JOHN KARIMA MACHARIA   SELECTING COST EFFECTIVE GREEN COMPUTING APPROACH FOR SERVER VIRTUALIZATION USING FAHP-TOPSIS   MASTER THESIS   2023

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M.Sc. THESIS

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We certify that we have read the thesis submitted by John Karima Macharia titled **"Selecting Cost-Effective Green Computing Approach for Server Virtualization Using FAHP-TOPSIS"** and that in our combined opinion, it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Educational Sciences.

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Declaration

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John Karima Macharia

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John Karima Macharia

Abstract

Selecting Cost-Effective Green Computing Approach For Server Virtualization Using FAHP-TOPSIS

Student: Macharia, John Karima

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Supervisor: Asst. Prof. Dr. Seren Başaran

Co-Supervisor: Prof. Dr. Nadire Çavuş

Increasing environmental consciousness and the COVID-19 global pandemic have made it essential to investigate sustainable methods through which the IT sector can effect meaningful change in the world while minimizing its carbon footprint. The study aims to investigate a leading green computing approach, server virtualization, and provide a method through which decision-makers can choose between the server virtualization alternatives available on the market, to best fit their needs while being eco-friendly. This entailed the use of ISO/IEC 25010 software quality standards coupled with Multi-Criteria Decision-Making Methods, specifically a hybrid FAHP-TOPSIS model in a novel server virtualization analysis approach. The study analyzed four server virtualization alternatives and made use of the expertise of two decision-makers. The study determined that Microsoft Hyper-V proved the most appropriate server virtualization option given the four alternatives analyzed. The results of the study may prove useful for corporations seeking to implement server virtualization in their operations. This research is unique as it proposes an approach to evaluation that strays from prior studies that focused primarily on the performance evaluation aspect of server alternatives. Instead, it takes a step back and provides a more holistic evaluation method in conjunction with Multicriteria Decision-Making Methods FAHP and TOPSIS, and the ISO/IEC software standards.

Key Words: FAHP, green computing, ISO/IEC 25010, server virtualization, TOPSIS

ÖZ

FAHP-TOPSIS Kullanarak Sunucu Sanallaştırması İçin Uygun Maliyetli Yeşil Bilgi İşlem Yaklaşımını Seçme

Öğrenci: Macharia, John Karima

M.Sc., Bilgisayar Bilişim Sistemleri Bölümü, Haziran 2023, 79 sayfa

Danışman: Yrd. Prof. Dr. Seren Başaran

Eş Danışman: Prof. Dr. Nadire Çavuş

Artan çevre bilinci ve küresel COVID-19 salgını, BT sektörünün karbon ayak izini en aza indirirken dünyada anlamlı bir değişiklik yaratabileceği sürdürülebilir yöntemlerin araştırılmasını zorunlu hale getirdi. Çalışma, önde gelen bir yeşil bilgi işlem yaklaşımı olan sunucu sanallaştırmayı araştırmayı ve karar vericilerin çevre dostu olmakla birlikte ihtiyaçlarına en uygun şekilde piyasada bulunan sunucu sanallaştırma alternatifleri arasından seçim yapabilecekleri bir yöntem sağlamayı amaçlamaktadır. Bu, ISO/IEC 25010 yazılım kalite standartlarının, Çok Kriterli Karar Verme Yöntemleri ile birleştiğinde, özellikle yeni bir sunucu sanallaştırma analizi yaklaşımında hibrit bir FAHP-TOPSIS modelinin kullanılmasını gerektirdi. Çalışma, dört sunucu sanallaştırma alternatifini analiz etti ve iki karar vericinin uzmanlığından yararlandı. Çalışma, analiz edilen dört alternatif göz önüne alındığında Microsoft Hyper-V'nin en uygun sunucu sanallaştırma seçeneğini kanıtladığını belirledi. Çalışmanın sonuçları, operasyonlarında sunucu sanallaştırmayı uygulamak isteyen şirketler için yararlı olabilir. Bu araştırma, öncelikle sunucu alternatiflerinin performans değerlendirme yönüne odaklanan önceki çalışmalardan ayrılan bir değerlendirme yaklaşımı önerdiği için benzersizdir. Bunun yerine, bir adım geri atıyor ve Çok Kriterli Karar Verme Yöntemleri FAHP ve TOPSIS ve ISO/IEC yazılım standartları ile birlikte daha bütünsel bir değerlendirme yöntemi sunuyor.

Anahtar Kelimeler: FAHP, yeşil bilgi işlem, ISO/IEC 25010, sunucu sanallaştırma, TOPSIS

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List of Abbreviations

AHP:	Analytical Hierarchy Process
ANP:	Analytical Network Process
BWM:	Best Worst Method
CIO:	Chief Information Officer
CIS:	Computer Information Systems
COPRAS:	COmplex PRoportional ASsessment
CPU:	Central Processing Unit
ELECTRE:	*ELimination Et Choix Traduisant la REalité*
FAHP:	Fuzzy Analytical Hierarchy Process
GPU:	Graphics Processing Unit
HLW:	Hierarchical Level Weights
HDD:	Hard Disk Drive
IBM:	International Business Machines
IEC:	International Electrotechnical Commission
IFNS:	Intuitionistic Fuzzy Number
I/O:	Input/Output
ISO:	International Organization for Standardization
IT:	Information Technology
KVM:	Kernel-Based Virtual Machine
MCDM:	Multi-Criteria Decision Making
NIC:	Network Interface Card
OS:	Operating System
PROMETHEE:	Preference Ranking Organization METHod for Enrichment of Evaluations
SWARA:	Stepwise Weight Assessment Ratio Analysis
TOPSIS:	Technique for Order of Preference by Similarity to Ideal Solution
VM:	Virtual Machine
VPS:	Virtual Private Servers

CHAPTER I

INTRODUCTION

This chapter explores green computing, its tenets and implementations, paying particular attention to virtualization, and Multi-Criteria Decision-Making with a focus on fuzzy AHP and TOPSIS. It also discusses the problem, the aim of the study, its significance, the limitations encountered, and gives a general overview of the study.

1.1. Background

The global IT sector has shown robust growth since its inception over 70 years ago. It is ubiquitous in most industries and households and is responsible for an ever-increasing carbon footprint, which has significant negative environmental implications. The sector collectively contributes as much as 3.9 % to the world's greenhouse gas emission levels, with projections pushing the figure much higher in the coming years (Freitag et al., 2021). Each step in the lifecycle of IT products and resources, from production to termination, has the potential to harm the environment. Industry practitioners, researchers, and governments, in their quest for lowering these levels, are implementing greener techniques in various areas of society (Bose & Luo, 2011). This has seen their efforts incorporated into the world of IT, resulting in the growth and subsequent development of green computing.

The COVID-19 pandemic also drastically altered how people work and live, necessitating a restructuring of employment practices. This saw a massive shift from people physically coming into the office space to them having to work remotely from their homes (Ch et al., 2023). The pandemic's effects were felt on a global scale, with resources often being bottlenecked due to interrupted supply chains and short-staffed businesses. Alternative solutions were required to speed up the recovery process and return the world to some semblance of normalcy. This spurred the adoption of green computing practices as they were rapidly embraced to mitigate the pandemic's dire conditions. For example, the implementation of virtualization allowed corporations to cut down on already strained costs of purchasing new physical servers, as it instead enabled them to increase their computer resources through the use of virtual processors. E-waste principles encouraged the reuse of devices as defunct supply chains stalled the progress of new purchases and new IT products incorporated advanced chipsets that saw devices last longer, reducing waste, and emphasizing energy efficiency as a design tenet.

Green computing is defined as using Information Technology (IT) resources in ways that conserve energy and reduce costs and negative impacts on the environment (Bose & Luo, 2011). It is the process of creating, assembling, and utilizing computers, servers, and different associated accessories in efficient ways with a focus on reducing environmental degradation and increasing energy efficiency. This may be approached through techniques such as virtualization, using renewable energy sources to power data centers while minimizing their overall energy consumption, the design and use of energy-efficient chips, and cutting down on electronic waste (Asadi et al., 2017). Green computing has been lauded as an important strategic resource for businesses and is capable of offering reduced carbon footprints and environmental impact, minimized energy consumption, reduced costs, enhanced systems performance, savings in space, and increased collaboration and synergy between stakeholders involved (Bose & Luo, 2011). Several techniques may be implemented under the banner of green computing to minimize the environmental impact of IT activities while making maximum use of computing resources (Harmon & Auseklis, 2009). These include data center infrastructure redesign and management with considerations such as the utilization of power and workload management techniques, thermal load management, and heat removal and recovery systems to better regulate the temperatures within data centers. Enhanced product and infrastructure designs mean computing practices are efficient in energy utilization, while cloud computing may be used to provide high-performance computing resources to consumers over the Internet, enabling users to easily deploy services on the cloud with few concerns as to infrastructure needs (Harmon & Auseklis, 2009). Virtualization entails running two or more logical computer systems on a single set of physical hardware which enables corporations to handle increased software applications while utilizing less physical space, power, and reduced staff (Liu et al., 2011).

Virtualization has advanced significantly since its inception in the 1960s by IBM for its mainframe operating systems. It is a green computing technology that allows a system administrator to combine various physical computing systems into “virtual machines” i.e., generated digitally by computers, in a way that is as energy efficient as possible, while also minimizing the idle time for hardware and subsequently lowering the power consumption of the overall system. Virtualization entails affixing a layer of software known as a hypervisor, which abstracts the software operating on top of the computer’s underlying hardware. The hypervisor organizes and controls the computer's virtualized resources and provisions them into logical instances known as virtual machines (VMs), each of which functions as an independent server (Bigelow & Gillis, 2021). Virtualization seeks to use system resources effectively as through this technique, the workload can be redistributed in ways that servers are either in use or are put in power-saving modes. Virtualization results in computer elasticity and scalable software solutions with the drawing together of underutilized and loosely-coupled resources while also enabling corporations to reduce staff and maintenance costs (Liu et al., 2011).

The adoption of server virtualization across corporations is growing due to its increasing importance and the numerous benefits it yields. A survey of 500 organizations across Europe and the United States of America indicates that 71% of Chief Information Officers (CIOs) agreed that server virtualization resulted in efficient consolidation of server operations and cost savings (Ogunyemi & Johnston, 2017). It also leads to reduced emissions and fewer negative environmental effects originating from IT thereby cutting down on a company’s carbon footprint. Ultimately, this facet of green computing is here to stay and should be treated as a strategic resource to corporations, as it offers a wide array of advantages to the company’s bottom line and mode of operations, in addition to being environmentally conscious.

Despite the growing importance of server virtualization as a green computing approach, there still exists a dearth of research on effective techniques to evaluate and assess its cost-effectiveness as a whole while comparing and contrasting against various server virtualization alternatives available. Existing literature does provide some evaluation techniques, however, these are more case-based and packaged as evaluations of particular aspects of server virtualizations themselves, as opposed to criteria. One such study only analyzed power consumption levels in virtualized servers (Liu et al., 2011).

Another study focused solely on cost savings associated with server virtualization (Ghorpade et al., 2013). There is a need to compare server virtualization alternatives against a set of evaluation criteria that pertains to assessing a software product's attributes, to endow prospective users with increased information about the options available to them. This may be achieved through the use of ISO standards, particularly ISO/IEC 25010 which decides the quality factors to be used when assessing a software product's attributes, in this case, virtualization software products (Barletta et al., 2022). ISO/IEC 25010 consists of eight quality characteristics, namely functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability (International Organization for Standards, 2022). The aforementioned criteria were well-suited to achieving the study's aim of evaluating different server virtualization alternatives and ranking the alternatives on the market. As the study was based on several criteria, the best-suited approach in carrying out this evaluation was Multi-Criteria Decision Making (MCDM).

Multi-Criteria Decision-Making (MCDM) is a field of study that evaluates among different options available in a particular situation (Pomerol & Barba, 2012). Several MDCM methods are used for decision-making, for example, TOPSIS, AHP, ANP, SWARA, BWM, ELECTRE, PROMETHEE, etc. MCDM forms a high-priority area for operations research and management science, with a range of applications in economics, engineering, management, and other such areas (Mohtashami, 2021).

A popular MCDM method in use is the Analytic Hierarchy Process (AHP). This was developed in 1980 and has been used for several years to assign weights to criteria, assess alternatives, and subsequently rank them (Saaty, 1980). It achieves this by comparing the criteria pairwise, with the comparative judgment passed by experts and recorded on a distinctive scale.

