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The Role of Network Virtualization Strategy in Enhancing Scalability and Cost Efficiency in Cloud Data Centers

Mohammad Alimorad[1], Babak Nouri Moghaddam [2], Abbas Mirzaei[2*], Nasser Mikaeilvand [3], Azadeh Zamanifar[1]

[1] Department of Computer Engineering, SR.C., Islamic Azad University, Tehran, Iran
[2] Department of Computer Engineering, Ard.C., Islamic Azad University, Ardabil, Iran,
[3] Department of Cognitive Computational Science, CT.C., Islamic Azad University, Tehran, Iran

*** Corresponding author email address**: A.mirzaei@iau.ac.ir

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Abstract

This study aimed to examine the role of network virtualization strategy in enhancing scalability and cost efficiency in cloud data centers. This applied quantitative study used a descriptive-correlational design. The statistical population consisted of cloud infrastructure specialists, network engineers, virtualization administrators, data center managers, IT project managers, and system architects working in cloud data centers and technology-based organizations in Tehran. A total of 214 participants were selected through purposive sampling based on their professional experience with cloud infrastructure, network virtualization, software-defined networking, or data center management. Data were collected using a structured questionnaire measuring network virtualization strategy, scalability, and cost efficiency. The validity of the questionnaire was confirmed through expert review, and its reliability was assessed using Cronbach's alpha. Data were analyzed using descriptive statistics, Pearson correlation, multiple regression analysis, and structural equation modeling with SPSS and AMOS software. The inferential findings showed that network virtualization strategy had a positive and significant correlation with scalability ($r = 0.68$, $p < 0.01$) and cost efficiency ($r = 0.63$, $p < 0.01$). Scalability also had a positive and significant correlation with cost efficiency ($r = 0.59$, $p < 0.01$). Regression analysis indicated that network virtualization strategy significantly predicted scalability ($\beta = 0.68$, $p < 0.001$) and explained 46% of its variance. It also significantly predicted cost efficiency ($\beta = 0.63$, $p < 0.001$) and explained 40% of its variance. Structural equation modeling confirmed the proposed model, showing significant direct effects of network virtualization strategy on scalability ($\beta = 0.69$, $p < 0.001$) and cost efficiency ($\beta = 0.61$, $p < 0.001$), as well as a significant direct effect of scalability on cost efficiency ($\beta = 0.28$, $p < 0.001$). The findings indicate that network virtualization strategy is a key technological and managerial capability for improving the scalability and cost efficiency of cloud data centers.

Keywords: *Network virtualization strategy; cloud data centers; scalability; cost efficiency; software-defined networking; infrastructure optimization.*

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1. Introduction

Cloud data centers have become the operational backbone of contemporary digital economies, supporting enterprise computing, online platforms, artificial intelligence workloads, large-scale storage, distributed applications, and service ecosystems that demand continuous availability and elastic capacity. As organizations increasingly migrate from traditional on-premises infrastructures toward cloud-based architectures, data centers are required to handle rapidly changing traffic patterns, heterogeneous workloads, multi-tenant service requirements, and cost-sensitive operational models. In this environment, scalability and cost efficiency are no longer secondary technical concerns, but central indicators of data center performance, competitiveness, and sustainability. Scalability refers to the ability of cloud data centers to expand or contract computing, storage, and network resources in response to workload variation, while cost efficiency reflects the ability to deliver reliable services with optimized resource utilization, reduced infrastructure waste, and controlled operational expenditure. However, the achievement of these two objectives is highly dependent on the architecture and management of the network layer, because the network determines how workloads communicate, how services are provisioned, how resources are orchestrated, and how efficiently traffic is routed across distributed cloud environments. In this regard, network virtualization has emerged as a strategic approach for transforming rigid, hardware-dependent network infrastructures into flexible, programmable, and software-driven environments that can better support the dynamic requirements of modern cloud data centers [1, 2].

Network virtualization refers to the abstraction of network resources from the underlying physical infrastructure and their management through software-based control mechanisms. This transformation enables cloud data centers to create multiple logical networks over shared physical resources, allocate bandwidth dynamically, segment traffic, automate provisioning, improve workload mobility, and reduce dependence on manual configuration. The strategic significance of network virtualization lies in its capacity to separate network services from fixed hardware devices and to make infrastructure management more adaptive, programmable, and scalable. Network hypervisors and virtualization layers allow multiple virtual networks to coexist on common physical substrates, which improves resource sharing and reduces the need for excessive hardware expansion [1]. Similarly, network acceleration technologies have increasingly been introduced into cloud environments to improve throughput, reduce latency, and support high-performance applications, indicating that the cloud network is becoming a critical site of innovation for infrastructure optimization [2]. In this context, network virtualization should not be understood merely as a technical upgrade; rather, it functions as a broader strategy through which cloud data centers can align infrastructure flexibility with organizational goals related to scalability, cost reduction, energy efficiency, and service quality.

The growing relevance of network virtualization is closely connected to the rise of software-defined networking and network function virtualization. Software-defined networking separates the control plane from the data plane and allows centralized, programmable control of network behavior, while network function virtualization replaces dedicated hardware appliances with software-based network functions running on virtualized infrastructure. These developments have influenced enterprise networks, telecommunications systems, smart communities, and cloud platforms by enabling centralized policy control, flexible service deployment, and automated network management [3, 4]. In enterprise environments, software-defined trends have changed the way networks are designed and managed by introducing greater modularity, programmability, and functional segmentation [4]. In smart community infrastructures, software-defined networking has been emphasized as an enabling technology for intelligent service delivery, dynamic resource allocation, and integrated digital services [3]. These characteristics are highly relevant to cloud data centers, where network demands fluctuate continuously and where manual, device-centered network administration often limits responsiveness. Accordingly, the strategic adoption of network virtualization can be expected to improve the scalability of cloud infrastructures by allowing network resources to be provisioned, modified, and optimized in real time.

Scalability is one of the most important requirements of cloud data centers because cloud services are frequently exposed to unpredictable workload growth, seasonal demand variation, traffic bursts, application migration, and service expansion. In traditional data center architectures, scaling often requires physical hardware expansion, complex configuration changes, and time-consuming coordination between network, server, and storage teams. Network virtualization reduces these barriers by enabling logical network resources to be created and modified through software, which supports faster deployment and greater adaptability. Studies on hybrid software-defined networks show that load balancing and server resource distribution can be optimized through multiparameter approaches that improve responsiveness under changing conditions [5]. Similarly, research on SD-WAN demonstrates that software-defined approaches can contribute to bandwidth and delay improvements across internet-based networks, thereby strengthening the capacity of distributed systems to support performance-sensitive applications [6]. These findings suggest that virtualization-oriented network strategies can help cloud data centers overcome performance bottlenecks, reduce provisioning delays, and support elastic growth. When networks are programmable, scalable service expansion becomes more feasible because infrastructure teams can adjust routing, segmentation, and traffic policies without relying exclusively on physical reconfiguration.

