Development of a Dedicated Calculator Supporting Decisions Regarding the Implementation of Virtualization and Cloud Computing Technologies

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Abstract

Proper operation of software requires increasingly larger memory resources and efficient IT equipment. Therefore, methods and technologies are being sought to optimize IT structures. One of the directions is virtualization and switching to cloud. These are methods of running multiple virtual computers or servers on a single hardware platform that supports multiple IT systems and applications. The implementation of these technologies means number of benefits, but also costs, including the need to purchase appropriate hardware, software and then maintain the system. Thus, a business decision to implement virtualization requires comprehensive supporting tools testing its financial and economical effectiveness. As an artifact of the research, a prototype of a calculator was developed to evaluate the effectiveness of virtualization, which can be measured using the TCO (Total Cost of Ownership) and ROI (Return On Investment) indicators. To achieve the research goal, the DSR (Design Science Research) method was used.

Keywords: virtualization, Cloud Computing, Green Computing, ROI, TCO

1. Introduction

The idea of virtualization was recently ignored in most digital transformation projects, especially in the area of optimizing the use of computer hardware. Virtualization is a method of running many virtual computers or servers on one hardware platform, without fear that the failure of one virtual component will automatically cause the others to fail. So, this software separates a real calculating unit into several virtual ones, any device can be simply used and handled [24]. This technology is easy to understand using the example of a virtual machine (VM): it is implemented when operating systems and applications are combined in various configurations to create virtual machines that are placed on a physical server that operates independently of the consolidated VMs [29]. While over the last dozen or so years new guidelines have appeared for software that requires more memory resources and IT hardware to function properly, virtualization has become an important technology on the ICT (Information and Communications Technology) services market and a response to the widespread complexity of systems and complicated IT architectures [26]. Virtualization technology is a very extensive topic that can be researched from not only the IT perspective, but also financial, economic, and ecological. The described technology is closely related to the concepts of CC (Cloud Computing), GC/GI (Green Computing/Green IT), CSR (Corporate Social Responsibility) and ESG (Environmental, Social, Corporate Governance). Only a holistic approach to discussing the topic will ensure a complete and comprehensive presentation of benefits from implementation of the virtualization technology.

In the era of the information society, there is no doubt that information tools and technologies should be used. The question remains: how should this be done to achieve the greatest effectiveness of use and how can this effectiveness be measured? The financial analysis

of an IT investment can be measured using indicators like TCO (Total Cost of Ownership) or ROI (Return On Investment) analysis. TCO analysis is used to assess current and forecast IT infrastructure costs in both options. It calculates all costs related to implementation and maintaining (or owning) IT technology by the enterprise. Measuring the effectiveness of virtualization technology is possible thanks to the use of ROI/TCO calculators, which transparently present the cost and benefits on investment incurred for transferring physical machines to a virtual environment. The ROI indicator determines the rate of return on investment as the ratio of profit to the initial investment outlay [17]. Profit in case of virtualization is understood as the difference in the costs of creation, operation and maintenance (for time *t*) between the physical and virtual environments [14]. The savings obtained from virtualization do not only refer to financial categories (e.g. lower investment outlays) but also to economic effects, where environmental efficiency appears to be a key factor. Virtualization is a way to reduce the costs of energy consumption and also reduces the amount of potential waste (e.g. e-waste). This fits into the idea of Green Computing and the widely developed CSR policy and ESG concept. Due to the length of the life cycle of IT systems, the introduced analysis period was 3 and 6 years ahead.

The aim of the research is to develop a prototype of an ROI/TCO calculator used to assess the effectiveness of virtualization technologies (as well as Cloud Computing services) and to indicate the level of carbon dioxide emissions. The process of creating the tool through practical verification, assessment and validation in selected surveyed organizations will also be presented. The research was carried out in accordance with the DSR (Design Science Research) method, which enables the development of an artifact, i.e. ROI/TCO calculator, in a research process combining theoretical knowledge and practical experience.