An improvement of AHP is the Fuzzy AHP (FAHP), which builds upon its predecessor through the use of fuzzy numbers garnered from fuzzy logic theory as opposed to assigning specific numbers to determine criteria weighting (Alghassab, 2022). These have the advantage of providing more flexibility when assigning the criteria with weights. The FAHP approach also allows for the handling of quantitative and qualitative data better and is applicable in this study as the criteria being implemented in server evaluation fall under both categories. FAHP is ideal for determining criteria weights and may be paired with another MCDM such as Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) to carry out the ranking of alternatives (Hwang & Yoon, 1981). TOPSIS is one of the more common techniques utilized for solving MCDM problems. It uses two reference points i.e., a pair consisting of a Positive Ideal Solution (PIS) and a Negative Ideal Solution (NIS), to order a set of decision alternatives. TOPSIS works under the premise that the preferred choice will be closest to the PIS and farthest from the NIS. TOPSIS is similar to how people make decisions in the real world and due to its relatability, intuitive reasoning, and relatively simple working theory, it is one of the predominant MCDM techniques in use by decision-makers (Corrente & Tasiou, 2023). The aforementioned MCDM tools, coupled with ISO/IEC 25010 standards are thus employed in tandem to identify a cost-effective server virtualization alternative that may be used such that the aim of green computing is achieved.

1.2. The Problem

The reverberating effects of the COVID-19 pandemic coupled with the fact that organizations are becoming more conscious of their negative contributions to the world's ecological balance have seen the rise of green computing's value as a strategic and environmentally sound alternative to traditional operations (Bose & Luo, 2011). Server virtualization in particular is attractive as a green computing option as not only does it reduce energy waste; it simultaneously increases efficiency while cutting down on several associated costs, such as reducing the need for technical staff to physically maintain servers (Ogunyemi & Johnston, 2017). However, corporations face challenges in determining the right server virtualization alternative to select for implementation into their operations as effectively choosing among them is hampered by the existence of complex quality standards. The study seeks to mitigate this through the use of MCDM, particularly the FAHP-TOPSIS method.

There still exists a scarcity of research for corporations to draw from however concerning server virtualization, particularly with matters to do with evaluating one's options and deciding which alternatives best suit a particular situation. Server virtualization solutions should not be a one-size-fits-all approach and considerate care must be taken before selecting one that matches an organization's needs and adds value to all its stakeholders. This study remedies this oversight and fills a gap in the literature that would enable corporations and researchers alike to better determine between server virtualization alternatives through the use of MCDM and the application of ISO/IEC 25010 standards.

1.3. Aim of the Study

The study aims to build a novel framework to assess server virtualization alternatives by incorporating aspects of the ISO/IEC 25010 quality standards together with a hybrid MCDM method FAHP-TOPSIS.

The study also seeks to implement the framework in selecting the best alternative out of those already on the market, and subsequently filling a gap in research available on choosing green IT approaches.

1.3.1. Research Objectives

- To build a framework based on ISO/IEC 25010 coupled with a hybrid FAHP-TOPSIS method for determining the quality of server virtualization alternatives.
- To rank among available server virtualization alternatives on the market and select the best one according to the aforementioned ISO/IEC 25010 framework and hybrid FAHP-TOPSIS method.

1.4. Significance of the Study

The use of ISO/IEC 25010 quality standards for the evaluation of server virtualization alternatives is a novel concept and one that is unique from prior approaches. The study will act as a proof-of-concept on how to accurately and holistically determine a cost-effective server virtualization alternative. Corporations can use the study to identify the alternative that is the right fit for them while keeping in line with green computing best practices. The study also adds knowledge to research in the field as the literature on deciding among server virtualization alternatives coupled with ISO/IEC 25010 standards and MCDM methods is a new approach and one that bears further investigation.

1.5. Contributions of the Study to the CIS Department

In addition to acting as a beacon for green computing for future inquiries by students and lecturers alike, the study also shows the best course of action if the department was to implement a server virtualization solution for its activities. The relevant steps are broken down into convenient and clear phases, allowing the department to select a server virtualization alternative that meets its requirements. This would increase the department's green computing impact, save costs and reduce its carbon footprint and would also enable it to lead by example to other departments in the school.

1.6. Limitations of the Study

The research seeks to achieve its aims but some limitations in this quest are noted as follows:

- The study only evaluates four server virtualization alternatives.
- The evaluation of alternatives is carried out according to the principles of ISO/IEC 25010.
- The study used two experts in the evaluation process.

1.7. Overview of the Study

The entire thesis contains six chapters:

Chapter 1 introduces the thesis and defines the problem, the significance of the research, its aims, and its limitations.

Chapter 2 establishes the conceptual framework and explains the related research on green computing, green computing approaches available, server virtualization, and the evaluation of server virtualization alternatives.

Chapter 3 covers the methodology implemented for selecting, evaluating, and writing the thesis.

Chapter 4 consists of the empirical study and findings.

Chapter 5 discusses the results.

Chapter 6 concludes the thesis and puts forward recommendations for future studies.

CHAPTER II

LITERATURE REVIEW

This chapter examines the findings and research gaps of prior studies that have been published on the topic under investigation. It also elucidates further on ISO/IEC 25010 as a software evaluation tool, analyzes the criteria the standards apply in appraising software, and builds upon this in conjunction with a hybrid FAHP-TOPSIS Multi-Criteria Decision-Making method for the evaluation of server virtualization alternatives. It details the server virtualization alternatives on the market that were used in the study as well.

2.1. Conceptual Framework

2.1.1. ISO/IEC 25010

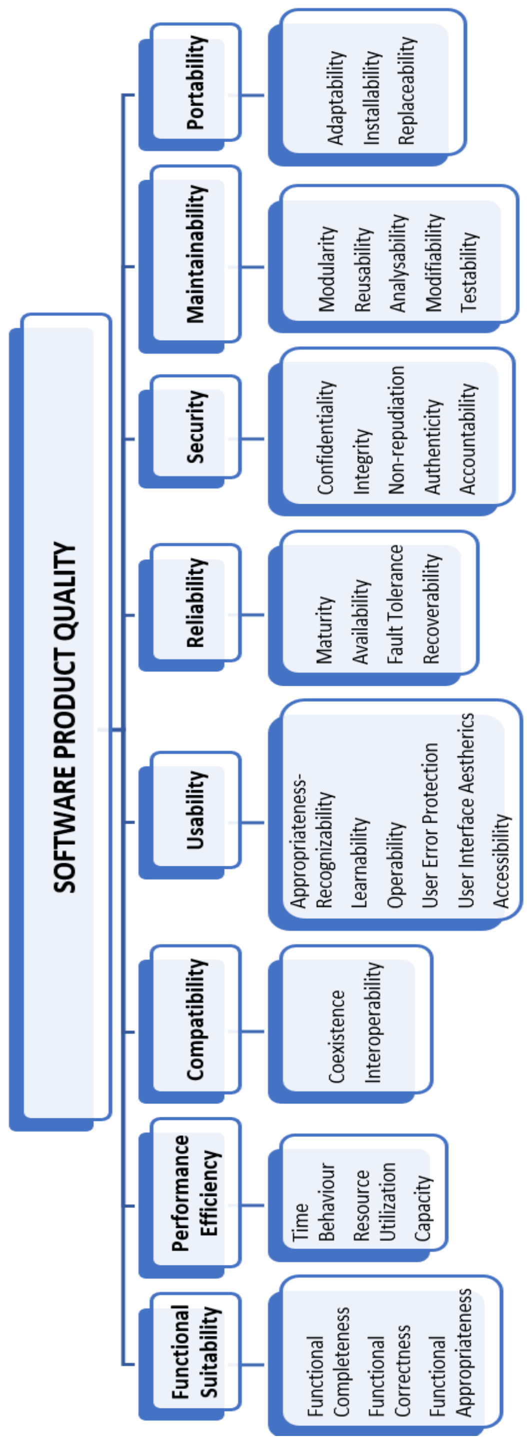
Quality models are convenient when it comes to carrying out software evaluations. These consist of a collection of software quality criteria that have been broken down hierarchically. While there are several available quality models, the most prevalent of these is the ISO/IEC set of standards, particularly the ISO/IEC 25010 standard (Oriol, et al., 2014). ISO/IEC 25010 consists of international standards that stipulate the quality criteria to be applied when evaluating the characteristics of a software product (International Organization for Standards, 2022). The standards stem from the ISO/IEC 25000 to ISO/IEC 25099 series of International Standards which handle software engineering systems and software quality requirements. The degree to which a system meets the explicit and implicit needs of its many stakeholders and contributes value is what determines its quality. ISO/IEC 25010 defines two models for the measurement of quality: “quality in use”, which analyses the extent to which a system or product may be utilized by specific users to satisfy their requirements in attaining specific goals (Barletta et al., 2022). The second model, i.e., “product quality” seeks to assess the software/system product's factual quality features. ISO/IEC 25010 describes a product quality model which comprises eight quality attributes, namely: functional appropriateness, performance effectiveness, compatibility, usability, dependability, security, maintainability, and portability.

2.1.2. Product Quality Model Attributes

Functional suitability indicates how well a system satisfies explicit and implicit demands when put to use in predetermined circumstances. It is a preliminary assessment of the product's anticipated efficacy (Estdale & Georgiadou, 2018). Performance efficiency deals with the number of resources consumed under specified conditions. Performance efficiency may not always be to the user’s exact specifications upon manufacture so some estimations may prove challenging at times. Compatibility is the extent to which a system communicates with others to carry out its necessary activities while utilizing similar environments. It covers the co-existence and interoperability of systems. Usability is how effectively, efficiently, and satisfactorily a product or system may be used by specific users to achieve specific. Reliability is the extent to which a system meets a set of predetermined requirements over a predetermined period. Security covers the amount of data protection that a system provides, allowing users or other goods or systems to access data to the limit that is necessary for their types and degrees of permission. Maintainability checks the extent to which a system may be adjusted to changes in the environment and needs. Portability is the ease with which a system may be adapted to a different hardware, software, or operating environment (Meira et al., 2020).

Figure 2. 1:

ISO/IEC 25010 Product Quality Model



Note. Model derived from *International Organization for Standardization*. (International Organization for Standards, 2022)

2.1.3. Multi-Criteria Decision-Making

Multi-Criteria Decision-Making (MCDM) is a key part of decision-making theory and involves the use of tools to analyze, evaluate and rank prospective alternatives given various differing criteria (Opabola & Galasso, 2022). MCDM forms a high-priority area for operations research and management science, with a range of applications in economics, engineering, management, and other such fields (Mohtashami, 2021). MCDM methods may be classified as either multi-attribute decision-making (MADM) methods or multi-objective decision-making (MODM) methods (Rezaei, 2015). MODM methods handle continuous optimization problems, working to assess an unlimited number of continuous options for which constraints are established as decision variable vectors. Of interest to this study are MADM methods, which handle finite sets of discrete options and are used to make decisions among them (Opabola & Galasso, 2022). The term MCDM is generally used to describe MADM methods and has also been used as such in this paper.

The four main steps followed in the appraisal process using MCDM techniques include; Specifying the problem's alternatives and criteria; Ascertaining the weights of each measure; Allocating individual performance to each option on each measure and; Assessing the alternatives based on how well they perform overall across all criteria (Alfares & Duffuaa, 2016). Numerous MCDMs have been put forward in literature such as WASPAS (Weighted Aggregated Sum Product ASsessment), WSM (Weighted Sum Model), PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations), ELECTRE (*ELimination Et Choix Traduisant la REalité*) TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), AHP (Analytic Hierarchy Process), EDAS (Evaluation based on Distance from Average Solution), BWM (Best Worst Method), COPRAS (COmplex PRoportional ASsessment), VIKOR (*Vise Kriterijumska Optimizacija I Kompromisno Resenje*), and MEREC (MEthod based on the Removal Effects of Criteria).

2.1.3.1. Fuzzy Sets

Fuzzy sets are groupings of numbers of uncertain quantities. They may also be likened to an addendum to Boolean logic whose sets are not limited to just 0 and 1, but a union of different values in which every value is given a weight. Fuzzy sets give more dynamism to expression. There are several kinds of fuzzy numbers including octagonal, pyramid, triangular, trapezoidal, pentagonal, and hexagonal fuzzy numbers with their use depending on the situation at hand (Ponnivalavan & Pathinathan, 2015). Researchers stated however that triangular fuzzy numbers and trapezoidal fuzzy numbers are the most popular (Klir & Yuan, 1995). This study thus incorporates the use of triangular fuzzy numbers for its purposes. This is a type of fuzzy number consisting of a set of three real numbers with weights that range from the minimum, most expected, and maximum weights.

2.1.3.2. Fuzzy AHP

FAHP is distinguished from its predecessor AHP through the use of fuzzy numbers derived from fuzzy logic theory rather than precise numbers to calculate criteria weighting (Alghassab, 2022). These offer the benefit of allowing for more freedom when allocating criterion weights. The FAHP approach also allows for the handling of quantitative and qualitative data better and is applicable in this study as the criteria being implemented in server virtualization alternatives' evaluation fall under both categories. FAHP is ideal for determining criteria weights and may be paired with another MCDM such as Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) to carry out the ranking of alternatives.

