noted that some of the software products (such as the virtualization layer software) are allocated to blades rather than to a vCPU, and therefore their costs need to be accounted separately.

3.2 "Cloud" Deployment Scenario

The costs of hardware acquisition (b_1) and maintenance (b_3) are zero in the "cloud" scenario. Depending on the software used, the costs of software licenses acquisition (b_2) and software support (b_4) may be zero (the case of open source), equal to the software costs in the "own" deployment scenario (the same software is used in the cloud), or in between. Also such a case can be envisioned, where different (and more expensive) software needs to be used in cloud due to the limitations of the cloud platform; this case is not considered here.

The costs of storage, data transfer, and computing depend both on the requirements of the service, and on the pricing of the cloud infrastructure providers. Specifically, based on the service requirements, the offerings of multiple cloud infrastructure providers are retrieved, the least expensive offering meeting the requirements is identified, and the corresponding values are used to assign the values to the storage (b_5), data transfer (b_6), and computing (b_7) costs.

Administering/operating costs (b_8) are roughly equal to the administering/operating in the "own" deployment scenario – the same personnel is assumed to administer the service infrastructure, whether it is deployed in-house or in the cloud. Since no hardware is used, the power and facility costs (b_9, b_{10}) are likely to be negligibly small and are therefore assigned 0.

3.3 "Mixed" Deployment Scenario

In the mixed deployment scenario, a part of the customer-facing element functionality is kept in house, while the remainder is allocated to the cloud-based infrastructure. This results in the following changes, as compared with the two deployment scenarios above.

First, data may need to be replicated in-house and in the cloud. Depending on the specifics of the service, it may be possible to divide the data among in-house and cloud infrastructure, but for simplicity it is assumed that complete replica of data needs to be presented in both locations. Thus, the costs of data storage (d_5) are equal to the data storage costs in the "cloud" deployment scenario.

Second, a part of the data communication with the customers is carried out in-house (by the in-house customer-facing element), while the rest is done by the cloud. Let q $(0 \leq q \leq 1)$ denote the portion of data transferred through the in-house customer-facing element, and let u denote the total volume of the traffic. The data transfer costs d_6 can be represented as a function $f_6(q, u)$; the details of this function will be discussed below.

Finally, a part of computing is performed with in-house (virtualized) infrastructure, while the rest is performed in the cloud. Both the computing demands and the volume of data transferred grow proportionally with the number of customers served. It is therefore reasonable to assume that q portion of computing power is assigned to the in-house infrastructure, whereas the rest (i.e. $1-q$) is assigned to the cloud.

Hardware Acquisition and Maintenance Costs. Only the portion of the hardware deployed in-house incurs costs. Therefore, the hardware costs d_1 and d_3 can be estimated as $d_1 = qa_1$ and $d_3 = qa_3$ respectively.

Software Acquisition and Maintenance Costs. A portion of software is used by the in-house hardware, and the rest is used in the cloud. Since the need for software licenses change with the vCPUs used in-house and in the cloud, the software acquisition costs can be estimated as

$$d_2 = qa_2 + (1-q)b_2; \quad (2)$$

$$d_4 = qk_1a_2 + (1-q)k_2b_2. \quad (3)$$

Data transfer costs. In total, $u_{\text{own}} = uq$ bytes are transferred through in-house infrastructure, and $u_{\text{cloud}} = u(1-q)$ bytes of data are transferred through the cloud. Let $p_{\text{own}}(u_{\text{own}})$ denote the price of one byte of data transferred via in-house infrastructure, and $p_{\text{cloud}}(u_{\text{cloud}})$ denote the price of one byte transferred through the cloud. The volume is included as a parameter in the brackets in order to emphasize the fact, that the data transfer price per byte depends (in fact, decreases with the growth of) the overall volume. Then, the data communication costs can be estimated as:

$$\begin{aligned} d_6 = f_6(q,u) \equiv u_{\text{own}}\, p_{\text{own}}(u_{\text{own}}) \\ + u_{\text{cloud}}\, p_{\text{cloud}}(u_{\text{cloud}}). \end{aligned} \quad (4)$$

The values of the cloud data transfer price $p_{\text{cloud}}(u_{\text{cloud}})$ can be derived from the offerings of the cloud infrastructure providers. In order to approximate the in-house data transfer costs, the dependency between the data volume and the price need to be determined. In this work, the following function is used in order to approximate this dependency:

$$p = c_1 u^{c_2}, \quad (5)$$

where c_1 and c_2 are empirically estimated from reference values. For instance, by using the reference values from http://www.prospeed.net/, the c_1 and c_2 can be estimated as $c_1 = 112.77$ and $c_2 = -0.22$ respectively.

