

## Enhancing Network Resilience and Disaster Recovery with SDN and NFV: A TOPSIS Analysis

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**Abstract:** In the contemporary digital environment, the importance of resilient and adaptable network infrastructures cannot be overstated. This research examines the efficacy of Software-Defined Networking (SDN), Network Functions Virtualization (NFV), and hybrid models in constructing robust networks capable of swift recovery from disasters and network outages. Utilizing the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a comprehensive evaluation is undertaken to gauge the performance of different network infrastructures based on crucial criteria including fault recovery time, scalability, cost-effectiveness, implementation complexity, latency, and security considerations. The findings from the TOPSIS analysis highlight NFV with Dynamic Scaling as the most effective infrastructure, particularly excelling in scalability, cost-efficiency, and fault recovery. Following closely, the Hybrid SDN-NFV Architecture offers a balanced approach by harnessing the strengths of both SDN and NFV technologies, securing the second position. SDN with Redundancy ranks third, demonstrating notable strengths in scalability, cost-efficiency, and latency. While Traditional Network Infrastructure and Cloud-based Network Virtualization are respectively cost-effective and secure, they exhibit limitations in fault recovery, scalability, and cost-effectiveness.

**Keywords:** Network Resiliency, Software-Defined Networking (SDN), Network Functions Virtualization (NFV), Disaster Recovery and Multi-Criteria Decision Method.

### 1. INTRODUCTION

Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) represent two groundbreaking technologies poised to revolutionize network design, deployment, and management. These innovations offer a promising solution to constructing more resilient and reliable networks capable of swiftly recovering from disasters and network failures, critical challenges in today's interconnected world. SDN introduces a novel network architecture by separating the control plane from the data plane, facilitating centralized control and programmability of network resources. Unlike conventional networks where devices handle both data forwarding and decision-making, SDN segregates these functions. Here, the control plane resides in a software-based controller, while the data plane is executed within network devices. Centralizing the control plane empowers network administrators with a holistic view of the network, enabling dynamic configuration and resource management. This programmability facilitates the implementation of intelligent traffic management, load balancing mechanisms, and the ability to promptly adapt to evolving network conditions or failures [1, 2]. NFV, on the other hand, entails virtualizing network functions traditionally carried out by dedicated hardware appliances like firewalls, load balancers, and intrusion detection systems. Through NFV, these functions are detached from hardware and operate as software instances on virtualized infrastructure such as virtual machines or containers [3, 4]. NFV's virtualization of network functions offers enhanced flexibility, scalability, and cost-efficiency in network deployments. Network functions can be swiftly provisioned, scaled, or migrated across different hardware platforms as required, diminishing the necessity for specialized hardware and streamlining the deployment and management of network services [5, 6]. The integration of SDN and NFV technologies brings forth numerous advantages in constructing resilient and robust networks capable of swift recovery from disasters and network failures: Network Automation and Programmability: Leveraging SDN's centralized control plane and programmable interfaces allows for automating network management tasks like configuration, traffic engineering, and fault detection and recovery. This automation significantly reduces response time and effort during network failures or disasters, facilitating faster recovery and minimizing service disruptions [7]. Dynamic Resource Allocation: SDN and NFV enable

dynamic allocation and optimization of network resources in response to changing traffic patterns or network conditions. In case of a network failure or disaster, resources can be swiftly reallocated to sustain critical services or reroute traffic around affected areas [8, 9]. Virtualized Network Functions: NFV facilitates the virtualization of network functions, enabling easy migration, replication, or instantiation on diverse physical hardware platforms. This flexibility ensures rapid recovery and service continuity during hardware failures or disasters impacting specific locations [10, 11]. Service Chaining and Orchestration: SDN and NFV empower the establishment of service chains, where multiple virtualized network functions are orchestrated to deliver intricate network services. In the event of a failure or disaster, these service chains can be promptly reconfigured or migrated to alternative locations, guaranteeing uninterrupted service delivery [12, 13]. Network Slicing: SDN and NFV enable the establishment of distinct logical network slices, each with dedicated resources and specific quality of service (QoS) requirements. This functionality enables the segregation of critical services or applications, ensuring their resilience and prioritization during network failures or disasters [14, 15]. Despite the promising opportunities presented by SDN and NFV in constructing more resilient and robust networks, several challenges need addressing. These include security considerations, interoperability issues, and the necessity for standardization and skilled personnel [16, 17]. Nonetheless, ongoing research and development endeavours, along with real-world deployments and use cases, continuously showcase the potential of these technologies in augmenting network resilience and disaster recovery capabilities.