2.1.3.3. Technique for Order of Preference by Similarity to Ideal Solution

TOPSIS is one of the more common techniques utilized for solving MCDM problems, initially developed in 1981 (Hwang & Yoon, 1981). It uses two reference points i.e., a pair consisting of a Positive Ideal Solution (PIS) and a Negative Ideal Solution (NIS), to order a set of decision alternatives. TOPSIS works under the premise that the preferred choice will be closest to the PIS and farthest from the NIS. Thus, decision alternatives are ordered based on their distances to both reference points. TOPSIS is similar to how people make decisions in the real world and due to its relatability, intuitive reasoning, and relatively simple working theory, it is one of the predominant MCDM techniques in use by decision-makers (Corrente & Tasiou, 2023). It comprises a subjective weighting method and possesses robust computational performance and comprehensibility.

2.1.4. Examples of Server Virtualization Alternatives

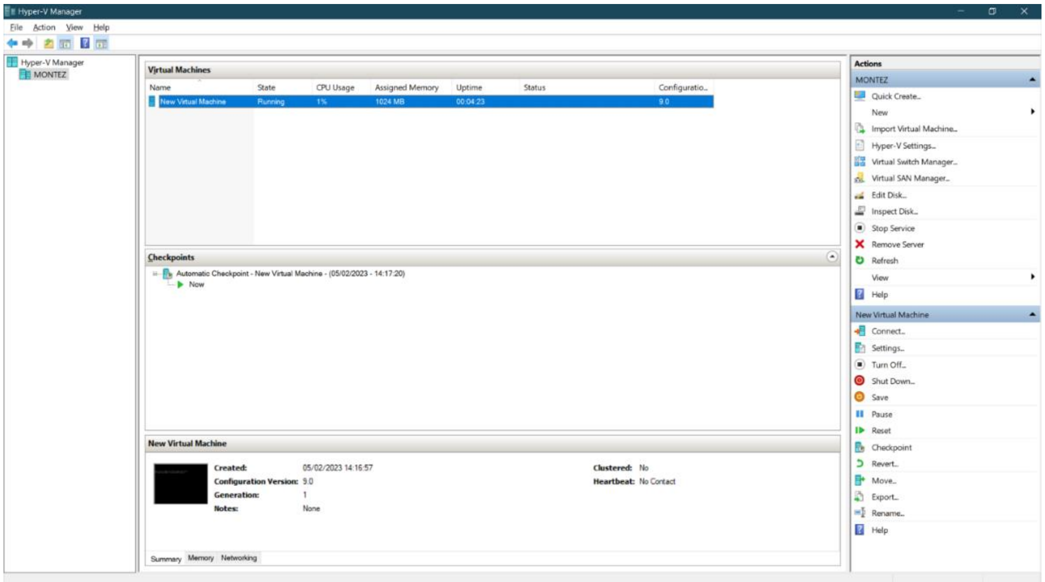
Although there are many virtualization options available today, the choice of vendors and solutions frequently depends greatly on the virtualization objectives and existing IT infrastructures. Companies can often choose from Microsoft Hyper-V, VMware vSphere, IBM Red Hat Enterprise Virtualization (RHEV), and Oracle VM Server for x86 among others when they require bare-metal (Type 1) hypervisors for production workloads. Organizations that currently rely on Microsoft Windows Server systems frequently use Microsoft Hyper-V. In systems running Linux, RHEV is often used and due to its extensive feature set and adaptability, VMware is quickly growing its market share in the virtualization industry.

2.1.4.1. Microsoft Hyper-V

Microsoft Hyper-V is a tool that adds enterprise-class virtualization to hybrid cloud and data centers. It assists customers in the growth or formation of private cloud environments in addition to encouraging optimal hardware utilization, improving business continuity, speeding up development and testing, and more. Hyper-V provides hardware virtualization, allowing the operation of virtual machines on virtual hardware, the creation of virtual hard drives, and even virtual switches. It also allows users to add several virtual devices to the setup. It is however limited in that programs that rely on particular hardware may not work as well on virtual machines, such as games that need GPUs (Cooley, 2022).

Figure 2. 2:

Microsoft Hyper-V Manager Interface

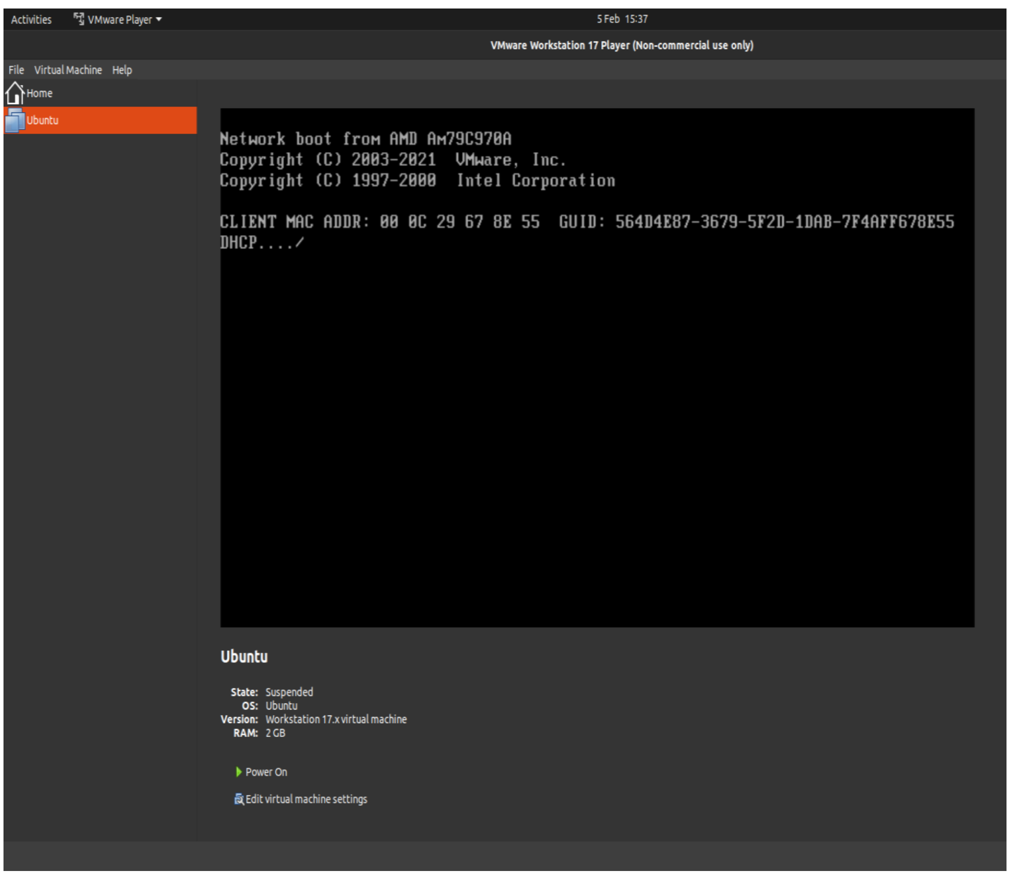


2.1.4.2. VMware vSphere

VMware vSphere is a collection of server virtualization tools that includes interface and administration layers for virtualization. It consists of elements like vCenter Server, which provides centralized management of all data center services, clients that may access the data center via the vSphere Client or a web browser, and infrastructure services like VMware vCompute, vStorage, and vNetwork. Its hypervisor also powers VMware Workstation Player. VMware offers integration to cloud services as well, interfacing with Kubernetes and operating containers simultaneously with Virtual Machines. It also increases the performance of services through its rapid DPU and GPU speeds (VMware, 2023).

Figure 2. 3:

VMWare User Interface

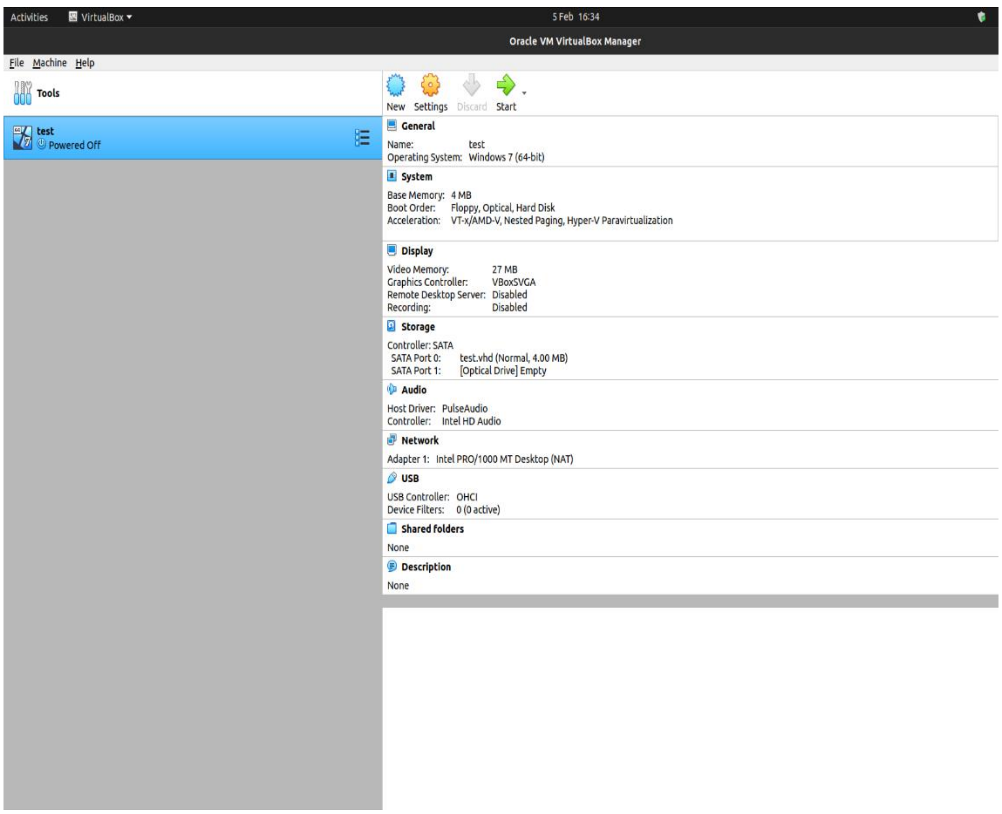


2.1.4.3. VirtualBox

Another virtualization software alternative available for both home and enterprise utilization is known as VirtualBox. This is an offering from Oracle and is publicly accessible as it is open source in nature. VirtualBox is feature-rich and is a high-performance multipurpose virtualization product for x86 hardware. It allows for guest additions such as programs and packages installed within the requisite guest systems and 3D virtualization as well as guest multiprocessing capabilities (Oracle, 1999).

Figure 2. 4:

Oracle VirtualBox User Interface

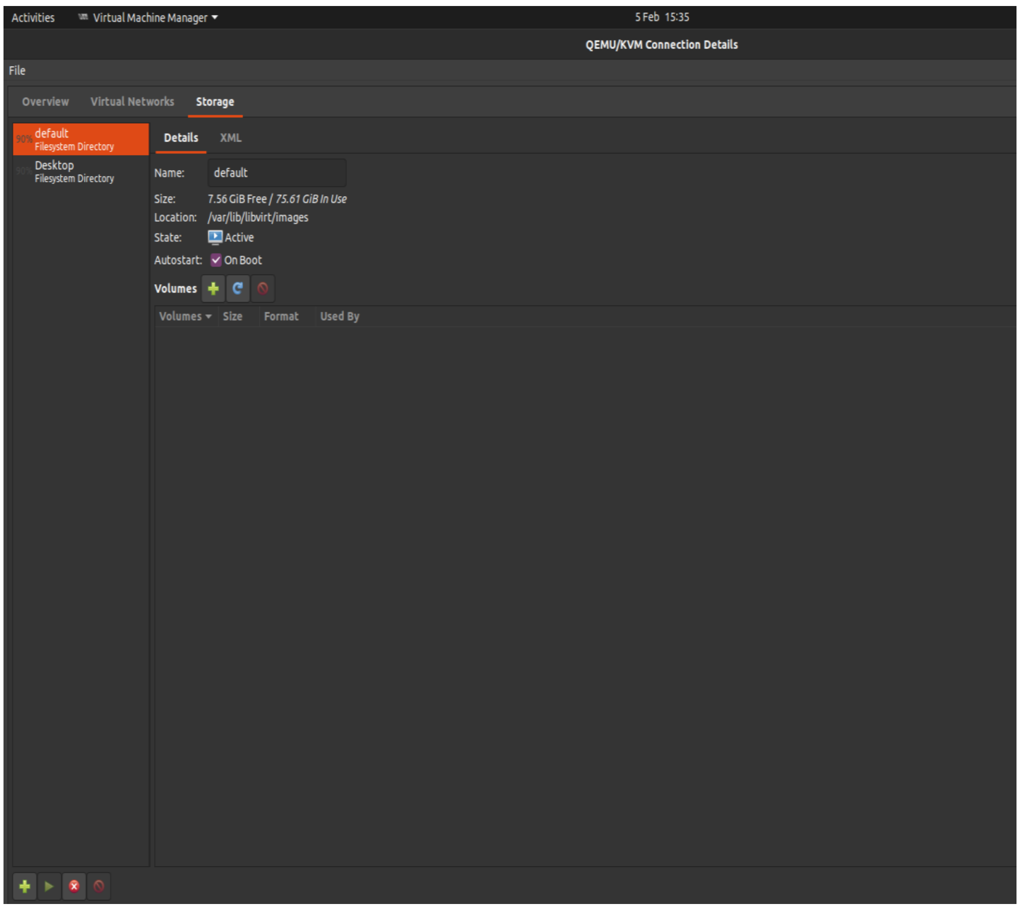


2.1.4.4. Red Hat KVM

Red Hat's KVM provides a complete infrastructure for virtualization. Kernel-based virtual machines turn the Linux kernel into a hypervisor. It is a part of the Red Hat Virtualization suite and was included in the mainline Linux kernel in kernel version 2.6.20. KVM makes it possible for Linux to act as a hypervisor, allowing a host system to run a variety of unique virtual environments known as guests (Red Hat, 2022).