Computing costs. Only the computing performed in the cloud incurs costs. Therefore, the computing costs d_7 can be estimated as $d_7 = (1-q)b_7$.

Administration/operating, power, and facility costs. As in the "cloud" deployment, the same personnel can be assumed to carry out the tasks, i.e. $d_8 = a_8$. The power and facility costs are assumed to be proportional to the in-house computational load and data transfer, which are manifested in the q value, i.e. $d_9 = qa_9$ and $d_{10} = qa_{10}$.

The estimators for different cost factors are summarized in Table 2. The factors whose values need to be assigned based on the real expenses or literature are shown in bold; the majority of such factors belong to the "own" deployment scenario. The factors in the "cloud" deployment are assigned based on the offerings of the cloud infrastructure vendors. The other costs can then be derived from these values.

The total costs of a deployment scenario are estimated as a sum of the cost factors constituting the scenario. It is assumed that the acquisition costs are incurred only once, whereas the operations costs are reoccurring on yearly basis. Then, for n years of ownership, the total costs are estimated for different scenarios as:

$$C_{\text{own}} = \sum_{i=1}^{2} a_i + n \sum_{i=3}^{10} a_i\,; \quad (6)$$

$$C_{\text{cloud}} = \sum_{i=1}^{2} b_i + n \sum_{i=3}^{10} b_i\,; \quad (7)$$

$$C_{\text{mixed}} = \sum_{i=1}^{2} d_i + n \sum_{i=3}^{10} d_i. \quad (8)$$

4 COMPARING THE DEPLOYMENT SCENARIOS

As described in the previous section, the costs in the "mixed" deployment scenario depend on the value of q indicating how large portion of data transport and computing is allocated to the in-house service infrastructure. In fact, the "mixed" scenario can be seen as a general case, with "own" and "cloud" being the special cases for $q = 1$ and $q = 0$ respectively. In this section, the effect of q on the overall costs in the "mixed" deployment scenario is studied, with the aim to identify the value of q at which the overall costs would be minimized.

In order to find the value of q corresponding to the minimum of C_{mixed}, the first and the second derivatives of C_{mixed} are considered:

$$C'_{\text{mixed}}(q) = \sum_{i=1}^{2} d'_i(q) + n \sum_{i=3}^{10} d'_i(q) = \\ = a_1 + a_2 - b_2 + n \times \\ (a_3 + k_1 a_2 - k_2 b_2 + f'_6(q,u) - b_7 + a_9 + a_{10}) \quad (9)$$

In the beginning of the paper, we assumed that the costs of network data transfer contributes the most to the overall service cost structure, i.e.

$$d_6 = f_6(q,u) \gg d_i, \\ i \in \{1,2,3,4,5,7,8,9,10\}. \quad (10)$$

Therefore, when evaluating the derivative $C'_{\text{mixed}}(q)$, it is reasonable to focus on the term $nf_6(q,u)$, while the remaining part can be substituted with a constant c:

$$C'_{\text{mixed}}(q) = nf'_6(q,u) + c'. \quad (11)$$

As described in the previous section, the function $f_6(q,u)$ is defined as

$$f_6(q,u) = qu\, c_1 u^{c_2} + (1-q) \\ \times u p_{\text{cloud}}\big((1-q)u\big). \quad (12)$$

Let us assume that the pricing of a cloud infrastructure provider can as well be represented as a power function of the volume:

$$p_{\text{cloud}} = c_3 {u_{\text{cloud}}}^{c_4}. \quad (13)$$

The function $f_6(q,u)$ can now be rewritten as:

$$f_6(q,u) = qu\, c_1 (qu)^{c_2} + (1-q)u\, c_3((1- \\ qu)c4=c1qu1+c2+c3(u-qu)1+c4. \quad (14)$$

Then, the derivative $C'_{\text{mixed}}(q)$ is:

$$C'_{\text{mixed}}(q) = n \times [c_1(1+c_2)(qu)^{c_2} u + c_3(1+c_4) \\ \times (u-qu)^{c_4}(-u)] \\ = nu[c_1(1+c_2)(qu)^{c_2} \\ - c_3(1+c_4)(u-qu)^{c_4}]. \quad (15)$$

The function C_{mixed} has an excess when $C'_{\text{mixed}}(q) = 0$, i.e. when

$$c_1(1+c_2)(qu)^{c_2} = c_3(1+c_4)(u-qu)^{c_4}. \quad (16)$$

When $c_1 = c_3$ and $c_2 = c_4$, it follows that $C'_{\text{mixed}}(q) = 0$, when $q = 0.5$.