The main hypothesis of the conducted research (where the hypothesis should be understood as a proposal to direct research into the indicated areas) is a dedicated calculator using ROI/TCO indicators to assess the effectiveness of IT system virtualization is a relevant and useful decision supporting tool. This hypothesis was detailed with the following auxiliary hypotheses:

H1. ROI/TCO calculators enable the assessment of the financial and economic effectiveness of virtualization technologies.

H2. Virtualization technology works in accordance with the idea of Green Computing and is part of the CSR policy and the concept of ESG.

H3. Virtualization is an efficient method of providing services in the Cloud Computing model.

This article has been organized as follows: after the introduction, a research background will be presented, in which the researched and verified areas are indicated as well as a research gap. The next section describes the DSR research method. Then, the research results will be described, i.e. the concept of artifact and the implementation and validation of this tool. This will be followed by a discussion of the research results and implications and limitations. At the end, conclusions will be described and references indicated.

2. Research background

Virtualization technology is a method of more effective use of existing infrastructure, where efficiency should be understood as the ratio between the effects achieved after implementing virtualization technology and the IT costs incurred for its implementation [18], [23]. Virtualization is mainly presented from technological perspective as classification of architecture types and methods [25], virtualization solutions on the IT market and applications of virtualization at the hardware level (e.g. server and desktop) and software (e.g. application and presentation) [30]. There are also relatively few studies [30] on strategies for implementing virtualization solutions, and those available only concern server resources. Moreover, there are few publications on this topic in the financial, economic and ecological context, hence the implementation of the indicated research goal allowed filling this cognitive gap.

Literature review includes the definition of IT technology effectiveness and its measurement, which must be based on clear criteria and methods and measures adequate

to be used in the environment of a given project [1]. Therefore, ROI and TCO were indicated for quantification along with the formulas according to which both indicators are estimated [2], [5], [11]. TCO is calculated as a sum of implementation (Capital Expenditures - CAPEX) and maintenance (Operating Expenditures - OPEX) costs. Efficiency expressed as a return on investment (ROI) is therefore the ratio of saving (or loss) from investment in time *t* to the investment costs incurred NI_0 minus 1 - determined by net benefits [18], which is an intuitive approach to the ROI, because the classic definition of the ROI (ratio of profit to the initial investment outlay [17]) does not fully fit in the case of investment analysis involving the implementation of an IT system. The saving of implementing virtualization technology is the difference in the total cost of implementation, operation and maintenance (for time *t*) between the physical (TCO_t^f) and virtual environments (TCO_t^w). Therefore, ROI is estimated according to formula (1):

$$ROI = \left(\frac{TCO_t^f - TCO_t^w}{NI_0} - 1\right) \times 100\% \quad (1)$$

The approach to calculating ROI is generic, but in the case of cloud computing services, the potential savings (or loss) should be calculated differently - as the difference in the total costs of creation, operation and maintenance (for time *t*) between owned (physical, virtual or hybrid) environment (TCO_t^a) and the services maintained in the cloud (TCO_t^{cc}). In this case, ROI should be calculated according to formula (2):

$$ROI = \left(\frac{TCO_t^a - TCO_t^{cc}}{NI_0} - 1\right) \times 100\% \quad (2)$$

It's crucial to present the meaning of virtualization in the context of CC, GC/GI, CSR and ESG. All concepts are closely related to the virtualization technology itself. Cloud Computing is a model that enables fast, convenient and universal access to the network on demand, i.e. a common pool of configurable computing resources (e.g. networks, servers, mass storage, applications and services) that can be delivered or released quickly with minimum management effort [19]. Virtual machine technology supports the cloud model, providing the most efficient solution for the development of CC services. The concept of virtualization is also connected to the idea of GC/GI, because in addition to financial benefits brings with it reduction in energy consumption, that means a reduction in carbon dioxide emissions produced by the organization's infrastructure. Thus, the implementation of virtual solutions fits into the ecological trend, making such a company socially responsible and operating in accordance with the definition of CSR (or the norm "ISO 26000 - Guidelines for social responsibility" [15]) and the concept of ESG, i.e. development indicators that help organizations report on their environmental, social and governance strategy and activities, e.g. in terms of reducing carbon dioxide emissions and reducing electricity consumption [3].