Cost efficiency represents another major concern in cloud data center management. Although cloud computing is often associated with flexibility and economic advantage, data centers are expensive to operate because they require substantial investments in network hardware, servers, cooling systems, energy consumption, maintenance, security, and skilled personnel. Cost inefficiency often arises from overprovisioning, underutilized hardware, fragmented network management, manual administrative processes, and poor workload prediction. Network virtualization can improve cost efficiency by increasing resource utilization, reducing the need for dedicated hardware appliances, lowering operational complexity, and enabling more precise allocation of network capacity according to actual demand. Research on sustainable cloud computing emphasizes that energy-efficient techniques are essential for reducing the environmental and economic burden of cloud infrastructures [7]. Similarly, studies on energy efficiency in cloud data centers highlight the importance of software technologies in reducing consumption and improving operational sustainability [8]. These perspectives show that cost efficiency is not limited to financial accounting but is also linked to technical decisions about resource management, workload placement, energy use, and infrastructure design. Network virtualization contributes to this agenda by allowing cloud data centers to do more with existing resources and by reducing unnecessary hardware dependence.

The economic value of virtualization becomes even more important when cloud data centers must support complex, distributed, and latency-sensitive services. Workloads are increasingly distributed across core cloud, edge, and hybrid environments, creating new demands for resource orchestration and service continuity. The technological transformation of telecommunications operators toward IoT edge-cloud continuum models demonstrates that modern infrastructures increasingly depend on seamless integration between network, cloud, and edge resources [9]. In vehicular cloud and 5G environments, software-defined architectures are also central to enabling convergence, mobility, and service coordination across highly dynamic network conditions [10]. These developments are relevant to cloud data centers because they reveal a broader transition from static infrastructure toward programmable and distributed service environments. As cloud services become more geographically dispersed and user expectations for low-latency access increase, the network layer must support real-time adaptation. Network virtualization provides the architectural foundation for such adaptation by enabling virtual networks, dynamic service chains, and flexible resource deployment across distributed environments.

Network function virtualization has also become an important strategy in telecommunications and next-generation network infrastructures. In 5G and 6G environments, NFV-based element management systems can optimize telecommunication infrastructure by virtualizing network functions and improving operational flexibility [11]. RAN-as-a-Service models similarly demonstrate how end-to-end virtualization layers can support multi-service mobile networks by abstracting radio access network functions and enabling more flexible resource sharing [12]. These advances indicate that virtualization is increasingly used not only in cloud computing but also in mobile, telecom, and service-provider environments. Cloud data centers are positioned at the intersection of these technological domains because they provide the computational and network foundations for virtualized services. Therefore, the strategies developed in NFV, SDN, and virtualized telecom systems have direct implications for cloud data center design. A data center that adopts network virtualization can better support service migration, virtual function deployment, automated scaling, and multi-tenant isolation, all of which are essential for scalable and cost-efficient operations.

The role of virtualization in service availability is also central to the performance of cloud infrastructures. Cloud data centers must maintain high availability despite failures, workload shifts, resource contention, and security risks. Shared service replication methods in IoT environments have been proposed as mechanisms to improve service availability and resource deployment, showing that replication and virtualization-based resource management can strengthen continuity in distributed infrastructures [13]. Similarly, research on virtualized intelligent electronic devices in smart grids highlights the importance of simulation frameworks that address networking and security requirements within virtualized systems [14]. Although these studies are located in IoT and smart-grid contexts, they demonstrate a broader principle that is also relevant to cloud data centers: virtualization enables services to be abstracted, replicated, migrated, and secured more flexibly than in purely physical infrastructures. This flexibility supports scalability because services can be expanded and redistributed more efficiently, and it supports cost efficiency because resources can be shared and optimized rather than duplicated unnecessarily.

Security and reliability remain major concerns in virtualized and software-defined infrastructures. While network virtualization increases flexibility, it also creates new requirements for secure orchestration, isolation, monitoring, and simulation. Comparative analysis of distributed systems using tools such as GNS3 and the SEED Internet Emulator has highlighted the importance of secure testing environments for understanding distributed network behavior and cybersecurity risks [15]. In power systems, software-defined protection, automation, and control have been discussed as emerging concepts that require careful attention to reliability, security, and future implementation challenges [16]. These insights are applicable to cloud data centers because virtualized networks must be designed not only for performance and cost reduction but also for security, resilience, and governance. A network virtualization strategy that lacks proper security controls may increase operational risk, whereas a well-designed strategy can improve segmentation, policy enforcement, monitoring, and automated response. Therefore, the evaluation of network virtualization in cloud data centers should consider both technical and managerial dimensions, including how virtualization supports reliable service delivery while controlling infrastructure costs.

Optimization methods are increasingly important for managing the complexity of communication networks and cloud infrastructures. Communication network optimization often involves difficult resource allocation problems, and column generation approaches have been used to address large-scale optimization challenges in communication networks [17]. In cloud computing, intelligent resource allocation through machine learning has also been proposed as a way to optimize infrastructure performance and allocate resources more effectively under dynamic conditions [18]. Adaptive resource scheduling for edge-to-cloud deep learning systems using reinforcement learning further demonstrates that intelligent scheduling can improve the performance of distributed cloud infrastructures [19]. These studies indicate that network virtualization strategy can be strengthened when combined with optimization and machine learning approaches. Virtualized networks generate programmable environments in which intelligent allocation algorithms can operate more effectively, while predictive models can help anticipate workload changes and reduce unnecessary resource consumption. Thus, the relationship between network virtualization, scalability, and cost efficiency is likely to become increasingly important as cloud data centers adopt intelligent automation.