## 2. METHODOLOGY

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) stands as a widely adopted multi-criteria decision-making (MCDM) technique, garnering substantial recognition across various domains like engineering, economics, and management. Fundamentally, TOPSIS operates on the premise that the chosen alternative should minimize its distance from the positive ideal solution while maximizing its distance from the negative ideal solution [18]. Initially introduced by Hwang and Yoon in 1981 [19], TOPSIS has found extensive application in resolving diverse decision-making challenges characterized by multiple conflicting criteria. This method proves particularly beneficial in scenarios where decision-makers must assess and prioritize a set of alternatives based on multiple, often opposing, criteria [20, 21]. The TOPSIS methodology unfolds through a sequence of steps aimed at identifying the optimal solution from a pool of alternatives [22]: Construct the decision matrix: This matrix comprises the alternatives (rows) and the evaluation criteria (columns), with each element signifying the performance rating of a specific alternative concerning a particular criterion. Normalize the decision matrix: To ensure equitable weighting of all criteria, the decision matrix undergoes normalization using a suitable method such as vector or linear normalization [21]. Compute the weighted normalized decision matrix: Each element of the normalized decision matrix is multiplied by the corresponding criterion weight, reflecting the relative significance of each criterion in the decision-making process [22]. Determine the positive ideal solution (PIS) and negative ideal solution (NIS): The PIS represents the optimal solution where all criteria are maximized (for benefit criteria) or minimized (for cost criteria), while the NIS symbolizes the worst-case scenario where all criteria are minimized (for benefit criteria) or maximized (for cost criteria) [23]. Calculate the separation measures: Separation measures are derived by calculating the Euclidean distances of each alternative from the PIS and NIS. The distance from the PIS is termed as the negative ideal separation, whereas the distance from the NIS is termed as the positive ideal separation [24]. Compute the relative closeness coefficient: The relative closeness coefficient for each alternative is determined by dividing the negative ideal separation by the sum of the positive and negative ideal separations. This coefficient ranges from 0 to 1, with higher values indicating a stronger preference for the alternative [25]. Rank the alternatives: Alternatives are ranked in descending order based on their relative closeness coefficients. The alternative with the highest closeness coefficient is deemed the optimal solution [26]. When evaluating infrastructure benefit-cost criteria for traditional network infrastructure, SDN (Software-Defined Networking), NFV (Network Functions Virtualization), and hybrid SDN-NFV architectures, several key factors must be considered: Fault Recovery Time: The time taken to recover from network faults or failures, which impacts the overall reliability and availability of the network. Initial Implementation Complexity: The complexity involved in deploying and setting up the network infrastructure initially, including configuration and integration efforts. Redundancy: The level of redundancy built into the network architecture to ensure resilience against failures and minimize service disruptions. Scalability: The ability of the network infrastructure to scale up or down easily to accommodate changes in demand or network growth. Latency: The delay experienced in transmitting data across the network, which can affect the performance of real-time applications and user experience. Dynamic Scaling: The capability to dynamically adjust network resources in response to changing workload requirements or traffic patterns. Cost-effectiveness: The balance between the initial investment and ongoing operational costs of deploying and maintaining the network infrastructure. Security Concerns: The measures in place to protect the network infrastructure from unauthorized access, data breaches, and other security threats. Cloud-based Network Virtualization: The utilization of cloud-based resources and virtualization technologies to optimize