Market-available ROI/TCO calculators can be helpful in analyzing the total cost of IT ownership and assessing the return on investment, allowing for a more accurate comparison of a system tailored to the special requirements of the enterprise in which such a solution is planned to be implemented [16]. The tools discussed enable a detailed analysis of all expenses related to the implementation of new technology in one's own infrastructure, as well as an analysis of the costs of migrating existing resources to CC services. Calculators are mainly offered by virtualization software and hardware producers, as well as by CC service providers. These are commercial, free tools made available after leaving your contact details [6, 7, 8], [10], [12], [13]. Assessment of the functionality of available ROI/TCO calculators, their comparison, and identification of ambiguities and gaps will be an important basis for creating a prototype of an ROI/TCO calculator.

3. Methods

The research goal and motivation became the basis for conducting three-way research: first - literature review; second - review of five commercially available ROI/TCO calculators

[6, 7, 8], [10], [12, 13], [22] (Parallels Virtuozzo Containers TCO Calculator, VMware ROI TCO Calculator, VMware TCO Comparison Calculator, VMware Cloud on AWS TCO Calculator, Azure TCO Calculator and VMware Carbon Calculator) and third - study five cases of virtualization technologies implementation by organizations, where the material was collected using the IDI (Individual in Depth Interview) method during meetings held in enterprises or by telephone, in which closed, semi-open and open. To achieve the research goal, the DSR (Design Science Research) method was used, and the presented in Figure 1 line of research was adopted.

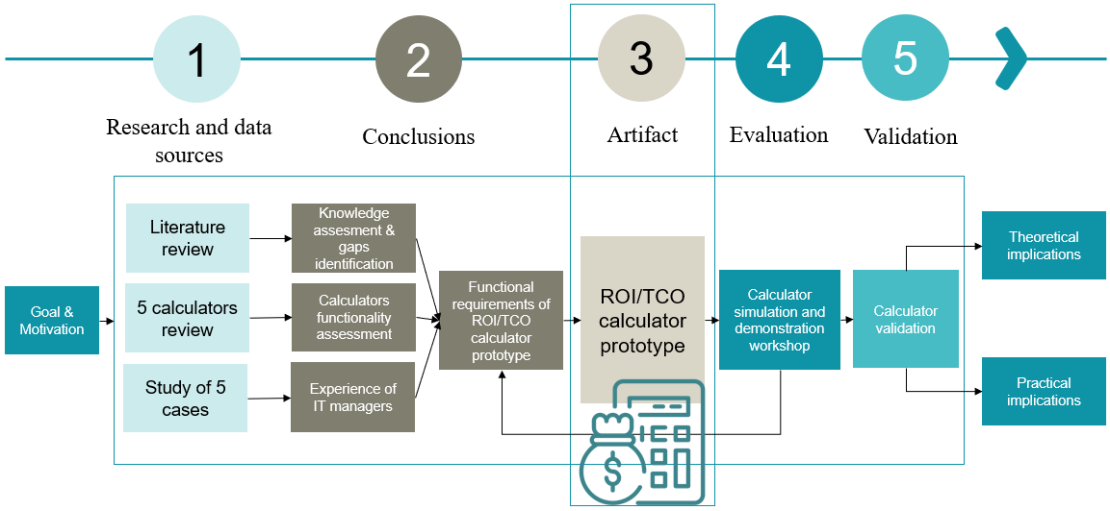

Fig. 1. DSR research line

DSR is a project nature research approach proposed by A. Hevner [4] in which new knowledge is created based on scientific and business knowledge, complementing the resources of prior knowledge, but at the same time being significant and useful for practice. Because of adopting the DSR approach, an original scientific solution and a tool useful for practitioners as an artifact should be expected. The artifact palette proves to be very broad and includes such types of artifacts as methods (42.7%), models (22.2%), systems (13.7%), constructs (6.8%), frameworks (6.1%) or architectures (2.0%), whereas 27.6% of artifacts might be classified as fully ready for use after their implementation and validation [27].