Figure 2. 5:

KVM User Interface



2.2. Related Research

2.2.1. Rise of Green IT Approaches

The COVID-19 pandemic first surfaced in the Chinese city of Wuhan at the end of 2019, and it resulted in widespread fatalities, with a significant portion of the world's populace (6,873,477 people) succumbing to the disease (World Health Organization, 2023). In addition to the disease being an emergency health crisis, it also constituted an economic crisis as restrictions on movement both locally and internationally, social distancing, event cancellations, supply chain breakdowns, and staff shortages plagued the world in its wake (Shah et al., 2022) With this ensuing "new normal", individuals and corporations alike turned to different methods to mitigate the disastrous effects of the pandemic and ensure that they revert to business as usual in light of the circumstances. One of the methods sought out was in the IT sector and consisted of green IT technologies. This approach enabled its users to meet some of the COVID-19 restrictions while simultaneously being environmentally conscious with its applications. Virtualization played a big part in green IT technology as it enabled data centers to be staffed by fewer people, reducing the chances of contracting the disease as installation and maintenance of new physical servers were halted in favor of virtualized alternatives. With fewer resources on hand, companies had to ensure that their IT product offerings and infrastructure were designed to reduce energy consumption costs, which lowered organizations' carbon footprints. The pandemic brought about significant harm to the world, and efforts to mitigate this negativity propelled green IT technology into the limelight, causing its proliferation and increased analyses into more effective ways to implement it to reduce emissions of greenhouse gases and also practice sustainability in the IT sector.

2.2.2. Green Computing

Recent years have seen an accelerating increase in the usage of electric and electronic devices by people and businesses which contributes to an increase in the power demand. This increased power usage has increased the carbon footprint of the IT industry and subsequently raised the levels of greenhouse gas emissions from it to unprecedented heights (Kumar, et al., 2022). According to estimates, the worldwide IT sector currently generates 3.9% of the world's greenhouse gas emissions, but that percentage is expected to rise significantly over the next several years (Freitag et al., 2021). Each stage of an IT resource's lifecycle has been shown to cause environmental degradation, from their manufacture and use up to their eventual disposal (Asadi et al., 2017). A need thus arises for the prudent use of electronic devices in ways that minimize the consumption of energy, utilize the physical systems to their maximum efficiency, and encourage safe recycling and disposal of e-waste that is generated at any point in an IT resource's lifecycle (Kumar, et al., 2022). This is crucial to maintaining and improving the environment's cleanliness and safety.

Green computing refers to improvements in the efficiency of computing devices and the resultant reduction in the negative effects they may have on people and the environment at large. It is the use of IT resources in a manner that conserves energy and reduces costs while being conscious of and trying to preserve the ecological balance that nature exhibits (Bose & Luo, 2011). The term green IT is used interchangeably with green computing henceforth and was first coined in a report, becoming commonplace ever since (Mingay, 2007). Green computing focuses on the process of creating, assembling, and utilizing computers, servers, and associated auxiliary accessories in ways that seek to increase energy efficiency while reducing environmental degradation.

There are several alternatives available for corporations and individuals alike to pursue green computing to achieve their strategic goals and mitigate the damage rendered to the environment by the IT sector. These include virtualization, utilizing renewable energy sources to power data centers, product and infrastructure design, and e-waste reduction (Asadi et al., 2017).

2.2.3. Server Virtualization

Since its origins in the 1960s by IBM for its mainframe operating systems, virtualization has advanced significantly. It is a green computing technology that allows a system administrator to combine different physical computing systems into "virtual machines" or those digitally generated by computers, in a way that is as energy-efficient as possible, while also minimizing hardware idle time and subsequently lowering the power consumption of the overall system (Liu et al., 2011). Virtualization enables a company to reduce the total number of server locations or servers that a company may require while allowing for server consolidation initiatives to be undertaken, which consist of transferring server activities to virtual machines. With the pulling together of underused and loosely-coupled resources, virtualization produces computer elasticity and scalable software solutions while also helping businesses to save labor and maintenance expenses.

Virtualization may be classified into two types, namely OS (Operating System) Level Virtualization and Hypervisor Virtualization (Liu et al., 2011). OS-level virtualization involves running independent virtual machines on the same physical server. This is also known as OS sharing and consists of a host OS placed below the virtualization layer being used to manage a pool of hardware resources. The ability of the host OS to connect directly with hardware resources and distribute them across virtual machines enables this architecture to achieve higher flexibility as programs may execute virtually on the guest OS or the host OS (Desai, 2007). Hypervisor Virtualization does not depend on a host OS contrary to OS-level virtualization but instead has its virtualization layer directly communicate with hardware resources. This thus enables it to act in the same manner as a host OS found in OS-level virtualization, and it can share computing resources such as storage, processing power, and networking capabilities. As a result, the overhead expended by the host OS is avoided (Liu et al., 2011).

Virtualization is a crucial facet of green computing, with benefits such as more efficient consolidation of server resources, cost savings, reduced carbon footprint from lessened total power consumption levels, increased power usage effectiveness, and overall increased data center efficiencies (Ogunyemi & Johnston, 2017). Virtualization also has positive strategic implications for corporations as the reduced power and labor costs translate directly to reduced operating expenses, shoring up a company's bottom line. It also improves fault tolerance and increases security within a corporation's operations (Soriga & Barbulescu, 2013).

There exist several virtualization alternatives on the market that corporations may use for their operations, such as Microsoft Hyper-V Server, VMware vSphere, VirtualBox, and Red Hat KVM, which all take advantage of hypervisor architecture to offer virtualization solutions to companies. Businesses need to evaluate and contrast these and other alternatives to pick the optimal option best suited to their needs and properly handle this green computing approach to reap the dual benefits of environmental conservation and utilization of this strategic resource.

2.2.4. Evaluation Techniques of Green IT Approaches for Server Virtualization

Several evaluations have been carried out over time to analyze the performance of server alternatives. A study was carried out to determine the suitability of server virtualization in companies to find out which business processes are appropriate for virtualization (Tanaka et al., 2009) The researchers selected DIVT (Direct IO Virtualization Technology) as their virtualization alternative out of four options which also included VMware ESX 3, Hitachi Prototype Virtualization, and Xen 3.0 upon which they proceeded to test the performance features of specific virtualized business applications. The researchers determined that DSS (Decision Support Systems) and Web Servers were the most appropriate business applications for virtualization, with DSS scoring 80-90% more in performance metrics while virtualized as compared to unvirtualized scenarios. They also determined a set of ideal characteristics for the selection of business applications to be virtualized and these include frequent access to relatively large files and heavy disk input/output coupled with low CPU utilization in the database server. The researchers primarily focused on a business-first approach while investigating the server virtualization alternatives, which was a unique method as opposed to pure performance analysis of virtualization alternatives. They however did not consider a wider array of quality characteristics to test for while conducting their study.

A related study did not implement a business-first approach in their research, but instead limited themselves to a solely performance-focused evaluation of virtual servers, particularly within KVM (Kernel-Based Virtual Machine) virtualization (Yang & Lan, 2015). The researchers conducted their study by analyzing the performance characteristics of virtual servers and inspecting the actors that influence performance in conjunction with the implementation of KVM virtualization. The researchers identified the throughput and response time of the system as necessary metrics for virtual servers.

They then constructed a performance model of the KVM built upon the queueing network model by the analytic method. A case study was subsequently used to prove the efficacy of the study's performance evaluation model which consisted of two experiments, each of which verified the researchers' proposed model for the performance evaluation of KVM servers. The researchers recognized the complexities that arose when analyzing virtual servers and were able to pinpoint specific performance criteria of throughput and response time, which are adequate measures of performance, but also leave the evaluation process lacking a more holistic approach.

A different study put forward a model for the utilization of server virtualization alternatives but with a focus on their use in the deployment of a cloud computing platform (Ding et al., 2016). They recognized the advantages that server virtualization offers to data centers such as total cost benefit, energy efficiency, and time efficiency, and noted that these benefits could directly transfer to cloud computing platforms as well if the two are implemented in tandem. The paper goes into detail on three technologies utilized for x86 CPU virtualization namely full virtualization using binary translation, OS-assisted virtualization, and hardware-assisted virtualization. The researchers develop a framework for the implementation of a cloud computing platform through virtualization, which was reviewed and found to share several of the same advantages that server virtualization possessed such as the faster deployment of applications and reduced hardware costs. The study acts not only as a proof-of-concept for the transferrable benefits that virtualization can endow cloud computing with but also focuses mostly on the performance evaluation aspect, particularly on metrics such as time, energy, and cost efficiencies. While these are important metrics, their augmentation with additional salient feature measurement metrics would make for a more robust model.

In line with the preceding work above, a different study noted the importance of virtualization and its necessity for cloud computing due to its provision of a platform that supports rapid deployment and scalability of resources (Elsayed & Abdelbaki, 2013). They identified a hypervisor as a crucial software component that allows for the running of multiple operating systems simultaneously on a single physical server and sought to compare and contrast the performance of different hypervisors on the market qualitatively and quantitatively. The hypervisors under consideration included Microsoft Hyper-V2008R2, Citrix XenServer 6.0.2, and VMware ESXi5. The researchers carried out software simulations under different scenarios but with each hypervisor being tested on a physical server with the same specifications. These simulations made use of tailored SQL (Structured Query Language) instances that mocked up real-life situations and their corresponding workloads to test performance. In tests to identify the hypervisor with the most effective SQL database performance, VMware ESXi5 emerged the winner, while in tests to determine the hypervisor with the most effective host server CPU utilization and heavy load management, the Citrix Xen Server beat out the other two. The Microsoft Hyper-V was identified as the best at the tests for memory handling. The study also noted that the implementation of server virtualization necessitated a reduced amount of staff and provided significant cost savings to corporations, a common theme for green computing. The performance evaluation was mostly geared toward metrics such as database performance, CPU utilization, and memory handling. While these metrics serve their purpose in the performance analysis of virtualization alternatives, they are still limited and do not constitute a rounded approach to the overall analysis process.

The prevalence of performance analysis is evident, with a different set of researchers conducting a study where performance comparisons between four virtualization alternatives in the market i.e., Xen, KVM, vSphere, and Hyper-V were carried out to better understand the overheads incurred by their use and how they perform under different workloads (Hwang et al., 2013). The results of the study showed that there is no clear winner and thus no perfect virtualization alternative, as different applications perform differently on different hypervisors and require varying features to work optimally. Overall vSphere performed better in the tests, however, each of the remaining hypervisors excelled in at least one benchmark outperforming its competitors. The tasks that resulted in the lowest level of overhead were observed to be CPU and memory-associated tasks, with higher overhead being noted for IO activities and multicore engagement. Despite there not being a standout champion, the researchers' recommendation for the utilization of multiple virtualization alternatives simultaneously was novel, as this in effect would create heterogeneous data centers where hypervisors may be swapped according to the needs of applications to ensure their smooth running and improve efficiency. This approach dispels the one-size-fits-all option and takes performance considerations on a case-by-case basis.

Another study was also carried out to ascertain the performance of different hypervisor solutions and contrast the efficiency of their main components (Graniszewski & Arciszewski, 2016). A CPU test, NIC test, HDD test, memory test, and kernel compilation were carried out using benchmarking tools such as *ramspeed, filebench, Netperf,* and *nbench*. The researchers concluded that VMware ESXi was the superior alternative and proceeded to identify VMware ESXi and Microsoft Hyper-V as the primary candidates for use in an enterprise-level virtualization operation as they possessed more features compared to competitors. Despite this, they noted that XenServer was ideal for smaller-sized operations with relatively good performance scores and affordability. The paper also noted that the organizations that would best benefit from an Oracle hypervisor were those already using other Oracle products due to the server alternative's smaller feature set and complex set-up procedures. The researchers' results contradict those of the preceding study which posits that no clear winner would be discernible in a performance evaluation of virtualization alternatives and this may be attributed to the difference in tests carried out as one study primarily analyzed workload overheads while another analyzed performance benchmarks (Hwang et al., 2013).