Workload prediction is another relevant dimension of scalability and cost efficiency. Cloud data centers must anticipate virtual machine demand, user traffic, and resource consumption in order to prevent service degradation and avoid overprovisioning. Clustering-based prediction for virtual machine workloads in green computing indicates that predictive techniques can support more sustainable and efficient cloud operations [20]. This is closely related to network virtualization because virtual network resources must often scale alongside virtual machines, containers, and application services. When workload prediction is integrated with network virtualization, cloud data centers can allocate network capacity more proactively and avoid both congestion and wasted resources. From a strategic perspective, this means that network virtualization should not be considered in isolation, but as part of a broader cloud management framework that includes workload monitoring, resource scheduling, automation, and sustainability-oriented optimization. In this sense, virtualization strategy becomes a managerial capability that links technical infrastructure design with operational and economic outcomes.

The relevance of cloud-based solutions extends beyond corporate data centers and into social, educational, and public service domains. Cloud-based solutions have been studied as tools for bridging the digital divide, showing that cloud infrastructures can support access to digital services in underserved regions when implementation is properly designed [21]. Although this line of research differs from data center optimization, it emphasizes the societal importance of scalable and cost-efficient cloud infrastructure. If cloud data centers cannot scale effectively or operate economically, the broader promise of cloud-based service delivery may be weakened. Similarly, research in smart supply chain management has shown that demand patterns affect integrated online-offline and buy-online-pickup-in-store models, reflecting the growing dependence of modern service systems on digital infrastructure, responsiveness, and resource coordination [22]. These examples demonstrate that scalability and cost efficiency in cloud data centers have implications that extend across sectors, including education, retail, public services, smart infrastructure, and digital inclusion. Therefore, improving network virtualization strategy may contribute not only to internal data center performance but also to the reliability and sustainability of the digital services that depend on these infrastructures.

The evolution of hyperconvergence in the telecommunications sector further illustrates the convergence of computing, storage, networking, and virtualization into integrated infrastructure models [23]. Hyperconverged and virtualized environments reduce the separation between hardware components and create unified management frameworks for infrastructure resources. For cloud data centers, this trend reinforces the importance of network virtualization as part of a larger shift toward integrated, software-defined infrastructure. In satellite communication systems, reconfigurable digital satellite-borne base station design and fast virtual function migration algorithms also show that virtualization can support rapid adaptation in highly specialized and dynamic communication environments [24]. These findings strengthen the argument that virtualization is a generalizable infrastructure strategy across different technological domains. Whether in cloud data centers, telecom networks, smart grids, satellite systems, or edge-cloud environments, virtualization enables infrastructures to become more flexible, responsive, and resource-efficient. Consequently, studying network virtualization in cloud data centers provides insight into one of the most important technological strategies shaping modern digital infrastructure.

Despite the growing body of research on software-defined networking, NFV, cloud energy efficiency, resource scheduling, and intelligent infrastructure optimization, there remains a need for empirical studies that examine how network virtualization strategy contributes simultaneously to scalability and cost efficiency in cloud data centers. Much of the existing literature addresses specific technologies, such as SD-WAN, NFV, RAN virtualization, network acceleration, workload prediction, or resource scheduling, but fewer studies integrate these concepts into a strategic model focused on organizationally relevant outcomes. Cloud data center managers require evidence not only about whether virtualization technologies are technically feasible, but also about whether virtualization strategy improves operational scalability and reduces costs in practice. This issue is particularly important in competitive technology markets where organizations must expand service capacity while controlling infrastructure expenditure. A strategic perspective allows network virtualization to be analyzed as a coordinated set of practices involving programmable control, automated provisioning, virtual network segmentation, workload mobility, resource optimization, and cost-aware infrastructure management.

Therefore, the present study aims to examine the role of network virtualization strategy in enhancing scalability and cost efficiency in cloud data centers.

2. Methodology

This study was conducted using an applied, quantitative, descriptive-correlational design to examine the role of network virtualization strategy in enhancing scalability and cost efficiency in cloud data centers. The statistical population consisted of cloud infrastructure specialists, network engineers, virtualization administrators, data center managers, IT project managers, and system architects working in public and private cloud data centers and technology-based organizations in Tehran. Data were collected from 214 participants who were selected through purposive sampling based on their professional involvement in cloud infrastructure, network virtualization, software-defined networking, network function virtualization, or data center management. The inclusion criteria were having at least one year of work experience in cloud computing or data center operations, direct familiarity with network virtualization technologies, and willingness to participate in the study. Participants who provided incomplete responses or lacked relevant professional experience were excluded from the final analysis. All participants were informed about the purpose of the study, the voluntary nature of participation, the confidentiality of their responses, and the exclusive use of the collected data for academic research purposes. The final sample included individuals with different organizational roles and levels of technical expertise, which allowed the study to capture a broad view of how network virtualization strategy contributes to scalability improvement and cost-efficiency enhancement in cloud data center environments.

Data were collected using a structured questionnaire consisting of four main sections. The first section included demographic and professional information such as age, gender, educational level, field of study, job position, years of work experience, organizational type, and level of involvement with cloud data center technologies. The second section measured network virtualization strategy through items related to the adoption of software-defined networking, network function virtualization, centralized network control, automated resource allocation, virtual network segmentation, traffic orchestration, workload mobility, and integration of virtualization policies with cloud infrastructure management. The third section assessed scalability in cloud data centers by examining the ability of the infrastructure to support dynamic workload growth, rapid provisioning of network resources, flexible expansion of services, reduction of network bottlenecks, efficient traffic management, and responsiveness to changing user demand. The fourth section measured cost efficiency by focusing on reduction in hardware dependency, optimization of operational expenditures, lower maintenance costs, improved resource utilization, decreased manual configuration efforts, and improved energy and infrastructure efficiency. All items were scored using a five-point Likert scale ranging from strongly disagree to strongly agree. The questionnaire was designed based on the conceptual dimensions of cloud computing, network virtualization, scalability, and IT cost-efficiency management. Its face and content validity were reviewed and confirmed by academic experts in information technology management and professional specialists in cloud infrastructure and data center operations. The internal consistency of the instrument was assessed using Cronbach's alpha, and the reliability coefficients for the main constructs were found to be within the acceptable range for quantitative research.