An important stage of the research line was the development of functional requirements and then a prototype of the calculator (artifact), which, after evaluation, was again improved and validated. The developed ROI/TCO calculator has strong implications, both theoretical and practical.

4. Results

4.1. Conceptualization of the Artefact

The final version of the ROI/TCO calculator prototype was published in the RepOD repository in the institutional collections of the University of Gdańsk [9]. The calculator with instructions can be downloaded for analysis and simulation.

In accordance with the DSR research line the basis for identifying the functional requirements of the ROI/TCO calculator prototype, in addition to the literature review, was primarily the analysis and review of ROI and TCO calculators in 1. step. The conclusions drawn from theoretical and empirical research have been specified in the framework of functional requirements (FR) in 2. step. These requirements have bees specified as follows:

FR1: The ROI/TCO calculator prototype should calculate the total cost of ownership TCO divided into CAPEX and OPEX costs in accordance with the adopted in the tool classification.
FR2: The input data for the ROI/TCO calculator should be:

- FR2.1: detailed and not predefined (possibly suggested based on a reliable data

source) by the tool and:

- FR2.2: in accordance with the adopted table 1 in the tool ("Input data" tab), in the case of data regarding your server infrastructure - infrastructure profile or:
- FR2.3: in accordance with the adopted table 1 in the tool ("Input data" tab), in the case of other data characterizing the functioning of the tested infrastructure.

FR3: Individual costs should be calculated in accordance with the algorithms described in the adopted table 0 in the tool.
FR4: TCO is the sum of CAPEX and OPEX.
FR5: ROI should be calculated:

- FR5.1: in accordance with the adopted formula (1), in the case of implementing virtualization technology in IT environment, the profit will be understood as the difference in the total costs of creation, operation and maintenance (for time *t*) between the physical (f) and virtual environments (w) or:
- FR5.2: in accordance with the adopted formula (2), in the case of implementing cloud solutions in IT environment (physical, virtual or hybrid), the profit will be understood as the difference in the total costs of creation, operation and maintenance (for time *t*) between owned environment (a) and the services maintained in the cloud (cc).

FR6: The carbon dioxide emission level should be calculated based on the algorithm presented in the VMware Carbon Calculator.
FR7: The input data should also include the current inflation or deflation rate to precisely calculate TCO over a 3–6-year period.
FR8: The input data to the ROI/TCO calculator prototype should be an open set in order to be able to add the necessary CAPEX or OPEX cost at any time, which affects the calculation of the total cost of ownership (TCO) and the ROI indicator.

Based on the functional requirements (FR1-FR6), the first prototype of the ROI/TCO calculator was defined. During the demonstration workshop, when the artifact was evaluated through simulation and demonstration workshops, two additional gaps were identified. Because the artifact is created in the research process in an iterative and incremental manner, based on the conclusions obtained during the workshop, the design of the artifact was improved to boost its effectiveness. This improvement was expressed through two additional functional requirements (FR7-FR8).