Similarly, the second derivative $C''_{\text{mixed}}(q)$ can be evaluated as

$$C''_{\text{mixed}}(q) = nu \times [c_1(1+c_2)c_2(qu)^{c_2-1}u \\ + c_3(1+c_4)c_4(u \\ - qu)^{c_4-1}u] > 0. \quad (17)$$

The second derivative is positive for all values of $q \in [0,1]$. Thus, the function $C_{\text{mixed}}(q)$ is concave, and hence the minimum of the costs is achieved at one of the boundary values: $q = 0$ or $q = 1$. Which of them corresponds to the minimum costs depends on the values of the coefficients c_1, c_2, c_3, and c_4, as well as on the interplay of other costs (encompassed by the constant c). Therefore, in case the data transfer costs dominate in the service infrastructure cost structure, either "in-house" or "cloud" deployment options are cost-optimal, whereas higher costs are going to be incurred with the "mixed" deployment.

Table 2: Cost estimation.

Cost	"Own" deployment	"Cloud" deployment	"Mixed" deployment
Acquisition costs			
Hardware	$\boldsymbol{a_1}$	0	$d_1 = qa_1$
Software	$\boldsymbol{a_2}$	$\boldsymbol{b_2}$	$d_2 = qa_2 + (1-q)b_2$
Operations costs			
Hardware support and maintenance	$a_3 = k_1 a_1$	0	$d_3 = qa_3$
Software support and maintenance	$a_4 = k_2 a_2$	0	$d_4 = qk_1 a_2 + (1-q)k_2 b_2$
Storage	0	$\boldsymbol{b_5}$	$d_5 = b_5$
Data transfer	$\boldsymbol{a_6}$	$\boldsymbol{b_6}$	$d_6 = f_6(q,u)$
Computing	0	$\boldsymbol{b_7}$	$d_7 = (1-q)b_7$
Administering/operating	$\boldsymbol{a_8}$	$b_8 = a_8$	$d_8 = a_8$
Power consumption	$\boldsymbol{a_9}$	0	$d_9 = qa_9$
Facility maintenance/rent	$\boldsymbol{a_{10}}$	0	$d_{10} = qa_{10}$

5 CASE STUDY: A UNIVERSITY CONTENT MANAGEMENT SYSTEM

In this section, the costs of deployment options are compared for the case of university content management system based on Plone.

In this case, the "own" deployment assumes the acquisition of a Dell PowerEdge M610 server, and installing a stack of open-software on it, including Zope WWW-application server, Zope Object Database, Zope Enterprise Objects, Plone content management system, etc. (Ojaniemi 2010). The costs of hardware acquisition are estimated based on the price of the server as €4102. The current outbound data transfer volume is estimated at the order of 1TB/month, which, assuming the price of $0.11 (€0.078) per GB, corresponds to the costs of €80.

In future, with the increased proliferation of online teaching content, the data transfer volume may increase dramatically by the factor of 100, thus reaching 100TB/month and resulting in the monthly data transfer costs of €8023. On the other hand, in a hypothetical case of shifting the content provisioning to individual departments' infrastructure, the data volume of the university content management system may be decreased tenfold to 0.1TB/month, resulting in the data transfer costs of €8/month.

In the "cloud" deployment scenario, the computing requirements of the current service are assumed to be met by EC2 extra large instance. With the Amazon pricing, the data transfer costs for the current load are €109.4/month; in case of the increase to 100TB/month, the data transfer cost will rise to €7720.5/month; in case of the downscaling to 0.1TB/month, the cost will drop to €10,9/month.

When the load increases by the factor of x, the number of requests to the server(s) is also going to increase, but at a smaller pace, e.g. the by the factor of $\sqrt{x}$ – reflecting the assumption that the increase in load due to new type of content rather than new students. Then, the increased load would need to be served by $\sqrt{x}$ in-house servers ("own" deployment) or by $\sqrt{x}$ extra large instances ("cloud" deployment).

Based on Amazon pricing, the computing costs for the current service in "cloud" deployment comprise €222/month. For the increased load, the costs would rise to €2218. For the decreased load, the smaller computing power is required; assuming that the Amazon Large instance is sufficient, the monthly computing costs would decrease to €111/month.

For "own" deployment, the maintenance costs for the acquitted hardware are assumed to be 20% of the acquisition price. The other costs (including the costs of storage needed) are either assumed equal for both alternatives, or are assumed negligible.