The collected data were analyzed using descriptive and inferential statistical methods. First, the completed questionnaires were screened to identify missing values, incomplete responses, and outliers. Descriptive statistics, including frequency, percentage, mean, and standard deviation, were used to summarize the demographic and professional characteristics of the participants as well as the main research variables. The normality of the data distribution was examined using skewness and kurtosis indices, and the reliability of the research constructs was evaluated through Cronbach's alpha. To examine the relationships among network virtualization strategy, scalability, and cost efficiency, Pearson correlation analysis was applied. Multiple regression analysis was then used to determine the predictive role of network virtualization strategy in explaining changes in scalability and cost efficiency in cloud data centers. In addition, structural equation modeling was used to evaluate the overall conceptual model and to assess the direct effects of network virtualization strategy on scalability and cost efficiency. Model fit was examined using common fit indices, including the chi-square to degrees of freedom ratio, comparative fit index, Tucker–Lewis index, goodness-of-fit index, root mean square error of approximation, and standardized root mean square residual. The significance level for all statistical tests was set at 0.05. Data analysis was performed using SPSS and AMOS software, and the findings were interpreted according to the research objectives and the theoretical assumptions of cloud data center virtualization and infrastructure optimization.

3. Findings and Results

The final analysis was conducted on data obtained from 214 professionals working in cloud data centers, IT infrastructure units, cloud service companies, and technology-oriented organizations in Tehran. The demographic and professional characteristics of the participants showed that 137 participants were male (64.0%) and 77 participants were female (36.0%). In terms of age, 42 participants (19.6%) were between 25 and 30 years old, 73 participants (34.1%) were between 31 and 35 years old, 61 participants (28.5%) were between 36 and 40 years old, and 38 participants (17.8%) were older than 40 years. Regarding educational level, 78 participants (36.4%) held a bachelor's degree, 104 participants (48.6%) held a master's degree, and 32 participants (15.0%) held a doctoral degree. The professional roles of the participants included network engineers (n = 58, 27.1%), virtualization administrators (n = 42, 19.6%), cloud infrastructure specialists (n = 39, 18.2%), data center managers (n = 29, 13.6%), IT project managers (n = 24, 11.2%), and system architects (n = 22, 10.3%). With respect to work experience, 47 participants (22.0%) had between 1 and 3 years of experience, 68 participants (31.8%) had between 4 and 6 years of experience, 56 participants (26.2%) had between 7 and 10 years of experience, and 43 participants (20.0%) had more than 10 years of experience. These characteristics indicate that the sample consisted of participants with sufficient technical and managerial exposure to cloud data center operations, network virtualization, and infrastructure optimization, making their responses appropriate for examining the role of network virtualization strategy in scalability and cost efficiency.

Table 1. Descriptive Statistics, Reliability, and Normality Indices of the Main Research Variables

Variable	Number of items	Mean	Standard deviation	Min.	Max.	Cronbach's alpha	Skewness	Kurtosis
Network virtualization strategy	12	3.87	0.61	2.10	5.00	0.89	-0.42	0.31
Scalability of cloud data centers	10	3.79	0.66	1.90	5.00	0.87	-0.36	0.18
Cost efficiency	10	3.72	0.69	1.80	5.00	0.88	-0.29	

As shown in Table 1, the mean score of network virtualization strategy was 3.87 with a standard deviation of 0.61, indicating that the participants generally evaluated the implementation of network virtualization practices in their organizations as higher than the midpoint of the scale. This suggests that practices such as software-defined networking, virtual network segmentation, automated network provisioning, centralized control, and network resource orchestration were relatively visible in the cloud data center environments studied. The mean score of scalability was 3.79 with a standard deviation of 0.66, showing that participants perceived their cloud data center infrastructures as moderately to highly capable of adapting to workload growth, service expansion, dynamic resource allocation, and fluctuating traffic demands. The mean score of cost efficiency was 3.72 with a standard deviation of 0.69, which also exceeded the theoretical midpoint and indicates that respondents generally believed network and cloud infrastructure practices contributed to reducing operational costs, improving resource utilization, and decreasing hardware dependency. The Cronbach's alpha coefficients ranged from 0.87 to 0.89, confirming acceptable internal consistency for all three constructs. In addition, the skewness and kurtosis values were within the conventional acceptable range of -2 to +2, indicating that the distribution of the main variables did not substantially deviate from normality and that parametric statistical analyses could be applied.

Table 2. Correlation Matrix of Network Virtualization Strategy, Scalability, and Cost Efficiency

Variable	Network virtualization strategy	Scalability	Cost efficiency
Network virtualization strategy	1		
Scalability	0.68**	1	
Cost efficiency	0.63**	0.59**	1

As presented in Table 2, network virtualization strategy had a positive and statistically significant correlation with scalability ($r = 0.68$, $p < 0.01$). This finding indicates that stronger implementation of network virtualization strategies was associated with higher perceived scalability in cloud data centers. In practical terms, organizations that used virtualized network resources, automated provisioning, software-defined control, and flexible traffic management were more likely to report greater capacity for service expansion, rapid workload adaptation, and efficient scaling of infrastructure. Network virtualization strategy also had a positive and statistically significant correlation with cost efficiency ($r = 0.63$, $p < 0.01$), suggesting that the adoption of network virtualization was associated with improved cost control, better utilization of infrastructure resources, reduced dependence on physical network hardware, and lower operational complexity. In addition, scalability showed a significant positive correlation with cost efficiency ($r = 0.59$, $p < 0.01$), indicating that cloud data centers with stronger scalability capabilities were also more likely to achieve cost-related benefits. Overall, the correlation results support the assumption that network virtualization is not only a technical mechanism for improving flexibility but also a strategic infrastructure capability that contributes simultaneously to operational scalability and economic efficiency.

Table 3. Regression Analysis of the Effect of Network Virtualization Strategy on Scalability

Predictor variable	B	Standard error	Beta	t	p	Tolerance	VIF
Constant	0.93	0.21	—	4.43	<0.001	—	—
Network virtualization strategy	0.74	0.05	0.68	13.52	<0.001	1.00	1.00

The results in Table 3 show that network virtualization strategy significantly predicted scalability in cloud data centers. The standardized regression coefficient was positive and strong ($\beta = 0.68$, $p < 0.001$), indicating that an increase in the adoption and maturity of network virtualization strategy was associated with a significant increase in scalability. The value of R^2 was 0.46, meaning that approximately 46% of the variance in scalability could be explained by network virtualization strategy. This is a substantial proportion of explained variance in organizational and technological research and suggests that network virtualization plays a central role in enabling cloud data centers to expand services, handle traffic growth, allocate resources dynamically, and respond to changing computational demands. The unstandardized coefficient ($B = 0.74$) indicates that for each one-unit increase in network virtualization strategy, the scalability score increased by 0.74 units. The significance of the F statistic confirms that the regression model was statistically valid. In addition, the tolerance and VIF values indicated that there was no multicollinearity problem in the model. These findings demonstrate that virtualization-based network design can be considered a major strategic factor in strengthening the scalability of cloud data center infrastructure.