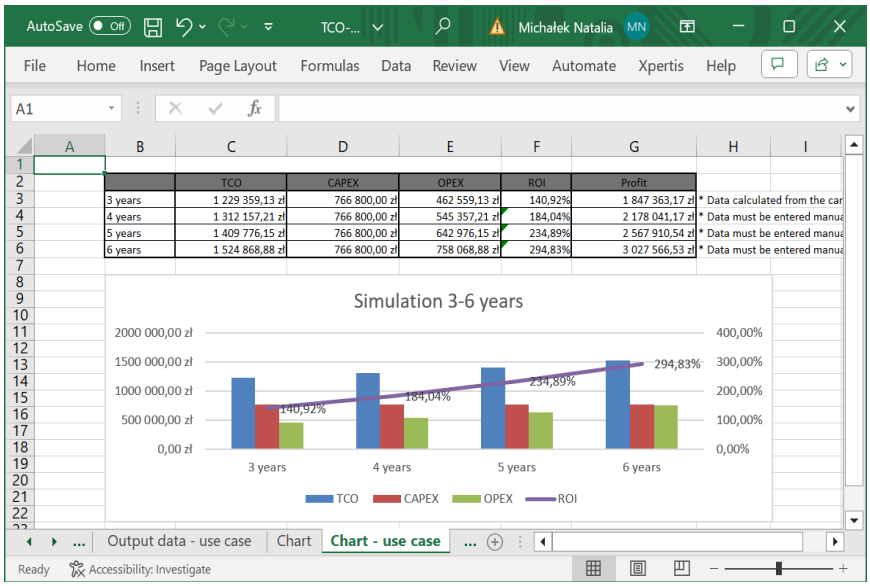

Fig. 2. ROI/TCO calculator prototype - simulation 3-6 years

The artifact as ROI/TCO calculator in step 3 was created in a prototype version in an Excel spreadsheet with a form for input data, drop-down lists with values to choose from, data dictionaries, and, above all, formulas developed in accordance with defined algorithms were implemented. On this basis, the calculator generates estimated values of TCO, ROI (expressed as a percentage, as well as the payback period in terms of time) and the potential level of carbon

dioxide emissions reduced because of virtualization. Additionally, the tool generates charts showing TCO and ROI over 3 to 6 years. Fig. 2 shows an example simulation result performed in the calculator.

4.2. Implementation and Validation of the Artifact

As part of the 4. step on research line, the artifact was evaluated during simulations and demonstration workshops of the ROI/TCO calculator prototype, which were conducted with selected IT managers who were also respondents as part of the empirical research. The workshops consisted of the presentation of the tool along with calculation simulation, i.e. comparative analysis using a prototype. The result of this analysis was the identification, for selected organizations subjected to empirical research, of all costs of implementing virtualization, the calculation of TCO and ROI, ranging from 3 to 6 years into the future, as well as the level of CO_2 emissions. Since the artifact had to be created in the research process in an iterative and incremental manner (which allows for its simultaneous verification and evaluation), based on the conclusions obtained during the workshop, improvements were made to the artifact's design to improve its effectiveness. This approach resulted in returning to step two and identifying new functional requirements.

Fifth step of the research line is the validation of the artifact, i.e. the assessment of the finished prototype, which was made in terms of accuracy, usefulness, effectiveness, efficiency and durability. As part of the validation of the ROI/TCO calculator prototype, another comparative analysis was carried out based on the collected research material in the artifact created and described in the dissertation, which was enriched with two additional functional requirements (FR7-FR8). The entire line of research was completed with the development of theoretical and practical implications regarding the effectiveness of virtualization technology and the artifact itself - the ROI/TCO calculator prototype.

5. Discussion

An important element of the study were interviews with representatives of 5 companies that carried out virtualization projects. The surveyed organizations do not have practical knowledge and skills in working with ROI/TCO calculators, even though these are free tools, widely available and promoted by virtualization technology providers. The lack of knowledge of calculators did not prevent them from making a positive decision to implement virtualization technology, but the respondents' participation in the study made them familiar with the techniques for calculating the effectiveness of virtualization, which was assessed positively. The research results showed that both the total cost of ownership (TCO) analysis and the return on investment (ROI) are indicators that can be used to calculate measurable benefits from the use of virtualization technology, which confirms the H1 hypothesis.

Conducted research made it possible to create a list of functional requirements that were used to develop a prototype of the ROI/TCO calculator. During the demonstration workshop (DSR evaluation phase), the artifact was simulated and additional shortcomings were identified and corrected, taking into account two additional functional requirements. The evaluation of the calculator also made it possible to demonstrate its functionalities that were not available in other commercial tools. They concerned the estimation of the costs of powering and cooling IT equipment, which are not incurred by organizations implementing virtualization. Therefore, the reduction in carbon dioxide emissions into the atmosphere was calculated. The ecological aspect, although not always considered, brings benefits to the natural environment when virtual infrastructure is implemented. This confirms the hypothesis H2.