network performance, flexibility, and resource utilization. Each of these factors plays a crucial role in determining the suitability of different network architectures for specific use cases and organizational requirements. The TOPSIS method can be employed to systematically evaluate and rank the alternatives based on these criteria, considering their relative importance and trade-offs. In traditional network infrastructure, fault recovery times are typically longer, ranging from hours to days, due to manual intervention and hardware reconfiguration. The initial implementation complexity is relatively low, following established standards, but there's a lack of inherent redundancy, leading to vulnerability against single points of failure. Scalability is limited by the need for additional physical hardware, increasing costs and complexity. Latency tends to be higher compared to SDN and NFV solutions. SDN architectures offer reduced fault recovery times with a centralized control plane and programmability. Although initial implementation complexity may be higher, SDN provides redundancy through dynamic traffic rerouting and resource reconfiguration. Scalability is improved as resources can be efficiently allocated and optimized. Latency can be minimized through traffic engineering and path optimization. However, SDN may require specialized hardware and software, potentially impacting cost-effectiveness. NFV brings virtualization benefits, enabling dynamic scaling and cost-effectiveness. It allows rapid provisioning, scaling, or migration of network functions, reducing expenses. Implementation complexity is moderate, requiring virtualization expertise. Fault recovery times can be improved with rapid function instantiation, and redundancy is achieved by distributing functions across hardware. Scalability is supported through elastic resources, and latency can be reduced by placing functions closer to the network edge. However, NFV introduces security concerns related to virtualized environments and shared infrastructure. Hybrid SDN-NFV architectures combine both technologies, offering a comprehensive solution. They leverage SDN's programmability to manage NFV's virtualized functions, enabling dynamic resource allocation and rapid provisioning. Fault recovery times are minimized through automated mechanisms, and redundancy is achieved by distributing functions. Scalability is enhanced through elastic resources and optimized allocation. Latency can be minimized with intelligent engineering. Cost-effectiveness improves through resource optimization, but security concerns must be addressed. Cloud-based network virtualization leverages cloud platforms' scalability and elasticity. Fault recovery times are minimized with instant resource provisioning and workload migration. Redundancy is inherent in distributed cloud infrastructure. Scalability is virtually unlimited, and latency can be optimized through strategic placement or edge computing. Cost-effectiveness improves with a pay-as-you-go model, but security concerns related to data privacy and shared infrastructure require attention.

### 3. ANALYSIS AND DISCUSSION

TABLE 1.

Infrastructure	EP1	EP2	EP3	EP4	EP5	EP6
A11	4	2	1	2	4	2
A12	2	4	4	3	5	3
A13	4	5	5	4	4	3
A14	3	4	4	4	4	3
A15	1	3	2	3	4	1

Here Infrastructure: Traditional Network Infrastructure (A11), SDN with Redundancy (A12), NFV with Dynamic Scaling (A13), Hybrid SDN-NFV Architecture (A14) and Cloud-based Network Virtualization (A15). Fault Recovery Time (hrs)(EP1), Scalability (EP2), Cost-effectiveness (EP3), Initial Implementation Complexity (EP4), Latency (ms) (EP5) and Security Concerns (EP6). Table 1 shows that SDN with redundancy excels in scalability, cost-effectiveness, and low latency but has moderate complexity and security concerns. NFV with dynamic scaling offers exceptional scalability, cost-effectiveness, and fault recovery but higher complexity and moderate security risks. Hybrid SDN-NFV combines their strengths for robust performance across criteria but with moderate complexity. Cloud-based virtualization tops fault recovery and security but faces trade-offs in scalability, cost, and complexity. Traditional infrastructure is economical but lacks agility, resilience, and performance. The choice depends on prioritizing resilience, agility, performance, or cost-effectiveness while considering complexity and security implications.