Similar to the aforementioned study, another set of researchers carried out a study where they compared the performance between different server virtualization alternatives to measure and benchmark their performance concerning file system I/O, CPU performance, network activity, and memory handling (Muditha & Keppitiyagama, 2011). The tests were carried out on two popular hypervisors on the market i.e., VMware ESXi and Xen, and benchmark tests were handled using tools such as Netperf to test network performance, RAMSpeed/SMP to test memory handling, IOzone to test the file system's I/O performance and a kernel compile in conjunction with an application build test and graphics manipulation analysis to test the CPU performance of the two hypervisors. The researchers concluded that while both server virtualization alternatives met their design goals, Xen was better than ESXi in CPU performance but only by a small margin. ESXi however outperformed Xen when it came to network performance while Xen was faster in handling the file system's I/O operations.

An alternative group of researchers had a unique approach in their performance analysis of server virtualization alternatives, which entailed inspecting the alternatives through the lens of several models and thus gauging the benefits offered by the green computing approach (Gemikonakli et al., 2010). They primarily made use of queuing models to determine performance measures such as response time, mean queue length, and utilization of virtual servers. The study was able to demonstrate through models employed that server virtualization should be considered when the server machines were under-utilized. They also indicated that virtualization corresponded with an increase in system utilization as compared to traditional approaches. However, they noted that heavy traffic degraded performance significantly in virtualized systems and made it unsuitable for this particular case implementation. The researchers emphasize the necessity of first calculating the system performance of virtualized systems and traditional systems to gain a better understanding of the facts and make better decisions concerning virtualization.

While most server virtualizations evaluated consisted of bare-metal hypervisors such as VMware and XenServer which are installed directly onto a physical host server, Virtual Private Servers (VPS) also exist. A VPS is a virtual computer that provides virtualized server resources on the cloud. In contrast to shared hosting, VPS hosting provides dedicated cloud server space with a certain number of resources and gives more flexibility and customization. Researchers conducted a study where they evaluated the performance of VPS on the market (Balen et al., 2020). They recognized the fact that virtualization is cost-effective, using less equipment and resources than a cloud computing approach, and that VPS is a pragmatic green computing initiative that lowers an organization's carbon footprint. The researchers compared Digital Ocean, VULTR, and Linode through a series of tests that analyzed performance measures such as CPU scheduling, hard disk drive management, memory management, and Unix OS system task scheduling. The study determined that VULTR was the ideal VPS for low and medium-demand users while higher-demand users would be best suited by Digital Ocean which consequently was found to be a high-performance VPS. The study's unique focus on VPS as opposed to bare-metal virtualization offers an alternative perspective to the world of virtualization and elucidates that there are additional options available to choose from if one is so inclined to do so. Nevertheless, the researchers also paid more attention to performance metrics such as CPU scheduling, memory management, and task scheduling as opposed to a more rounded approach in their analysis.

As discussed above, bare-metal hypervisors primarily function on physical servers. However, a study was carried out where server virtualization alternatives were evaluated on desktop-class systems instead, as opposed to server-grade hardware (Pousa & Rufino, 2017). They noted that properly configured desktop hardware was often utilized as servers as they were more affordable than acquiring actual servers for the purpose. The virtualization alternatives they examined included Proxmox, Citrix XenServer, VMware ESXi, oVirt, and Microsoft Hyper-V and the researchers evaluated them using benchmark applications such as UnixBench and PassMark. The virtualization alternatives were stress-tested to see how well CPU, memory, GPU, local and remote storage, OS, and network links held up under multiple workloads. The researchers conclude by recommending Citrix XenServer, VMware ESXi, and oVirt as their top choices based on their performances under testing. The study was also distinct as it took into consideration additional parameters, not limiting itself solely to performance metrics. The researchers noted that other factors such as the organizational culture, the technical background of the IT employees, and the budget allocated for IT should also be considered as influential elements in the decision-making process when companies select server virtualization alternatives. The increased scope of measurement bodes well for future studies, as an overreliance on cut-and-dry performance metrics makes it difficult to consider other stakeholders who might be affected by virtualization decisions, such as the actual IT staff themselves as this study elucidates.

The scalability of virtualization software is an oft-neglected characteristic in their evaluation, and this is an oversight that researchers sought to correct in their study where they analyzed the scalability and performance between two popular server virtualization alternatives, KVM and Xen (Soriga & Barbulescu, 2013). The researchers examined what influence the number of virtual machines exerts on benchmarks measuring I/O throughput, network, and compute power. The results show that both alternatives performed adequately based on scalability, while Xen exhibited a slight performance advantage in measures of CPU power. The study noted that once the number of virtual machines exceeds the number of physical cores, performance drops across the board. This is a problem that can be mitigated slightly through hyperthreading. Both alternatives showed similar network performance upon testing while virtual disk I/O was identified to be the most troublesome area for virtualization, with the hypervisors only achieving 30-50% of I/O throughput compared to the usage of real hardware. The analysis of the scalability capacities of virtualization alternatives equips decision-makers with more data as to how well the options function under pressure and can make for an intriguing metric to look out for.

A group of researchers carried out a study to compare the performance of two server alternatives, namely KVM and Proxmox (Dordevic et al., 2022). They clarified that Proxmox implements some elements of KVM behind the scenes for its functionality and this was corroborated with the results of their performance analysis, which identified that in general, both server virtualization alternatives performed in a relatively similar manner. However, it was noted that KVM outperforms Proxmox in workloads involving random file access and web servers, while Proxmox outperformed KVM when it came to workloads involving file servers and mail servers. The study noted that there was no overall winner between the performance tests of the two hypervisors as they both exhibited stellar scores in half of the tests administered. The results of this study, while inconclusive, may have benefitted from a different approach in the evaluation as opposed to strict reliance on performance metrics which have been shown to yield uneven results across the board.

2.2.5. ISO/IEC 25010 Standards and MCDM in Evaluation Applications

The aforementioned studies indicate that while server virtualization is an important area of research, researchers tend to focus their efforts on the use of limited performance metrics. Fleeting efforts are made to pay attention to more holistic aspects and metrics such as the opinions of stakeholders and the implications that their choice of virtualization software may have on the organization, be it cost or compatibility with the overall strategy of the corporation. The use of a different set of metrics, such as ISO/IEC 25010 may lay the foundation of an alternative framework for the evaluation of said server virtualization alternatives. This is in conjunction with a varied approach to decision-making such as Multi-Criteria Decision-Making Methods which involve the use of tools to analyze, evaluate and rank prospective alternatives given various differing criteria (Opabola & Galasso, 2022).

A team of researchers conducted a study where they compared two chatbot versions with a set of metrics derived from ISO/IEC 25010 standards (Barletta et al., 2022). This comparison was facilitated through the use of AHP which calculated criteria weights. The authors postulated that the standard provided robust features for the evaluation of software products and was ideal in determining a set of characteristics upon which to measure the quality of chatbot versions. This approach described an alternate way of analyzing software products as opposed to the strict performance norms exhibited by the evaluation of server virtualization alternatives and was more rounded in its assessment. While it does not involve server virtualization directly, the virtualization alternatives are software in their composition and the application of said standards may translate in some form to the subject matter at hand.

Some researchers also conducted a study that implemented the use of ISO/IES standards to evaluate the software quality of a web application that they developed for making value decisions through environmental MCDM (Haag et al., 2022). They recognized that the field of environmental and public policy was riddled with complex decision-making and sought to mitigate this problem such that choices could be made by stakeholders without the need for programming knowledge. Once their application was operational, they tested its quality by evaluating it via the lens of operationalized

ISO/IEC standards for software quality. This enabled the researchers to receive important feedback, from which they were able to make improvements to the web app's quality and functionality. The study shows that ISO/IEC standards have great potential to be utilized as evaluation criteria and can be an important source of quality management and upgrades to software products.

A team of researchers carried out a study to evaluate the quality and user satisfaction of Mobile Learning Applications for Mathematics (MLAM) by integrating FAHP and TOPSIS MCDM methods (Başaran & Haruna, 2017). The researchers developed a framework consisting of technical and non-technical features of MLAMs. They then proceeded to use these to derive their criteria and evaluate the applications to determine the best one overall. This resulted in the application *Mathematics* being ranked first. This approach also handles the problem of deciding from a single perspective as it instead combines several aspects along with a robust MCDM method to decide.

2.2.6. Summary

Server virtualization is an increasingly relevant research topic, especially in the wake of recent events such as COVID-19 and the push for corporations to be more environmentally conscious of their operations. While studies exist as to the performance evaluation of server virtualization alternatives, these often overlook other key metrics such as the effect the choice has on stakeholders, instead choosing to focus on black-and-white metrics like CPU performance and memory management, which is limiting in nature. The lack of availability of a predetermined set of characteristics upon which to evaluate virtualization may be mitigated through the implementation of the ISO/IEC 25010 software quality model as this is a comprehensive approach to analyzing software products and accurately handles the stakeholders' needs, as diverse as these may be. The implementation of the standards in evaluating software has been proven with researchers able to successfully utilize it to analyze software products, effect improvements on them where necessary and even decide between several software alternatives such that a choice on the most appropriate one concerning the need at hand is made. MCDM is also a key component in the decision-making process and has been coupled with the standards in some cases to enable researchers to select appropriately between options. The application of MCDM in the evaluation of server alternatives is also largely overlooked, with researchers choosing instead to focus on more traditional performance measurement metrics. This study seeks to apply these two facets gleaned from the literature review, i.e., the ISO/IEC standards coupled with MCDM to carry out a unique evaluation of server virtualization alternatives that does not overly focus on performance metrics but instead incorporates more rounded attributes in evaluating the options available. This will build on the already existing literature and improve how corporations make choices when it comes to selecting ways in which to implement this green computing approach.

CHAPTER III

METHODOLOGY

This chapter describes the research methodology for the entire study, including the research model, the instruments utilized in the research process, techniques used for data analysis, the research procedures, and ultimately research timetables.

3.1. Selected Criteria

The goal of this study is to compare and contrast server virtualization alternatives through the use of a hybrid multicriteria decision-making method i.e., FAHP-TOPSIS, to determine the best alternative to be implemented to benefit users. As research into ranking server virtualization alternatives through the use of MCDM is scant, additional research was carried out to identify appropriate criteria through which to evaluate the available alternatives. The use of ISO/IEC 25010 was deemed appropriate to apply in the quest of determining evaluation criteria as its product quality model aims to evaluate the software/system product's factual quality features (International Organization for Standards, 2022). These will enable the comparison between server virtualization alternatives to determine their weights and performance levels and subsequently rank them. The aforementioned approach thus proposes the following decision criteria for use in the evaluation of server virtualization alternatives as shown in Table 3.1 below:

Table 3. 1:

Adopted server virtualization evaluation criteria

Proposed Sub-Criteria	Corresponding Value
Functional appropriateness	C1
Performance Effectiveness	C2
Compatibility	C3
Usability	C4
Dependability	C5
Security	C6
Maintainability	C7
Portability	C8

3.2. Selected Server Virtualization Alternatives

The server virtualization alternatives included in the study consisted of Microsoft Hyper-V, VMware vSphere, VirtualBox, and Red Hat KVM. These were chosen after careful consideration of the available options currently on the market coupled with a thorough analysis of reputable online reviewers, and also the inspection of past studies on the matter (G2, 2023; Gartner, 2023; Jethva, 2022).