Respondents who have been using CC services for years unanimously stated that virtualization technology is the most efficient solution for providing services in the cloud computing model or creating a private cloud, which, in the light of empirical research and literature review, allows us to assume the true research hypothesis H3. To sum up, the confirmation of the auxiliary hypotheses leads the authors to state that the main hypothesis of the conducted research was also confirmed, at the evaluation stage, that a calculator using ROI/TCO indicators to assess the effectiveness of IT system virtualization

is an effective decision supporting tool.

6. Implications and Limitations

6.1. Implications for Theory and Practice

The entire DSR-compliant research process ends with the development of theoretical and practical implications. As indicated in this study, virtualization is mainly presented from a technological perspective as classification of architecture types and methods [25], [30]. However, there are only a few publications [18], [23] on this subject in the financial, economic and ecological context, hence the implementation indicated research goal allowed to fill this cognitive gap. Therefore, as part of the theoretical implications, i.e. scientific studies and articles, in addition to the new article already published [20, 21, 22] in the field of the effectiveness of virtualization technologies, an artifact - a prototype of the ROI/TCO calculator - was added to the RepOD knowledge base [9] and subjected to public criticism.

Additionally, to check the usefulness of the proposed artifact in practice and its practical implications, the constructed artifact should be used in socio-economic practice. Therefore, as part of the practical implications, the artifact developed in the research process was made available along with instructions for use to all respondents who responded as part of the in-depth interview. Making the prototype calculator publicly available will allow all socio-economic organizations to correctly assess the effectiveness of their investments in virtualization technology or in CC services based on virtualization technology. Therefore, it can be assumed that the ROI/TCO calculator prototype will help organizations make investment decisions more effectively and efficiently. In accordance with the adopted DSR approach, an original scientific solution and a tool useful for practitioners were developed. Thus, by applying DSR to a line of research, practical challenges have been addressed while contributing to both practice and theory.

6.2. Limitations

The first limitation of this study relates to the possibility of verifying only five commercially available ROI/TCO calculators. The tools available on the Internet have limited parameterization options, and in many cases the development of these tools has been suspended. A review of available tools confirmed the sense of developing an original prototype that filled the gaps encountered during the literature review, interviews and evaluation of the case study. Larger number of calculators would allow for even more precise verification of the available functionalities and strengthen the need to extend them by calculating ROI/TCO as well as new functionalities related to ESG, GC/GI and CSR. Secondly, the number of interviews conducted (5 companies took part in them), as well as the small participation of companies in the DSR process at the evaluation stage (only 2 companies took part in the simulation demonstration of the calculator's operation) meant that the evaluation of the calculator prototype was limited to the evaluation of two virtualization projects. It should also be considered that due to the relatively small research sample, the results should not be generalized. Increasing the number of virtualization cases passed through the calculator would probably result in more imperfections of this artifact being identified. The general challenge related to the analysis of the effectiveness of IT systems is limited access to data on additional revenues from the implementation of specific services or IT solutions.

7. Conclusions And Potential Future Research Directions

Virtualization is crucial for development towards a more dynamic IT structure while application workload uses only a fraction of the hardware capabilities of a computer or server. By combining complementary data processing and memory workloads the number of physical machines decreases, using less space and hardware that influence reduction of electricity consumption for hardware operating, heating and cooling. Virtualization increases the efficiency of infrastructure and improves the level of organization's services, works in accordance with the idea of "green IT" and in accordance with the CSR and ESG policies.

It is the most efficient solution for providing services in the cloud computing model and maximizes benefits of this technology. ROI/TCO calculators enable the assessment of the economic and ecological effectiveness of virtualization technologies, however, they require the preparation of data and input information. Virtualization reduces OPEX cost, increased level of services, flexibility and scalability of the infrastructure, but it is not without some disadvantages - potential failure of the host server.

In future research is important to intensify their assessment of the effectiveness of cloud services, considering that nowadays, many maintenance activities (both in software development and infrastructure maintenance) are subject to automation, also using artificial intelligence [28]. The evaluation of such projects will allow the refinement of ROI/TCO calculation algorithms to consider intelligent automation in the cost and environmental context.

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