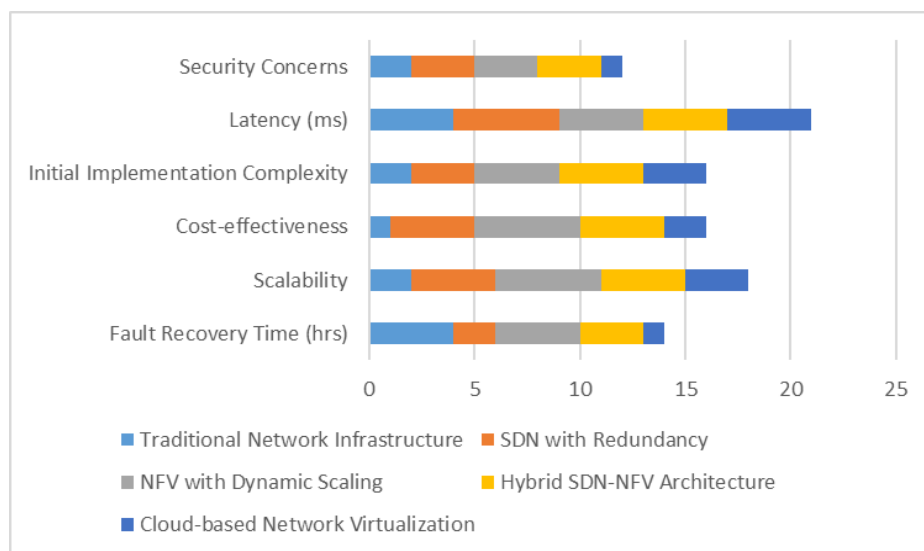


FIGURE 1.

Figure 1 illustrates that SDN with redundancy excels in scalability, cost-efficiency, and minimal latency, yet it entails moderate complexity and security concerns. NFV with dynamic scaling offers outstanding scalability, cost-effectiveness, and fault recovery capabilities, albeit with increased complexity and moderate security risks. The hybrid SDN-NFV approach combines their strengths, ensuring robust performance across various criteria despite moderate complexity. Cloud-based virtualization leads in fault recovery and security but faces compromises in scalability, cost, and complexity. Traditional infrastructure remains economical but lacks agility, resilience, and performance. Ultimately, the choice depends on prioritizing resilience, agility, performance, or cost-effectiveness while considering complexity and security implications.

TABLE 2. Normalized Data

0.5898	0.2949	0.1474	0.2949	0.5898	0.2949
0.2949	0.5898	0.5898	0.4423	0.7372	0.4423
0.5898	0.7372	0.7372	0.5898	0.5898	0.4423
0.4423	0.5898	0.5898	0.5898	0.5898	0.4423
0.1474	0.4423	0.2949	0.4423	0.5898	0.1474

Table 2 employs the TOPSIS method to assess various infrastructure options across different metrics, aiming for values closer to 1 to indicate superior performance. NFV with Dynamic Scaling emerges with the highest score (0.737) for Fault Recovery Time, signifying its exceptional fault recovery capabilities. Both SDN with Redundancy and NFV with Dynamic Scaling lead in Scalability, each scoring 0.737. NFV with Dynamic Scaling and SDN with Redundancy dominate Cost-effectiveness, with scores also at 0.737. Initial Implementation Complexity remains consistent across all options, hovering around 0.59. SDN with Redundancy obtains the highest score (0.737) in Latency, while Cloud-based Network Virtualization records the lowest score (0.147) in Security Concerns.

TABLE 3. Weight Distribution

0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
0.1667	0.1667	0.1667	0.1667	0.1667	0.1667

Table 3 delineates the allocation of weights across diverse criteria for assessing various network infrastructure alternatives. Each type of infrastructure, such as Traditional Network Infrastructure, SDN with Redundancy, NFV with Dynamic Scaling, Hybrid SDN-NFV Architecture, and Cloud-based Network Virtualization, receives identical weights across fault recovery time, scalability, cost-effectiveness, initial implementation complexity, latency, and security concerns. This implies an equitable evaluation methodology, wherein no individual criterion is favored above others. This fosters a thorough examination and juxtaposition of the infrastructure options, considering their performance across a spectrum of dimensions.