3.3. Data Collection

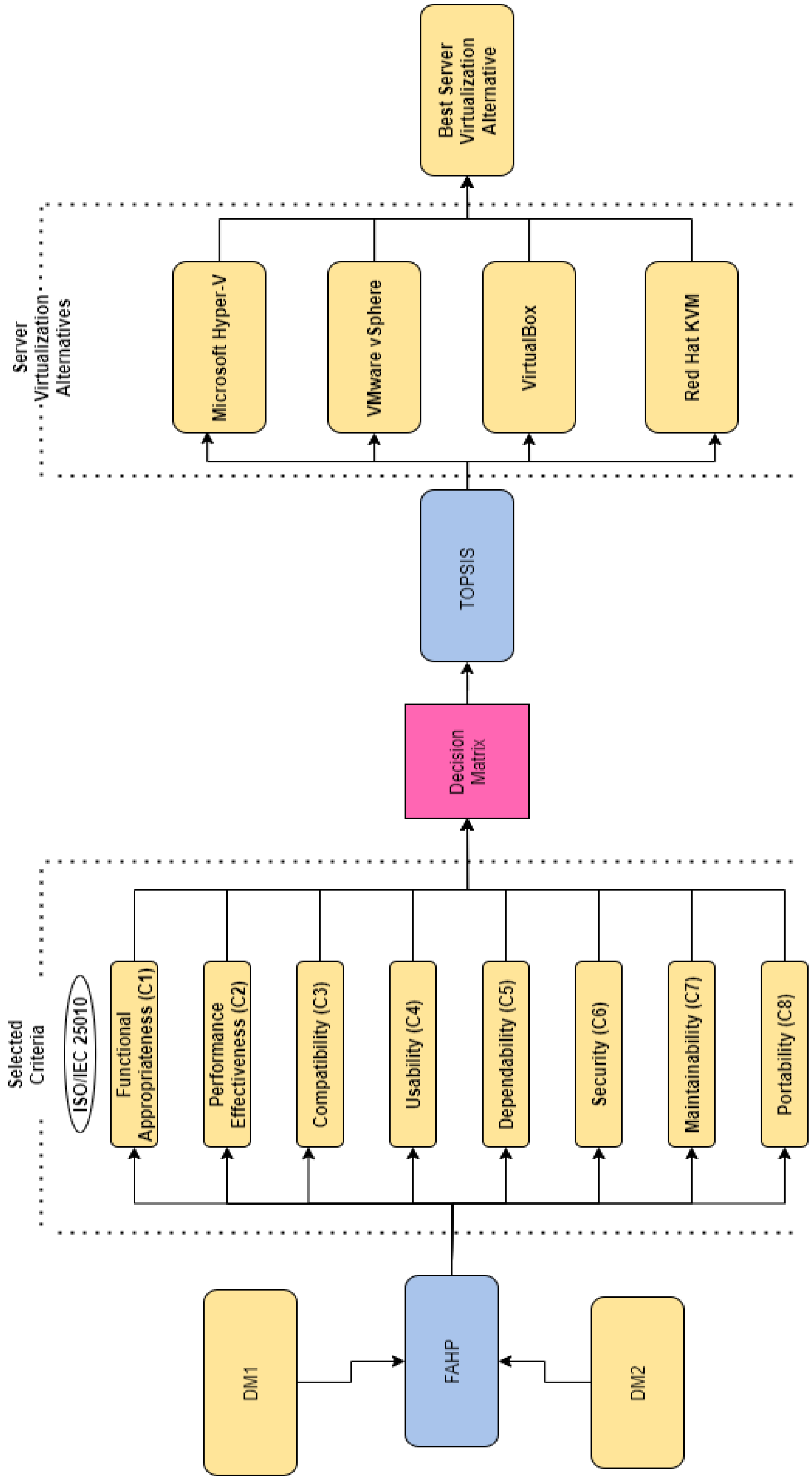
The data was collected through the combined efforts of the supervisor and the author, both of who possess a background in Computer Information Systems and are referred to as Decision Maker 1 (DM_1) and Decision Maker 2(DM_2) respectively for this study. Two decision-makers were arrived at as the optimal number for the study and this stemmed from a review of prior related research, with decision-makers varying from as few as one to as many as three in number (Samanlioglu, et al., 2018; Başaran & Haruna, 2017). The DMs assessed the server virtualization alternatives on hand against the selected criteria to determine their respective rankings.

3.4. Selection and Evaluation Method

The current study evaluates server virtualization alternatives with sub-criteria derived from the ISO/IEC 25010 standards on software quality. The eight decision sub-criteria obtained from the standards are utilized in conjunction with a hybrid MCDM technique namely FAHP and TOPSIS. The adopted method seeks to combine the strengths of both these MCDM techniques, with FAHP's rigorous weighting method and TOPSIS's efficacy and straightforward working theory to rank conclusively among alternatives (Alghassab, 2022; Corrente & Tasiou, 2023). This framework allows for the holistic analysis and ranking of the four server virtualization alternatives sampled from the market.

Figure 3. 1

Hierarchy structure for decision-making problem for server virtualization alternatives



3.4.1. Hybrid FAHP-TOPSIS Model

The hybrid MCDM method consists of FAHP which is utilized in weighting the criteria, while TOPSIS is utilized for the rankings of server virtualization alternatives.

3.4.1.1. Triangular Fuzzy Numbers

This is the set of three actual values that make up this type of fuzzy number and it spans the least, most likely, and highest weights. This stems from fuzzy set theory, which may be defined as a mathematical theory of groupings with blurred boundaries. To mitigate any distortion of information garnered from human discretion, a linguistic scale is employed to convert linguistic preferences into fuzzy numbers (Lin, 2013). This scale shown in Table 3.2 enables a pairwise comparison to be carried out on a scale of 0-4, with a score of 0 indicating “no influence”, 1 indicating “very low influence”, 2 indicating “low influence”, 3 indicating “high influence” and 4 indicating “very high influence”.

Table 3. 2:

Fuzzy linguistic scale

Linguistic Terms	Influence Score	Triangular Fuzzy Number
No influence (NI)	0	(0, 0.1, 0.3)
Very low influence (VLI)	1	(0.1, 0.3, 0.5)
Low influence (LI)	2	(0.3, 0.5, 0.7)
High Influence (HI)	3	(0.5, 0.7, 0.9)
Very High Influence (VHI)	4	(0.7, 0.9, 1)

Note. Adapted from *Using fuzzy DEMATEL to evaluate the green supply chain management*. (Lin, 2013).

3.4.1.2. FAHP Steps

- **Step 1**: Hierarchical level weights (HLW) are first determined, as the significance of the DMs' verbal assessments differs depending on their hierarchical skill level as shown in Table 3.3 (Samanlioglu, et al., 2018).

Table 3. 3:

Linguistic terms and comparable intuitionistic fuzzy numbers (IFNs) to evaluate DMs' verbal analyses

Linguistic Terms	IFNS $D_k = (\mu_k, \pi_k)$
Very important	(0.80; 0.10)
Important	(0.55; 0.25)
Medium	(0.50; 0.50)
Unimportant	(0.30; 0.50)
Very unimportant	(0.20; 0.70)

Note. Adapted from *A Fuzzy AHP–TOPSIS-based group decision-making approach to IT personnel selection.* (Samanlioglu, et al., 2018)

Thus, assuming that there are *l* DMs, the HLW for DM *k*, denoted as λ_k, is computed through the application of the associated intuitionistic fuzzy number (IFNS) $D_k = (\mu_k, \pi_k)$ shown in Table 3.3 above as:

$$\lambda_k = \frac{\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)}{\sum_{k=1}^{l} \mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)}, \text{ where, } \sum_{k=1}^{l} \lambda_k = 1 \tag{3.1}$$

For each comparison in fuzzy AHP, the weighted average of each DM's evaluation using the HLW λ_k is used to produce the aggregate, total evaluation scores of the DMs as follows, where P*k* is the *k*th DM's assessment score.

$$\sum_{i=1}^{k} \lambda_k * P_k \tag{3.2}$$

Once this is calculated, let DM represent the number of Decision Makers that assess the criteria where:

$$\{DM_1, DM_2, \dots, DM_K\} \text{ (K} \geq 2) \tag{3.3}$$

For this research, DM = 2. DMs assign verbal variables on assessment of the criteria which are then transformed into their corresponding fuzzy numbers and develop a fuzzy evaluation matrix.

- **Step 2:** The value of the fuzzy artificial extent regarding the i^{th} object is calculated as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \oplus \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{3.4}$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$, the fuzzy addition computation of *m* extent analysis digits for the certain matrix is calculated as:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3.5}$$

To arrive at $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]$, calculate the fuzzy addition computation of $\mathrm{M}_{gi}^{j} (j = 1, 2, \dots,)$ such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3.6}$$

And $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ can be computed by the inverse of Equation 3.3 as shown below:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right) \quad (3.7)$$

- **Step 3:** If $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ constitute two triangular fuzzy digits, the extent of the chance of $M_2 \geq M_1$ is established as:

$$(M_2 \geq M_1) = \underset{y \geq x}{\mathrm{SUP}} \left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \quad (3.8)$$

And as a result, can be equally expressed as:

$$V(M_1 \geq M_2) = hg\,t(M_1 \cap M_2) = \mu_{M_1}(d) = \begin{cases} 1 & \text{if } m_1 \geq m_2 \\ 0 & \text{if } l_2 \geq u_1 \\ \dfrac{(l_2 - u_1)}{(m_1 - u_1) - (m_2 - l_2)} & \text{Otherwise} \end{cases} \quad (3.9)$$

Where *d* is the ordinate of the highest meeting point uniting $\mu(M1)$ and $\mu(M2)$.

To contrast $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the values of $V(M_1 \geq M_2$ and $VM_2 \geq M_1$ are required.

- **Step 4:** The magnitude likelihood for a convex fuzzy digit to be larger than k convex fuzzy M_i $(i = 1, 2, \ldots, k$ digits may be conveyed by:

$V(\mathrm{M} \geq \mathrm{M}_1, \mathrm{M}_2, \ldots, \mathrm{M}_k) = v[M \geq M_1$ and $M \geq M_2$ and $M \geq M_k] = minv\ M \geq M_1, i = 1, 2, \ldots, k$

(3.10)

Assuming:

$\mathrm{d}'(A_i) = minV(\mathrm{S}_i \geq S_k)$ for $k = 1,2, \ldots, n; k \neq i$, The weight factor is then given by computing

$$W' = \left(d'(A_1), d'\left(A_2, \ldots, d'(A_n)\right)^{\mathrm{T}}\right. \quad (3.11)$$

Where A_i $(i = 1, 2, \ldots, n)$ are n elements.

- **Step 5:** Lastly, normalization, yields the weight vectors (Samanlioglu, et al., 2018).

$$w = \left(\mathrm{d}(A_1), \mathrm{d}(A_2), \ldots, \mathrm{d}(A_n)\right)^T \tag{3.12}$$

3.4.1.3. TOPSIS

Let DM represent the number of Decision Makers that assess the criteria where:

$$\{DM_1, DM_2, \ldots, DM_K\} \; (\mathrm{K} \geq 2) \tag{3.13}$$

For this research, DM = 2. DMs evaluated the alternatives on hand against the criteria and subjected them to ratings on a scale of 0-10 to form decision matrices.

- **Step 1:** Calculate the normalized decision matrix with the digit r_{ij}:

$$r_{ij} = x_{ij} \sqrt{\sum_{i-1}^{m} x_{ij}^2} i = 1,2, \ldots, m \text{ and } j = 1,2, \ldots, n \tag{3.14}$$

- **Step 2:** Calculate the weighted normalized decision matrix with the digit v_{ij}:

$$v_{ij} = r_{ij} \times w_j \mathrm{i} = 1,2, \ldots, \mathrm{m} \text{ and } \mathrm{j} = 1,2, \ldots, \mathrm{n} \tag{3.15}$$

Where w_j is the designated weight of each j^{th} criterion $\sum_{j=1}^{n} w_j = 1$

- **Step 3:** Then calculate the ideal (A^*) and negative ideal (A^-) solutions.

$$A^* = \left\{\left(\max_i v_{ij} \mid j \in C_b\right), \left(\min_i v_{ij} \mid j \in C_c\right)\right\} = \{v_j^* \mid j = 1,2, \ldots, m\} \tag{3.16}$$

$$A^- = \left\{\left(\min_i v_{ij} \mid j \in C_b\right), \left(\max_i v_{ij} \mid j \in C_c\right)\right\} = \{v_j^- \mid j = 1,2, \ldots, m\} \tag{3.17}$$

- **Step 4:** Next is the calculation of separation measures using the m-dimensional Euclidean distance of every alternative from the positive and negative ideal solutions:

$$S_i^* = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^*\right)^2}, j = 1,2, \dots, m \quad (3.18)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2}, j = 1,2, \dots, m \quad (3.19)$$

- **Step 5:** This is followed by the calculation of the relative nearness to the ideal solution of the alternative A_i with regards to A^* as shown below:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1,2, \dots, m \quad (3.20)$$

- **Step 6:** Lastly, rank according to preference scores, i.e., in decreasing order of closeness coefficient from best to worst (Samanlioglu, et al., 2018).

3.5. Research Procedure

The study was carried out in line with the ensuing successive phases:

1. A review of prior literature was carried out focusing on the associated research field to determine the reason previous research was carried out, how the studies were carried out and their findings to gain a better understanding of the subject and discover any study gaps.
2. A research proposal was approved by the department to conduct the study.
3. A conceptual framework was constructed to assess the quality of server virtualization alternatives in line with the results gleaned from the literature review

4. A research model based on ISO/IEC 25010 quality standards was developed and used to derive evaluation criteria upon which the server virtualization alternatives could be evaluated.
5. FAHP and TOPSIS were utilized to assess the four selected server virtualization alternatives.
6. Discussion of the results and subsequent recommendations based upon these were drawn up.

3.6. Research Schedules

The study took 12 weeks to complete as shown in Table 3.4 and the Gantt Chart depicted in Figure 3.2.