Table 4. Regression Analysis of the Effect of Network Virtualization Strategy on Cost Efficiency

Predictor variable	B	Standard error	Beta	t	p	Tolerance	VIF
Constant	0.98	0.24	—	4.08	<0.001	—	—
Network virtualization strategy	0.71	0.06	0.63	11.83	<0.001	1.00	1.00

As shown in Table 4, network virtualization strategy had a positive and statistically significant effect on cost efficiency in cloud data centers. The standardized regression coefficient was $\beta = 0.63$, and the effect was significant at $p < 0.001$. This result indicates that organizations with stronger network virtualization strategies reported higher levels of cost efficiency. The R^2 value was 0.40, showing that network virtualization strategy explained approximately 40% of the variance in cost efficiency. This finding suggests that virtualization strategy can reduce costs through multiple operational mechanisms, including lower reliance on physical network equipment, improved use of existing infrastructure, reduced manual configuration time, decreased maintenance complexity, faster service deployment, and more efficient allocation of computing and network resources. The unstandardized coefficient ($B = 0.71$) shows that each one-unit increase in network virtualization strategy was associated with a 0.71-unit increase in cost efficiency. The statistically significant F value confirmed the overall adequacy of the regression model. These results support the argument that network virtualization should not be viewed only as a technical modernization tool, but also as a cost-management strategy that can improve the economic performance of cloud data centers.

Table 5. Structural Equation Modeling Results for the Proposed Conceptual Model

Path	Standardized coefficient	Standard error	Critical ratio	p	Result
Network virtualization strategy → Scalability	0.69	0.052	13.26	<0.001	Supported
Network virtualization strategy → Cost efficiency	0.61	0.057	10.70	<0.001	Supported
Scalability → Cost efficiency	0.28	0.061	4.59	<0.001	Supported

The structural equation modeling results presented in Table 5 confirm the adequacy of the proposed conceptual model. The model fit indices were within acceptable ranges, with χ^2/df below 3, CFI and TLI above 0.90, GFI above 0.90, RMSEA below 0.08, and SRMR below 0.05. These values indicate that the empirical data adequately supported the theoretical model. The direct path from network virtualization strategy to scalability was positive and statistically significant ($\beta = 0.69$, $p < 0.001$), confirming that network virtualization strategy directly enhances the scalability of cloud data centers. The direct path from network virtualization strategy to cost efficiency was also positive and statistically significant ($\beta = 0.61$, $p < 0.001$), showing that virtualization strategy contributes directly to the reduction of operational and infrastructure-related costs. Furthermore, the path from scalability to cost efficiency was significant ($\beta = 0.28$, $p < 0.001$), indicating that scalability itself can contribute to cost efficiency by allowing organizations to allocate resources according to demand, avoid overprovisioning, and manage capacity more effectively. These findings show that network virtualization strategy improves cost efficiency both directly and indirectly through enhanced scalability. Therefore, scalability can be interpreted as an important operational mechanism through which network virtualization contributes to economic optimization in cloud data centers.

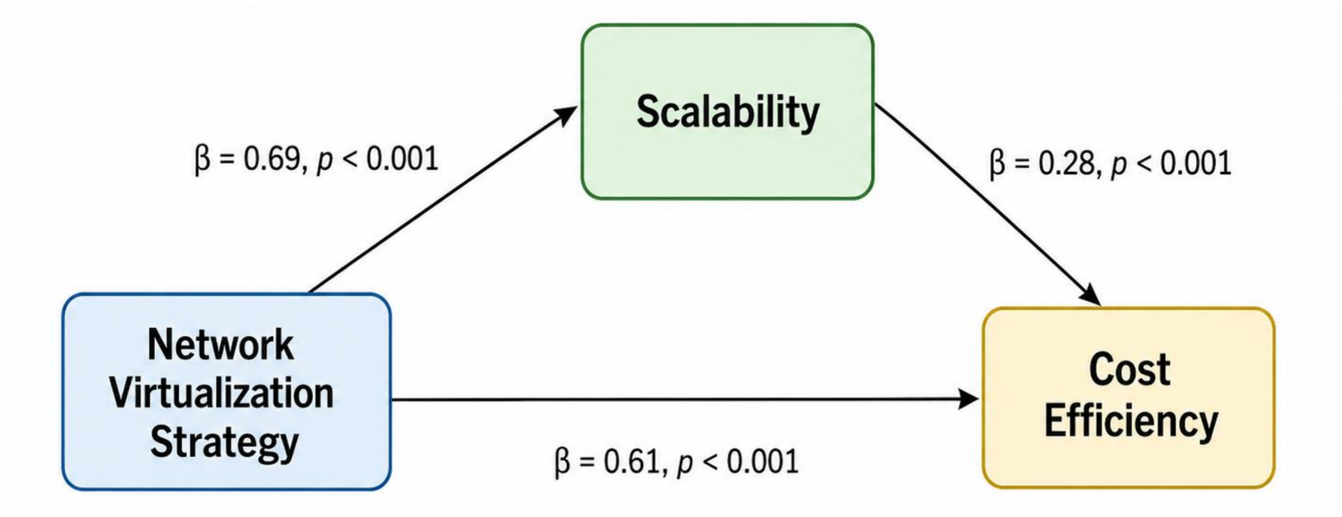

Figure 1. Structural Model of the Relationship between Network Virtualization Strategy, Scalability, and Cost Efficiency in Cloud Data Centers

Figure 1 illustrates the conceptual and empirical relationship among the main variables of the study. In this model, network virtualization strategy is positioned as the main independent variable, while scalability and cost efficiency are considered the key outcome variables. The figure shows that network virtualization strategy has a direct positive effect on both scalability and cost efficiency. It also shows that scalability has a positive effect on cost efficiency, suggesting that the ability of a cloud data center to expand dynamically and respond flexibly to workload changes can strengthen its economic performance. The model therefore demonstrates that network virtualization strategy is not limited to improving technical flexibility; rather, it creates an integrated pathway through which cloud data centers can achieve both higher scalability and better cost efficiency. This finding is particularly important for cloud data center managers because it emphasizes that investment in network virtualization technologies can generate multidimensional benefits, including operational agility, infrastructure flexibility, cost reduction, and improved resource management. Overall, the findings confirm that network virtualization strategy plays a decisive role in enhancing the performance and economic sustainability of cloud data centers.