**TABLE 4.** Weighted Normalized Decision Matrix

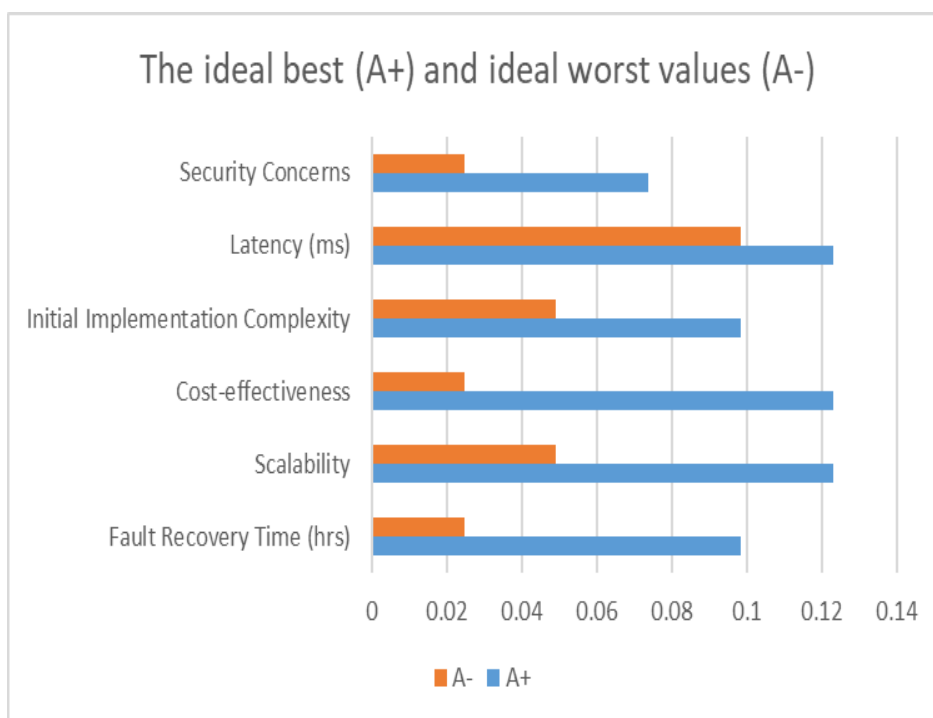
0.0983	0.0491	0.0246	0.0491	0.0983	0.0491
0.0491	0.0983	0.0983	0.0737	0.1229	0.0737
0.0983	0.1229	0.1229	0.0983	0.0983	0.0737
0.0737	0.0983	0.0983	0.0983	0.0983	0.0737
0.0246	0.0737	0.0491	0.0737	0.0983	0.0246

Table 4 employs the TOPSIS method to analyze diverse network infrastructure options based on several criteria. Evaluation factors include fault recovery time, scalability, cost-effectiveness, initial implementation complexity, latency, and security concerns. Traditional Network Infrastructure demonstrates lower scores across all metrics. Conversely, SDN with Redundancy and NFV with Dynamic Scaling exhibit superior performance, particularly in scalability and cost-effectiveness. The Hybrid SDN-NFV Architecture strikes a balance across various aspects. Cloud-based Network Virtualization shines in fault recovery and latency but falls short in other domains. These evaluations facilitate the selection of the most suitable infrastructure, considering different priorities and trade-offs.

**TABLE 5.** The ideal best (A+) and ideal worst values (A-)

A+	0.098295	0.122868	0.122868	0.098295	0.122868	0.073721
A-	0.024574	0.049147	0.024574	0.049147	0.098295	0.024574

Table 5 presents the optimal best (A+) and worst (A-) values across various metrics within TOPSIS analysis. Lower scores in A+ signify superior performance, implying an ideal scenario with minimal fault recovery time, scalability, cost, complexity, latency, and security concerns. Conversely, higher scores in A- denote poorer performance, depicting a scenario with notably higher values for these metrics. These insights aid in comprehending the relative performance of diverse scenarios or systems based on predefined criteria.