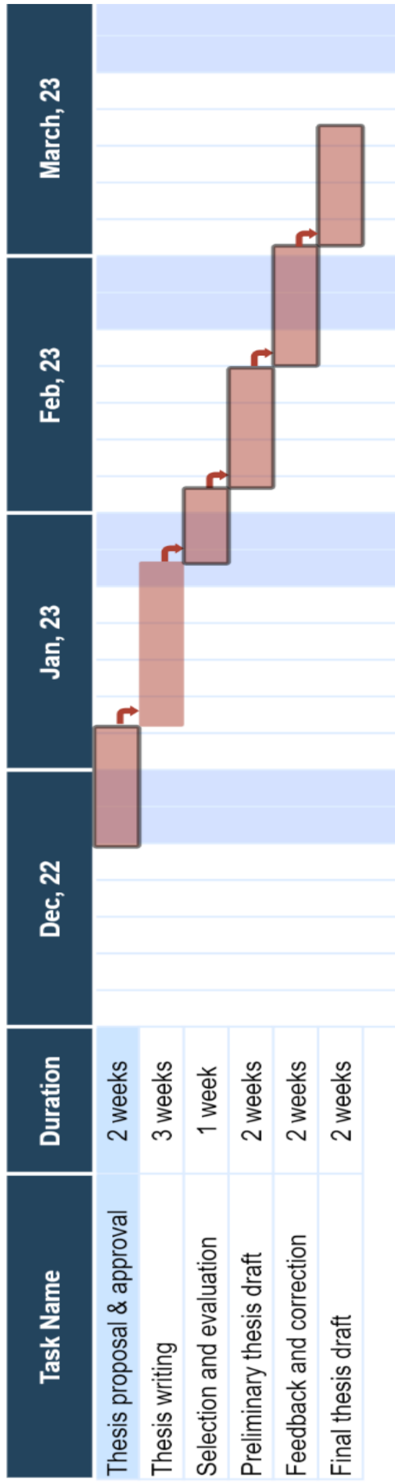
Table 3. 4:

Research schedule

Task	Duration
Thesis proposal and approval process	2 weeks
Thesis writing	3 weeks
Sample selection and evaluation process	1 week
Preliminary thesis draft	2 weeks
Feedback from supervisor and correction of thesis	2 weeks
Final thesis Draft	2 weeks
Total	12 weeks

Figure 3. 2:

Gantt Chart



CHAPTER IV

RESULTS AND FINDINGS

This chapter demonstrates and discusses how to choose the optimal server virtualization alternative utilizing the FAHP and TOPSIS methods from among four competing alternatives that were sampled, namely Red Hat KVM, VirtualBox, Microsoft Hyper-V, and VMware vSphere.

4.1. Evaluation of Server Virtualization Alternatives

4.1.1. FAHP

The FAHP evaluation method commenced with a pairwise comparison matrix developed under a linguistic scale. The proposed linguistics scale along with associated TFN values are described in the following Table 4.1:

Table 4. 1:

Fuzzy linguistic scale (Lin, 2013)

Linguistic Terms	Influence Score	Triangular Fuzzy Number
No influence (NI)	0	(0, 0.1, 0.3)
Very low influence (VLI)	1	(0.1, 0.3, 0.5)
Low influence (LI)	2	(0.3, 0.5, 0.7)
High Influence (HI)	3	(0.5, 0.7, 0.9)
Very High Influence (VHI)	4	(0.7, 0.9, 1)

The created fuzzy evaluation matrices for doing a pairwise comparison of each criterion are shown in the following Table 4.2. and Table 4.3. The matrices were created by the two decision-makers (DMs).

Up next was the calculation of the verbal evaluations of DM_1 and DM_2, which were rated as “Important and “Very Important” based on their skill levels. By making use of the associated IFNS described in Table 4.3 along with Equation 3.1, the DMs’ HLWs are computed as;

$$\lambda_1 = 0.55 + \frac{0.55 * 0.25}{0.55 + 0.25} = 0.722$$

$$\lambda_2 = 0.8 + \frac{0.8 * 0.1}{0.8 + 0.1} = 0.889$$

Normalizing using Equation 3.2 yields the following results;

$$\lambda_1 = 0.448, \qquad \lambda_2 = 0.552$$

Which are used in the FAHP analysis in Table 4.6.

Table 4.2 shows the decision matrix in linguistic terms for a pairwise comparison of criteria for DM_1.

Table 4. 2:

DM_1 decision matrix

	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	
C_1	-	HI	LI	LI	VLI	LI	LI	HI	C_1
C_2	VLI	-	HI	LI	HI	VLI	HI	HI	C_2
C_3	LI	VLI	-	HI	VLI	HI	LI	HI	C_3
C_4	LI	LI	VLI	-	LI	VLI	HI	LI	C_4
C_5	VHI	VLI	HI	LI	-	VLI	LI	HI	C_5
C_6	LI	VHI	VLI	HI	HI	-	LI	HI	C_6
C_7	LI	VLI	LI	VLI	LI	LI	-	LI	C_7
C_8	VLI	VLI	VLI	LI	VLI	VLI	LI	-	C_8
	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	

Table 4.3 shows the decision matrix in linguistic terms for a pairwise comparison of criteria for DM_2.

Table 4. 3:

DM_2 decision matrix

	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	
C_1	-	LI	HI	HI	LI	VLI	HI	HI	C_1
C_2	LI	-	VLI	LI	HI	LI	HI	LI	C_2
C_3	VLI	HI	-	HI	VLI	LI	LI	HI	C_3
C_4	VLI	LI	VLI	-	HI	LI	HI	HI	C_4
C_5	LI	VLI	HI	VLI	-	HI	HI	HI	C_5
C_6	HI	LI	LI	LI	VLI	-	VLI	HI	C_6
C_7	VLI	VLI	LI	VLI	VLI	HI	-	LI	C_7
C_8	VLI	LI	VLI	VLI	VLI	VLI	LI	-	C_8
	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	

Table 4.4 shows the decision matrix in triangular fuzzy numbers for DM_1.

Table 4. 4:

DM_1 fuzzy decision matrix

	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	
C_1	1 1 1	1/2 1/1.43 1/1.11	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/10 1/3.33 1/2	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	C_1
C_2	1.11 1.43 2	1 1 1	1/2 1/1.43 1/1.11	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	1/10 1/3.33 1/2	1/2 1/1.43 1/1.11	1/2 1/1.43 1/1.11	C_2
C_3	1.43 2 3.33	1.11 1.43 2	1 1 1	1/2 1/1.43 1/1.11	1/10 1/3.33 1/2	1/2 1/1.43 1/1.11	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	C_3
C_4	1.43 2 3.33	1.43 2 3.33	1.11 1.43 2	1 1 1	1/3.33 1/2 1/1.43	1/10 1/3.33 1/2	1/2 1/1.43 1/1.11	1/3.33 1/2 1/1.43	C_4
C_5	2 3.33 10	1.11 1.43 2	2 3.33 10	1.43 2 3.33	1 1 1	1/2 1/1.43 1/1.11	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	C_5
C_6	1.43 2 3.33	2 3.33 10	1.11 1.43 2	2 3.33 10	2 3.33 10	1 1 1	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	C_6
C_7	1.43 2 3.33	1.11 1.43 2	1.43 2 3.33	1.11 1.43 2	1.11 1.43 2	1.43 2 3.33	1 1 1	1/3.33 1/2 1/1.43	C_7
C_8	1.11 1.43 2	1.11 1.43 2	1.11 1.43 2	1.43 2 3.33	1.43 2 3.33	1.11 1.43 2	1.43 2 3.33	1 1 1	C_8
	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	

Table 4.5 shows the decision matrix in triangular fuzzy numbers for DM_2.

Table 4. 5:

DM_2 fuzzy decision matrix

	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	
C_1	1 1 1	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	1/2 1/1.43 1/1.11	1/3.33 1/2 1/1.43	1/10 1/3.33 1/2	1/10 1/3.33 1/2	1/2 1/1.43 1/1.11	C_1
C_2	1.43 2 3.33	1 1 1	1/10 1/3.33 1/2	1/10 1/3.33 1/2	1/10 1/3.33 1/2	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	C_2
C_3	1.11 1.43 2	2 3.33 10	1 1 1	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	C_3
C_4	1.11 1.43 2	1.43 2 3.33	1.11 1.43 2	1 1 1	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	C_4
C_5	1.43 2 3.33	1.11 1.43 2	2 3.33 10	1.11 1.43 2	1 1 1	1/3.33 1/2 1/1.43	1/2 1/1.43 1/1.11	1/2 1/1.43 1/1.11	C_5
C_6	2 3.33 10	1.43 2 3.33	1.43 2 3.33	1.43 2 3.33	1.11 1.43 2	1 1 1	1/2 1/1.43 1/1.11	1/2 1/1.43 1/1.11	C_6
C_7	1.11 1.43 2	1.11 1.43 2	1.43 2 3.33	1.43 2 3.33	1.11 1.43 2	2 3.33 10	1 1 1	1/2 1/1.43 1/1.11	C_7
C_8	1.11 1.43 2	1.43 2 3.33	1.11 1.43 2	1.11 1.43 2	1.11 1.43 2	1.11 1.43 2	1.43 2 3.33	1 1 1	C_8
	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8	

Table 4.6 shows the aggregated fuzzy evaluation matrix in triangular fuzzy numbers after combining decision matrices from both DM_1 and DM_2 by use of respective HLWs.

Table 4. 6:

Aggregated fuzzy evaluation matrix

	C_1	**C_2**	**C_3**	**C4**	**C_5**	**C_6**	**C_7**	**C_8**	
C_1	1 1 1	0.39 0.59 0.79	0.41 0.61 0.81	0.41 0.61 0.81	0.21 0.41 0.61	0.19 0.39 0.59	0.19 0.39 0.59	0.41 0.61 0.81	**C_1**
C_2	1.29 1.74 2.73	1 1 1	0.28 0.48 0.68	0.19 0.39 0.59	0.28 0.48 0.68	0.21 0.41 0.61	0.39 0.59 0.79	0.39 0.59 0.79	**C_2**
C_3	1.25 1.69 2.6	1.60 2.48 6.42	1 1 1	0.39 0.59 0.79	0.21 0.41 0.61	0.39 0.59 0.79	0.3 0.5 0.7	0.5 0.7 0.9	**C_3**
C_4	1.25 1.69 2.6	1.43 2 3.33	1.11 1.43 2	1 1 1	0.3 0.5 0.7	0.21 0.41 0.61	0.39 0.59 0.79	0.41 0.61 0.81	**C_4**
C_5	1.69 2.6 6.32	1.11 1.43 2	2 3.33 10	1.25 1.69 2.6	1 1 1	0.39 0.59 0.79	0.41 0.61 0.81	0.5 0.7 0.9	**C_5**
C_6	1.74 2.73 7.01	1.69 2.6 6.32	1.29 1.74 2.73	1.69 2.6 6.32	1.51 2.28 5.58	1 1 1	0.41 0.61 0.81	0.5 0.7 0.9	**C_6**
C_7	1.25 1.69 2.6	1.11 1.43 2	1.43 2 3.33	1.29 1.74 2.73	1.11 1.43 2.00	1.74 2.73 7.01	1 1 1	0.41 0.61 0.81	**C_7**
C_8	1.11 1.43 2	1.29 1.74 2.73	1.11 1.43 2	1.25 1.69 2.6	1.25 1.69 2.6	1.11 1.43 2	1.43 2 3.33	1 1 1	**C_8**
	C_1	**C_2**	**C_3**	**C4**	**C_5**	**C_6**	**C_7**	**C_8**	

The aggregated fuzzy evaluation matrix was designed to represent a hierarchical structure. This was then later used to compute the summation of rows and columns shown in Table 4.7.

Table 4. 7:

Aggregate of rows and columns

Criteria	Sum of Rows	Sum of Columns
C_1	(3.21, 4.61, 6.01)	(10.59, 14.56, 26.85)
C_2	(4.02, 5.68, 7.87)	(9.61, 13.27, 24.59)
C_3	(5.65, 7.95, 13.80)	(8.63, 12.02, 22.55)
C_4	(6.10, 8.23, 11.84)	(7.47, 10.30, 17.43)
C_5	(8.35, 11.94, 24.42)	(5.87, 8.20, 13.78)
C_6	(9.82, 14.26, 30.68)	(5.25, 7.55, 13.40)
C_7	(9.35, 12.63, 21.48)	(4.52, 6.29, 8.82)
C_8	(9.55, 12.41, 18.26)	(4.12, 5.52, 6.92)
	Aggregate of rows and columns	**(56.05, 77.71, 134.35)**

The weight of each criterion is established once the fuzzy pairwise comparison matrix has been formed via FAHP. A key step though consists of determining the synthesis extent values. Equation 3.4 may be used to obtain these values. Using the aforementioned synthesis extent values, comparisons, and weights were calculated with the aid of Equation 3.9 and Equation 3.11 respectively. The priority weights were subsequently normalized using Equation 3.12 to get the ensuing vector concerning the primary objective. This resulted in the values observed in Table 4.8.

Table 4. 8:

Synthesis extent values of criteria

Criteria	S_i	$W_i^{`} = d'(A_n)^T$	$W_i = d(A_n)^T$
C_1	(0.0783, 0.1878, 0.478)	1	0.1759
C_2	(0.0711, 0.1712, 0.4377)	0.9559	0.1682
C_3	(0.0638, 0.1551, 0.4015)	0.9081	0.1597
C_4	(0.0553, 0.1329, 0.3103)	0.8086	0.1422
C_5	(0.0435, 0.1057, 0.2453)	0.6704	0.1125
C_6	(0.0388, 0.0974, 0.2385)	0.6393	0.1125
C_7	(0.0335, 0.0811, 0.157)	0.4245	0.0747
C_8	(0.0305, 0.0712, 0.1232)	0.278	0.0489

4.1.2. TOPSIS

With the FAHP technique being computed and having derived the requisite weights, what follows is the implementation of the TOPSIS method to determine the ranking of the alternatives. Creating a decision matrix is the first stage in the TOPSIS approach. This matrix is created based on the eight criteria that have been put out concerning the server virtualization options, and it was then utilized for ranking in the following Tables 4.9 and 4.10. The DMs evaluated the decision matrix, rating the criteria in light of the four server virtualization options. The ratings for the criteria were formed from a scale ranging from 0-10.