4. Discussion and Conclusion

The present study examined the role of network virtualization strategy in enhancing scalability and cost efficiency in cloud data centers. The findings showed that the participants evaluated network virtualization strategy, scalability, and cost efficiency above the midpoint of the measurement scale, indicating that virtualization-oriented network practices were perceived as relatively established and beneficial in the studied cloud data center environments. The reliability coefficients of the three constructs were also acceptable, which suggests that the measurement model had adequate internal consistency and that the respondents interpreted the items related to network virtualization, scalability, and cost efficiency in a coherent manner. From a conceptual perspective, this result is consistent with the idea that network virtualization is not a single technical function but a strategic infrastructure capability that includes software-defined control, virtualized network segmentation, automated provisioning, traffic orchestration, workload mobility, and integration between network resources and cloud management systems. This interpretation is aligned with prior work describing network virtualization and network hypervisors as mechanisms for abstracting network resources from physical infrastructures and enabling multiple logical networks over shared physical substrates [1]. It is also compatible with recent discussions on cloud network acceleration, where the network layer is viewed as a decisive component of cloud performance, latency reduction, and high-throughput service delivery [2]. Therefore, the relatively high mean score of network virtualization strategy in the present study indicates that cloud data center professionals increasingly recognize virtualization as a core requirement for managing complex and dynamic cloud environments.

The correlation analysis showed a strong positive relationship between network virtualization strategy and scalability. This means that cloud data centers with more developed virtualization strategies were also perceived as more capable of expanding services, responding to workload changes, provisioning network resources rapidly, and managing traffic growth. This finding can be explained by the architectural logic of software-defined and virtualized networking. In conventional data center networks, scalability is constrained by hardware dependency, manual configuration, fixed routing structures, and fragmented control. By contrast, network virtualization separates logical network functions from physical devices, making it possible to scale services through software-based control and automated resource allocation. This result is consistent with studies showing that software-defined networking improves flexibility and responsiveness in enterprise and smart community networks by enabling centralized control, programmability, and adaptive service management [3, 4]. It is also supported by evidence from hybrid SDN research, where software-defined load balancing can improve server utilization and network responsiveness under variable conditions [5]. Similarly, SD-WAN has been shown to improve bandwidth and delay performance, which is directly relevant to the scalability of distributed cloud infrastructures [6]. Accordingly, the positive association found in this study confirms that network virtualization strengthens the technical foundations required for scalable cloud data center operations.

The regression results further demonstrated that network virtualization strategy significantly predicted scalability and explained a substantial proportion of its variance. This finding suggests that scalability in cloud data centers is not merely a function of adding servers, storage devices, or bandwidth capacity; rather, it depends on how effectively infrastructure resources are virtualized, orchestrated, and controlled. The predictive effect of network virtualization on scalability reflects the importance of dynamic provisioning, workload-aware routing, virtual network creation, and centralized policy management in cloud environments. This result is aligned with research on cloud and network optimization, which emphasizes that large-scale communication networks require advanced resource allocation and optimization mechanisms to manage complexity and demand variation [17]. It is also consistent with studies on adaptive resource scheduling in edge-to-cloud deep learning systems, where intelligent scheduling improves the ability of distributed infrastructures to respond to changing computational demands [19]. In the same direction, machine-learning-based resource allocation models demonstrate that intelligent cloud management can optimize resource distribution and improve infrastructure performance [18]. The present finding extends this literature by showing that the strategic virtualization of the network layer can serve as an enabling condition for scalable cloud infrastructure, especially when combined with automation and intelligent resource management.

The findings also showed a significant positive relationship between network virtualization strategy and cost efficiency. This result indicates that stronger implementation of virtualization-oriented network practices was associated with better cost control, improved resource utilization, reduced operational complexity, and lower dependency on physical network hardware. This relationship can be explained by the fact that network virtualization allows cloud data centers to consolidate resources, reduce dedicated hardware appliances, minimize manual configuration, and deploy network functions through software. Cost efficiency in cloud data centers is closely connected to energy use, infrastructure utilization, maintenance workload, and operational automation. Prior studies on sustainable cloud computing have emphasized that energy-efficient techniques are necessary for reducing both environmental and economic costs in cloud infrastructures [7]. Similarly, research on software technologies for cloud data center energy efficiency shows that software-based management can play a major role in reducing consumption and improving operational sustainability [8]. The present results are consistent with these findings because network virtualization contributes to cost efficiency by improving the software-based control of infrastructure resources and reducing wasteful overprovisioning. In this sense, virtualization strategy should be viewed not only as a performance-enhancement mechanism but also as an economic strategy for cloud data center management.

The regression model predicting cost efficiency confirmed that network virtualization strategy had a significant positive effect on cost efficiency and explained a meaningful proportion of its variance. This finding is important because it demonstrates that the financial benefits of cloud data center virtualization are not indirect or marginal; rather, they are embedded in the operational mechanisms of virtualized infrastructure. When network functions are virtualized, organizations can reduce the need for specialized physical appliances, shorten deployment cycles, improve maintenance efficiency, and align resource allocation with real-time demand. This is consistent with NFV-based infrastructure optimization in 5G and 6G telecommunications, where virtualization improves flexibility and reduces dependency on dedicated network elements [11]. It is also aligned with research on RAN-as-a-Service, which shows that end-to-end virtualization layers can support multi-service environments through shared and flexible resource use [12]. Furthermore, studies on hyperconvergence in telecommunications show that integrated infrastructure models are increasingly important for reducing fragmentation and improving the efficiency of network, storage, and computing resources [23]. The present study supports these arguments by showing that network virtualization strategy can generate tangible cost-efficiency benefits in cloud data center environments.

The structural equation modeling results confirmed the adequacy of the proposed conceptual model. Network virtualization strategy had a direct positive effect on scalability and cost efficiency, and scalability also had a positive effect on cost efficiency. This finding indicates that network virtualization contributes to cost efficiency through two pathways: first, directly by reducing hardware dependency, simplifying operations, and improving resource utilization; and second, indirectly through scalability, because scalable infrastructures can allocate resources according to actual demand and avoid unnecessary overprovisioning. This interpretation is consistent with studies on service availability and resource deployment in IoT environments, where shared service replication methods improve resource use and continuity [13]. It is also supported by research on software-defined and virtualized infrastructures in smart grids, where networking and security requirements are addressed through simulation and virtualization frameworks [14]. These studies demonstrate that virtualization improves not only isolated technical functions but also broader infrastructure adaptability. In cloud data centers, this adaptability allows organizations to expand capacity without proportional increases in cost, which explains the observed relationship between scalability and cost efficiency.