The resulting costs are summarized in the table below, and the computing, bandwidth, and total costs accumulated over 3 years are visualized in Figure 2. As could be seen from the table, as soon as the data transfer costs represent the major cost constituent (which is the case with the increased data transfer), the "cloud" deployment option is less expensive than the "own" deployment. Furthermore, according to the discussion in the previous section, the cost of "mixed" scenario will be greater than the "cloud" deployment's costs in this case.

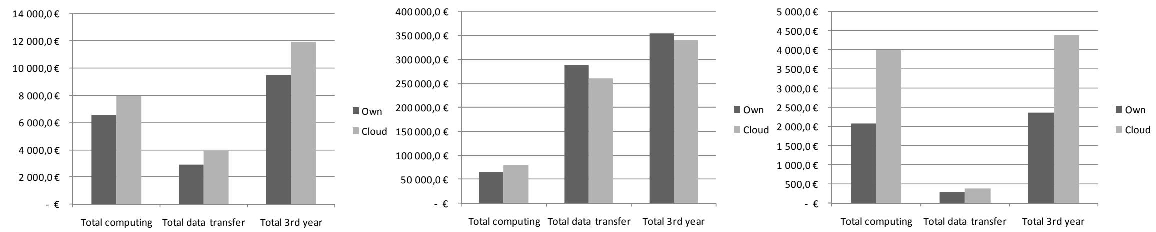
For the case with the current and the decreased data transfer, the contribution of the data transfer to the total costs is more significant. As a consequence, the result of the comparison is different: the "cloud" deployment option is more expensive. Primarily, this is due to the high costs of Amazon instances.

6 CONCLUSIONS

In this paper, a quantitative model for assessing the total costs of alternative software deployment options has been introduced, whereby the costs of

Table 3: Costs of the university management system.

Costs	Current data transfer		Increased data transfer		Decreased data transfer	
	"Own"	"Cloud"	"Own"	"Cloud"	"Own"	"Cloud"
Acquisitions	4 102,9 €	0,0 €	41 028,6 €	0,0 €	1 296,5 €	0,0 €
Computing	820,6 €	2 661,3 €	8 205,7 €	26 613,5 €	259,3 €	1 330,7 €
Data transfer	962,7 €	1 312,8 €	96 273,5 €	86 646,2 €	96,3 €	131,3 €
Total 1st year	5 886,2 €	3 974,2 €	145 507,8 €	113 259,6 €	1 652,1 €	1 462,0 €
Total 2nd year	7 669,5 €	7 948,3 €	249 987,0 €	226 519,3 €	2 007,7 €	2 923,9 €
Total computing	6 564,6 €	7 984,0 €	65 645,8 €	79 840,5 €	2 074,5 €	3 992,0 €
Total data transf.	2 888,2 €	3 938,5 €	288 820,5 €	259 938,5 €	288,8 €	393,8 €
Total 3rd year	9 452,8 €	11 922,5 €	354 466,3 €	339 778,9 €	2 363,3 €	4 385,9 €



a) Current load b) Increased load c) Decreased load

Figure 2: Comparing the computing, bandwidth, and total costs accumulated over three years for the "own" and the "cloud" deployments.

in-house service infrastructure can be compared with the cost of cloud-based infrastructure. Relevant cost factors for the model have been identified. Some of these factors are to be estimated based on the real expenses of expert opinion, while for the others, their values are derived from the already assigned variables.

The costs of the mixed scenario, wherein the computing and data transfer load is distributed between the in-house and cloud infrastructure have been analytically analyzed. According to the obtained results, either the "in-house" or the "cloud" deployment options, but not the "mixed" deployment are cost-optimal whenever the data transfer costs represent the major component of the infrastructure costs.

The usual assumption of mixed cloud being cost-effective in combining less expensive stable in-house capacity with use of cloud for handling demand peaks (Weinman 2009a) seems to be a somewhat limited view. That is, the assumption seems to hold mainly in computing intensive applications, where the additional relevant cost, including network bandwidth costs, are minor and hence can be ignored. Meanwhile, communication intensive applications are most cost-effective in a single point of service, which can make use of economy of scale in purchasing communication capacity. For these communication intensive cases, the mixed cloud solution has to bear the costs of two smaller communication pipes (for in-house and for the cloud), thus enforcing the use of higher costs of a unit of bandwidth applied to smaller capacity. Even if the communication cost between the in-house implementation and the cloud site neglected, such a mixed cloud is likely to be more expensive than the single point of service (Weinman 2009b).

This work has focused on costs of the communication intensive applications. Further work will still be needed to analyze costs related to various combinations of processing, data and communication intensive cases in mixed clouds.

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