Table 4.9 shows the decision matrix for DM_1 under the TOPSIS method.

Table 4. 9:

TOPSIS DM_1 decision matrix

	C_1	**C_2**	**C_3**	**C4**	**C_5**	**C_6**	**C_7**	**C_8**
Hyper-V	8	8	9	9	8	8	8	9
KVM	7	6	7	7	8	9	7	7
VirtualBox	6	7	9	8	7	8	7	8
VMware	8	8	8	9	8	9	7	8

Table 4.10 shows the decision matrix for DM_2 under the TOPSIS method.

Table 4. 10:

TOPSIS DM_2 decision matrix

	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8
Hyper-V	8	8	9	9	7	8	8	9
KVM	8	7	8	7	7	9	8	8
VirtualBox	7	7	9	8	8	8	8	8
VMware	8	8	7	8	7	9	7	8

The above decision matrices are subsequently normalized by utilizing Equation 3.14, resulting in the following Table 4.11.

Table 4. 11:

Normalized decision matrix

	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8
Hyper-V	0.5299	0.5394	0.5432	0.5525	0.4983	0.4698	0.5309	0.5518
KVM	0.5002	0.4418	0.4558	0.4297	0.4983	0.5285	0.5012	0.463
VirtualBox	0.434	0.472	0.5432	0.4911	0.5052	0.4698	0.5012	0.4905
VMware	0.5299	0.5394	0.4495	0.5186	0.4983	0.5285	0.4645	0.4905

Using Equation 3.11, each normalized weight is then assessed by multiplying it with the associated decision matrix. The outcome is shown in the following Table 4.12. This table also shows the smallest and largest value of each criterion. These are then used to establish the ideal positive and negative solutions using Equations 3.16 and 3.17.

Table 4. 12:

Weighted normalized decision matrix

	C_1	C_2	C_3	C4	C_5	C_6	C_7	C_8
Hyper-V	0.0846	0.0656	0.0853	0.0816	0.0386	0.0579	0.0523	0.0571
KVM	0.0846	0.0574	0.0758	0.0635	0.0386	0.0651	0.0523	0.0508
VirtualBox	0.074	0.0574	0.0853	0.0726	0.0441	0.0579	0.0523	0.0508
VMware	0.0846	0.0656	0.0664	0.0726	0.0386	0.0651	0.0458	0.0508
A^*	0.0846	0.0656	0.0853	0.0816	0.0441	0.0651	0.0523	0.0571
A^-	0.074	0.0574	0.0664	0.0635	0.0386	0.0579	0.0458	0.0508

The distance of each of the four alternatives from the positive ideal solution and the negative ideal solution is computed concerning each criterion using Equations 3.18 and 3.19 with Equation 3.20 being used to calculate how closely each alternative came to the ideal answer. The results of the ranking of the alternatives are displayed in the following Table 4.13.

Table 4. 13:

Results of ranking the server virtualization alternatives

	S_i^*	S_i^-	RC_i^{*-}	Order
Hyper-V	0.00005	0.00113	0.8331	1
KVM	0.00082	0.00019	0.3245	4
VirtualBox	0.00055	0.00034	0.4389	3
VMware	0.00028	0.00076	0.6209	2

4.2. Results on the Cost-Effective Green Computing Approach for Server Virtualization

The study showed that the most preferred alternative for the implementation of server virtualization was Microsoft Hyper-V. This was followed by VMware, then VirtualBox, and lastly KVM. The findings were obtained after successfully using two different MCDM techniques, i.e., FAHP and TOPSIS to yield a more accurate result. The criteria selected from the ISO/IEC 25010 framework were also used with beneficial effects, ensuring the process did not linger solely on performance measures but instead encompassed a more comprehensive measurement model to better suit other stakeholders in the decision process.

CHAPTER V

DISCUSSION

This chapter analyzes the results garnered during the evaluation process in determining the ranking of server virtualization alternatives.

5.1. Discussion of the Analysis Results

The study sought to derive alternative criteria to determine the quality aspects of server virtualization alternatives and rank these alternatives through an MCDM. It performed this by use of a different measurement framework in its evaluation of server alternatives which involved software evaluation criteria derived from the ISO/IEC 25010 standards. This is in sharp contrast to prior studies which all focused primarily on performance aspects of the server virtualization alternatives that they evaluated (Balen et al., 2020; Dordevic et al., 2022; Graniszewski & Arciszewski, 2016; Hwang et al., 2013; Muditha & Keppitiyagama, 2011; Pousa & Rufino, 2017) Some precedent was also taken from studies that implemented the use of ISO/IEC standards in conjunction with AHP as MCDM criteria (Barletta et al., 2022) Research that focused on the use of the same ISO/IEC standards to evaluate the software quality of an environmental MCDM web application also provided precedent (Haag et al., 2022). The work of researchers where a study was carried out using a hybrid FAHP-TOPSIS MCDM technique to evaluate the quality and user satisfaction of MLAMs also provided a yardstick for the current research (Başaran & Haruna, 2017).

This study integrates aspects of ISO/IEC 25010 standards to improve the outcome of the results. It does this in an attempt to offer a holistic approach to the evaluation of server virtualization alternatives as opposed to sticking solely to a performance perspective. This coupled with the hybrid MCDM system allows stakeholders to make decisions with needs factored into the selection and evaluation process. The use of fuzzy numbers allows for increased dynamism during assessment and the insertion of ambiguity on boundaries and the combined FAHP-TOPSIS model enabled the advantages of both MCDMs to be utilized, i.e., the weighting prowess of FAHP and the reliability, intuitiveness, and simplicity of TOPSIS.

The results of the study indicate that Microsoft Hyper-V was the preferred choice among other server virtualization alternatives on the market. This may be attributed to the software company's prevalence in the market, allowing for usability in the hypervisor's implementation. Switching to it may also be familiar to users compared to utilizing other hypervisors. Researchers have also praised its memory handling efficiency and this may also play into its lead (Elsayed & Abdelbaki, 2013). However, its possession of the top position in this study contrasts with prior reviewed studies which place VMware over it in terms of performance (Elsayed & Abdelbaki, 2013; Graniszewski & Arciszewski, 2016). VMware came in second after Hyper-V, followed by VirtualBox and KVM. VMware's and KVM's second and last rankings respectively contrast with the prevailing wisdom, as several researchers placed them in their top spots (Elsayed & Abdelbaki, 2013; Hwang et al., 2013; Pousa & Rufino, 2017). This disparity may be attributed to new holistic attributes being taken into consideration as opposed to a pure performance metric focus, as was the case in prior research. VirtualBox's third position may be mitigated by it being an Oracle offering, with its utilization best suiting organizations that already use other Oracle products due to ease of implementation and enterprise support (Hwang et al., 2013).

Table 5. 1:

Comparison between server virtualization analysis approaches and results

Reference	Server Virtualization Alternatives	Analysis approach	Features/Focus of analysis approach	Results
Dordevic et al., (2022)	KVM and Proxmox	Performance-Focused Evaluation	Random file access, web server utilization, file server workloads, and mail server workloads.	No overall winner.
Pousa & Rufino, (2017)	Proxmox, Citrix XenServer, VMware ESXi, oVirt, and Microsoft Hyper-V	Performance-Focused Evaluation	CPU, memory, GPU, local and remote storage, OS, and network links.	Citrix XenServer, VMware ESXi, and oVirt were recommended as top choices.
Graniszewski & Arciszewski, (2016)	VMware ESXi, Microsoft Hyper-V, XenServer, and Oracle hypervisors	Performance-Focused Evaluation	CPU test, NIC test, HDD test, memory test, and kernel compilation.	VMware ESXi was the preferred alternative.
Elsayed & Abdelbaki, (2013)	Microsoft Hyper-V2008R2, Citrix XenServer 6.0.2, and VMware ESXi5	Performance-Focused Evaluation	SQL database performance, host server CPU utilization, heavy load management, memory handling	For SQL database performance; VMware ESXi5 scored highest. For the most effective host server CPU utilization & heavy load management; Citrix Xen Server scored highest. For memory handling; Microsoft Hyper-V was preferred.

Table 5. 2 (continued).

Reference	Server Virtualization Alternatives	Analysis approach	Features/Focus of analysis approach	Results
Hwang et al., (2013)	Xen, KVM, vSphere, and Hyper-V	Performance-Focused Evaluation	CPU and memory-associated tasks i.e., I/O activities, multicore engagement.	vSphere was preferred.
Muditha & Keppitiyagama, (2011)	VMware ESXi and Xen	Performance-Focused Evaluation	File system I/O, CPU performance, network activity.	For CPU performance and I/O operations; Xen was preferred. For network performance; ESXi was preferred.
Tanaka et al., (2009)	VMware ESX 3, Hitachi Prototype Virtualization, Xen 3.0, DIVT	Performance-Focused Evaluation	Disk I/O, CPU utilization.	DIVT is rated as the best alternative.
Current Research Study	Microsoft Hyper-V, VMware vSphere, VirtualBox, and Red Hat KVM	Holistic evaluation approach via ISO/IEC 25010 standards	Functional appropriateness, Performance Effectiveness, Compatibility, Usability, Dependability, Security, Maintainability, and Portability.	Microsoft Hyper-V was preferred.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the study and offers recommendations for future avenues of exploration.

6.1. Conclusion

With green computing and the rise of server virtualization quickly gaining traction globally, it becomes necessary for individuals and organizations alike to make decisions for how best to implement this green IT approach for the sake of gaining a strategic advantage and protecting our fragile environment. This paper proposes a departure from the standard operating procedure, namely limiting decision-making to dry performance aspects solely, instead choosing to create a holistic measurement model that incorporates the stakeholders' needs in addition to the aforementioned performance aspects. This comprises the ISO/IEC 25010 standards. These were derived and used in conjunction with a hybrid MCDM framework, namely FAHP-TOPSIS which was used by the decision-makers to weigh and evaluate the server virtualization alternatives on hand to come up with a definite ideal alternative in light of the criteria mentioned. The study noted that Microsoft’s Hyper-V was the best choice to make in this situation while VMware came in second, followed by VirtualBox and lastly KVM. This may be attributed to Microsoft’s prevalence in the IT industry giving it a leg-up in better understanding consumers’ needs. The novel method implemented bore the advantage of reduced bias from the decision makers due to the hybrid FAHP-TOPSIS model and an intuitive and accessible set of criteria from the ISO/IEC 25010 standards that comprehensively lend themselves easily to all those affected by the server virtualization selection decision.

6.2. Recommendations

6.2.1. Recommendations For Corporations

The study has practical implications for corporations who have to decide between server virtualization alternatives available on the market while considering the overarching needs of all the stakeholders involved in the process. The study may also be utilized by companies creating server virtualization alternatives to better understand where on the spectrum their products fall and what aspects can be improved upon to capture more market share and entice more customers.

6.2.2. Recommendations for Researchers

Future studies should seek to apply alternative MCDM techniques such as BWM, MEREC, SWARA, COPRAS, etc., in different combinations to shed light and verify the results of the study. More server virtualization alternatives may also be considered as this study was limited to four alternatives. Additionally, an increase in the number of industry experts as decision-makers may be considered in the process to ratify the evaluation process. Researchers may also contrast this study with other established performance evaluation techniques for the selection of server virtualization alternatives to corroborate its efficacy.

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APPENDICES

Appendix A: Ethical Committee Approval Letter

NEAR EAST UNIVERSITY

SCIENTIFIC RESEARCH ETHICS COMMITTEE

20.06.2023

Dear JOHN KARIMA MACHARIA

Your project **"SELECTING COST-EFFECTIVE GREEN COMPUTING APPROACH FOR SERVER VIRTUALIZATION USING FAHP-TOPSIS"** has been evaluated. Since only secondary data will be used the project does not need to go through the ethics committee. You can start your research on the condition that you will use only secondary data.

Prof. Dr. Aşkın KİRAZ

The Coordinator of the Scientific Research Ethics Committee

Appendix B: Similarity Report

MASTER THESIS

by John Karima Macharia

Submission date: 20-Jun-2023 11:58PM (UTC+0300)
Submission ID: 2119889455
File name: JOHN-FINAL_THESIS_CONTROL.docx (885.92K)
Word count: 13544
Character count: 75767

NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF COMPUTER INFORMATION SYSTEMS

SELECTING COST-EFFECTIVE GREEN COMPUTING APPROACH FOR SERVER VIRTUALIZATION USING FAHP-TOPSIS

M.Sc. THESIS

John Karima MACHARIA

Supervisor

Asst. Prof. Dr. SEREN BAŞARAN

Co-Supervisor

Prof. Dr. NADIRE ÇAVUŞ

Nicosia

March, 2023

1

MASTER THESIS

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