The significant path from scalability to cost efficiency is one of the most important findings of the study. It suggests that scalability itself is an economic capability. When a cloud data center can scale dynamically, it can prevent resource underutilization during low-demand periods and avoid service disruption during peak demand. This reduces the need for excessive reserve capacity and allows more accurate matching between infrastructure resources and workload requirements. Studies on workload prediction in green computing similarly show that predictive techniques can support efficient virtual machine management and reduce unnecessary resource consumption [20]. In addition, research on reconfigurable satellite-borne base stations and fast virtual function migration demonstrates that rapid function migration can improve adaptability in dynamic communication systems [24]. These findings help explain why scalability contributed to cost efficiency in the present study. A scalable virtualized data center can move, replicate, and resize services more efficiently, which reduces wasted capacity and improves the economic logic of infrastructure operation.

Another implication of the findings is that network virtualization strategy must be implemented with attention to security, reliability, and governance. Although the present study focused on scalability and cost efficiency, virtualized networks introduce new requirements for monitoring, isolation, simulation, and protection. Prior research comparing secure distributed system deployment tools such as GNS3 and SEED Internet Emulator highlights the importance of secure testing and evaluation in distributed network environments [15]. Likewise, studies on software-defined protection, automation, and control in power systems show that software-defined infrastructures must address reliability and security challenges alongside flexibility [16]. Therefore, the positive effects observed in the present study should be interpreted within a broader strategic framework. Network virtualization can enhance scalability and reduce costs, but these benefits are maximized when organizations also establish secure orchestration policies, proper monitoring systems, access controls, and resilience mechanisms.

The findings also have broader relevance for emerging cloud, edge, IoT, and digital service ecosystems. As cloud infrastructures become more distributed, the relationship between virtualization, scalability, and cost efficiency becomes increasingly important. Research on the edge-cloud continuum in telecommunications shows that seamless integration between IoT, edge, and cloud systems requires flexible and programmable infrastructure [9]. Studies on software-defined vehicular cloud and 5G technologies similarly emphasize the convergence of cloud, mobility, and communication technologies in highly dynamic environments [10]. In addition, cloud-based solutions designed to bridge digital divides show that scalable and cost-effective cloud infrastructures can support broader access to digital services [21]. The relevance of such infrastructures is also visible in smart supply chain environments, where demand patterns require responsive digital coordination across online and offline systems [22]. These studies support the broader interpretation of the present results: network virtualization strategy is a foundational capability for modern digital infrastructure, and its effects on scalability and cost efficiency can influence not only data center performance but also the quality and sustainability of cloud-dependent services.

Overall, the results of this study confirm that network virtualization strategy plays a decisive role in enhancing cloud data center performance. The positive correlations, regression results, and structural model all support the same conclusion: data centers that adopt stronger network virtualization strategies are better positioned to scale dynamically and operate more cost-efficiently. These findings align with the broader literature on software-defined networking, NFV, cloud optimization, sustainable computing, resource scheduling, and virtualized communication systems [1-3, 7, 8, 11, 18, 19]. The study therefore contributes to the literature by integrating technical and managerial perspectives and by showing that network virtualization strategy should be considered a strategic driver of both scalability and economic optimization in cloud data centers.

This study had several limitations that should be considered when interpreting the findings. First, the research was conducted among cloud data center and IT infrastructure professionals in Tehran, which may limit the generalizability of the results to other geographic regions, technology markets, and organizational environments. Second, the data were collected through self-report questionnaires, and the findings therefore reflect participants' perceptions rather than direct technical measurements of data center performance, resource utilization, latency, bandwidth efficiency, or operational cost records. Third, the cross-sectional design of the study does not allow causal conclusions to be drawn with complete certainty, even though regression and structural equation modeling were used to test directional relationships. Fourth, the study examined network virtualization strategy as a general construct and did not separately analyze the independent effects of specific technologies such as SDN, NFV, SD-WAN, network slicing, container networking, or cloud-native service mesh architectures. Finally, organizational factors such as budget constraints, staff expertise, vendor dependency, security maturity, and governance policies were not directly included in the model, although these factors may influence the successful implementation of network virtualization.

Future studies are recommended to examine the role of network virtualization strategy in different regions, organizational sectors, and cloud service models in order to improve the external validity of the findings. Researchers may also use longitudinal designs to investigate how the adoption of virtualization strategies affects scalability and cost efficiency over time. Future research would benefit from combining questionnaire data with objective technical indicators such as network latency, bandwidth utilization, virtual machine migration time, service provisioning speed, energy consumption, hardware reduction, and actual operating costs. It is also suggested that future studies compare different network virtualization technologies and assess whether SDN, NFV, SD-WAN, edge virtualization, or cloud-native networking have different levels of influence on scalability and cost efficiency. In addition, future models can include mediating and moderating variables such as automation maturity, cybersecurity readiness, staff expertise, organizational size, cloud governance quality, and artificial intelligence-based resource optimization. Comparative studies between public cloud, private cloud, hybrid cloud, and edge-cloud infrastructures may also provide deeper insight into how virtualization strategy operates across different architectural contexts.

Based on the findings, cloud data center managers should treat network virtualization as a strategic infrastructure priority rather than a limited technical upgrade. Organizations should invest in software-defined network control, virtualized network functions, automated provisioning, traffic orchestration, and centralized monitoring systems in order to improve scalability and reduce operational costs. Before implementation, managers should assess current network architecture, identify bottlenecks, determine virtualization readiness, and develop a phased migration plan that minimizes service disruption. Technical teams should also be trained in virtualization management, network automation, security configuration, and performance monitoring so that the organization can fully benefit from the new infrastructure model. In practice, network virtualization should be integrated with workload prediction, capacity planning, energy management, and cost-control systems to ensure that technical flexibility leads to measurable economic benefits. Data center managers should also establish clear governance policies for access control, segmentation, monitoring, backup, and incident response because the success of virtualized environments depends not only on flexibility and cost reduction but also on security, reliability, and operational discipline.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

References

[1] A. Blenk and W. Kellerer, "Network Virtualization and Network Hypervisors," pp. 1-11, 2022, doi: 10.1002/047134608x.w8428.

[2] L. Rosa, L. Foschini, and A. Corradi, "Empowering Cloud Computing With Network Acceleration: A Survey," *Ieee Communications Surveys & Tutorials,* vol. 26, no. 4, pp. 2729-2768, 2024, doi: 10.1109/comst.2024.3377531.

[3] R. Chaudhary, G. S. Aujla, N. Kumar, and P. K. Chouhan, "A Comprehensive Survey on Software-defined Networking for Smart Communities," *International Journal of Digital & Analog Cabled Systems,* vol. 38, no. 1, 2022, doi: 10.1002/dac.5296.

[4] D. Pratiba, R. K. Pattar, and V. Reddy, "Functional Segments and Software Defined Trends in Enterprise Networks," *Indonesian Journal of Electrical Engineering and Computer Science,* vol. 31, no. 2, p. 957, 2023, doi: 10.11591/ijeecs.v31.i2.pp957-967.

[5] T. Malbašić, P. D. Bojović, Ž. Bojović, J. Šuh, and D. Vujošević, "Hybrid SDN Networks: A Multi-Parameter Server Load Balancing Scheme," *Journal of Network and Systems Management,* vol. 30, no. 2, 2022, doi: 10.1007/s10922-022-09642-y.

[6] Z. Qin, "SD-WAN for Bandwidth and Delay Improvements on the Internet," *SHS Web of Conferences,* vol. 144, p. 02004, 2022, doi: 10.1051/shsconf/202214402004.

[7] S. Bharany *et al.*, "A Systematic Survey on Energy-Efficient Techniques in Sustainable Cloud Computing," *Sustainability,* vol. 14, no. 10, p. 6256, 2022, doi: 10.3390/su14106256.

[8] A. Katal, S. Dahiya, and T. Choudhury, "Energy Efficiency in Cloud Computing Data Centers: A Survey on Software Technologies," *Cluster Computing,* vol. 26, no. 3, pp. 1845-1875, 2022, doi: 10.1007/s10586-022-03713-0.

[9] K. Öztoprak, Y. K. Tuncel, and İ. Bütün, "Technological Transformation of Telco Operators Towards Seamless IoT Edge-Cloud Continuum," *Sensors,* vol. 23, no. 2, p. 1004, 2023, doi: 10.3390/s23021004.

[10] L. Nkenyereye, L. Nkenyereye, and J.-W. Jang, "Convergence of Software-Defined Vehicular Cloud and 5G Enabling Technologies: A Survey," *Electronics,* vol. 12, no. 9, p. 2066, 2023, doi: 10.3390/electronics12092066.

[11] A. Arulappan, G. Raja, K. Passi, and A. Mahanti, "Optimization of 5g/6g Telecommunication Infrastructure Through an NFV-Based Element Management System," *Symmetry,* vol. 14, no. 5, p. 978, 2022, doi: 10.3390/sym14050978.

[12] M. Kist, J. F. Santos, D. Collins, J. Rochol, L. A. DaSilva, and C. B. Both, "AIRTIME: End-to-End Virtualization Layer for RAN-as-a-Service in Future Multi-Service Mobile Networks," *Ieee Transactions on Mobile Computing,* vol. 21, no. 8, pp. 2701-2717, 2022, doi: 10.1109/tmc.2020.3046535.

[13] K. Kaâniche, S. Othmen, A. Alfahid, A. Yousef, M. Albekairi, and O. I. Elhamrawy, "Enhancing Service Availability and Resource Deployment in IoT Using a Shared Service Replication Method," *Heliyon,* vol. 10, no. 3, p. e25255, 2024, doi: 10.1016/j.heliyon.2024.e25255.

[14] N. Kabbara, A. Mwangi, M. Gibescu, A. Abedi, A. Ştefanov, and P. Pálenský, "Specifications of a Simulation Framework for Virtualized Intelligent Electronic Devices in Smart Grids Covering Networking and Security Requirements," 2023, doi: 10.1109/powertech55446.2023.10202950.

[15] L. Golightly, P. Modesti, and V. Chang, "Deploying Secure Distributed Systems: Comparative Analysis of GNS3 and SEED Internet Emulator," *Journal of Cybersecurity and Privacy,* vol. 3, no. 3, pp. 464-492, 2023, doi: 10.3390/jcp3030024.

[16] N. Kabbara *et al.*, "Towards Software-Defined Protection, Automation, and Control in Power Systems: Concepts, State of the Art, and Future Challenges," *Energies,* vol. 15, no. 24, p. 9362, 2022, doi: 10.3390/en15249362.

[17] Z. Jia, Q. Wu, C. Dong, C. Yuen, and Z. Han, "Column Generation for Optimization Problems in Communication Networks," *Ieee Network,* vol. 37, no. 3, pp. 86-92, 2023, doi: 10.1109/mnet.108.2100634.

[18] H. Wang and M. Rahman, "Intelligent resource allocation optimization for cloud computing via machine learning," arXiv Preprint, 2025.

[19] Y. Zhang and X. Wang, "Adaptive resource scheduling for edge-to-cloud deep learning systems via reinforcement learning," *Future Generation Computer Systems,* vol. 140, pp. 21-34, 2025.

[20] S. Saxena, "Clustering Based Prediction for VM Workload in Green Computation," *Asian Journal of Convergence in Technology,* vol. 10, no. 1, pp. 1-8, 2024, doi: 10.33130/ajct.2024v10i01.001.

[21] Y. Shen *et al.*, "'Cloud for Youth': An Implementation Research of Cloud-based Solutions for Bridging the Digital Divide in Rural China," *British Journal of Educational Technology,* 2025, doi: 10.1111/bjet.70037.

[22] A. S. Mahapatra, S. Sengupta, A. Dasgupta, B. Sarkar, and R. T. Goswami, "What is the impact of demand patterns on integrated online-offline and buy-online-pickup in-store (BOPS) retail in a smart supply chain mana gement?," *Journal of Retailing and Consumer Services,* vol. 82, p. 104093, 2025/1/1/ 2025, doi: 10.1016/J.JRETCONSER.2024.104093.

[23] G. S. Atencio and M. Umaña-Ramírez, "The Evolution and Trends of Hyperconvergence in the Telecommunications

Sector: A Competitive Intelligence Review," *Dyna,* vol. 90, no. 227, pp. 126-132, 2023, doi: 10.15446/dyna.v90n227.107360.
[24] Y. Shi, P. Wang, X. Zhu, and H. Zhu, "Reconfigurable Digital Satellite-Borne Base Station Design and Virtual Function Fast Migration Algorithm," *Sensors,* vol. 23, no. 17, p. 7591, 2023, doi: 10.3390/s23177591.