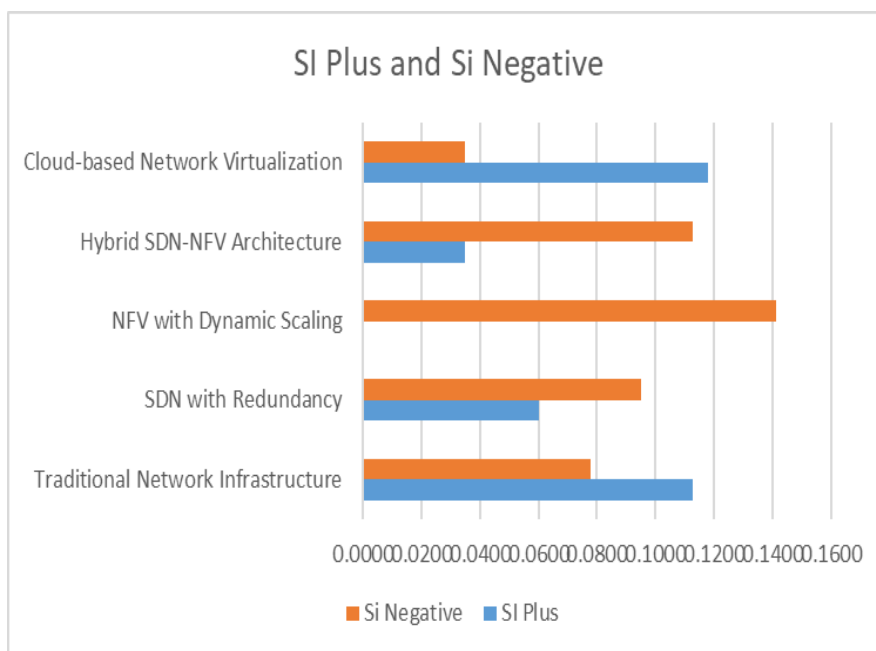
**FIGURE 2.**

Figure 2 displays the ideal best (A+) and worst (A-) values across multiple metrics in TOPSIS analysis. A lower score in A+ indicates superior performance, suggesting an optimal scenario with minimal fault recovery time, scalability, cost, complexity, latency, and security concerns. Conversely, higher scores in A- represent poorer performance, illustrating a scenario with significantly higher values for these metrics. These observations assist in understanding the relative performance of various scenarios or systems based on predetermined criteria.

**TABLE 6.** SI Plus and Si Negative

Infrastructure	SI +	Si -
Traditional Network Infrastructure	0.1126	0.0777
SDN with Redundancy	0.0602	0.0952
NFV with Dynamic Scaling	0.0000	0.1412
Hybrid SDN-NFV Architecture	0.0348	0.1126
Cloud-based Network Virtualization	0.1179	0.0348

Table 6 presents the results of TOPSIS analysis, indicating the relative performance of different network infrastructure options through SI Plus and SI Negative scores. Traditional Network Infrastructure demonstrates moderate scores in both SI Plus (0.1126) and SI Negative (0.0777). SDN with Redundancy displays a lower SI Plus score (0.0602) but a higher SI Negative score (0.0952), implying mixed performance. NFV with Dynamic Scaling records the lowest SI Plus score (0.0000) but the highest SI Negative score (0.1412), highlighting notable drawbacks. Hybrid SDN-NFV Architecture and Cloud-based Network Virtualization achieve competitive scores, with Cloud-based Network Virtualization excelling in SI Plus (0.1179) and Traditional Network Infrastructure exhibiting a considerable SI Negative score (0.0348).



**FIGURE 3.**

Figure 3 illustrates the outcomes of TOPSIS analysis, presenting the comparative performance of diverse network infrastructure options based on SI Plus and SI Negative scores. Traditional Network Infrastructure demonstrates moderate ratings in both SI Plus (0.1126) and SI Negative (0.0777). SDN with Redundancy exhibits a lower SI Plus score (0.0602) but a higher SI Negative score (0.0952), indicating mixed performance. NFV with Dynamic Scaling records the lowest SI Plus score (0.0000) but the highest SI Negative score (0.1412), emphasizing significant drawbacks. Hybrid SDN-NFV Architecture and Cloud-based Network Virtualization achieve competitive scores, with Cloud-based Network Virtualization excelling in SI Plus (0.1179), while Traditional Network Infrastructure presents a notable SI Negative score (0.0348).

**TABLE 7.** The Closeness Coefficient values and corresponding ranks.

Infrastructure	Ci	Rank
Traditional Network Infrastructure	0.4083	4
SDN with Redundancy	0.6126	3
NFV with Dynamic Scaling	1.0000	1
Hybrid SDN-NFV Architecture	0.7642	2
Cloud-based Network Virtualization	0.2277	5

The Closeness Coefficient values and corresponding ranks from TOPSIS analysis indicate NFV with Dynamic Scaling as the top-performing infrastructure, scoring a perfect 1.0, securing the first rank. Hybrid SDN-NFV Architecture follows closely with a coefficient of 0.7642, securing the second position. SDN with Redundancy ranks third with a coefficient of 0.6126. Traditional Network Infrastructure holds the fourth position with a

coefficient of 0.4083, while Cloud-based Network Virtualization ranks fifth with the lowest coefficient of 0.2277. This analysis suggests that NFV with Dynamic Scaling and Hybrid SDN-NFV Architecture are the most favourable options, while Cloud-based Network Virtualization performs relatively poorly in this evaluation.

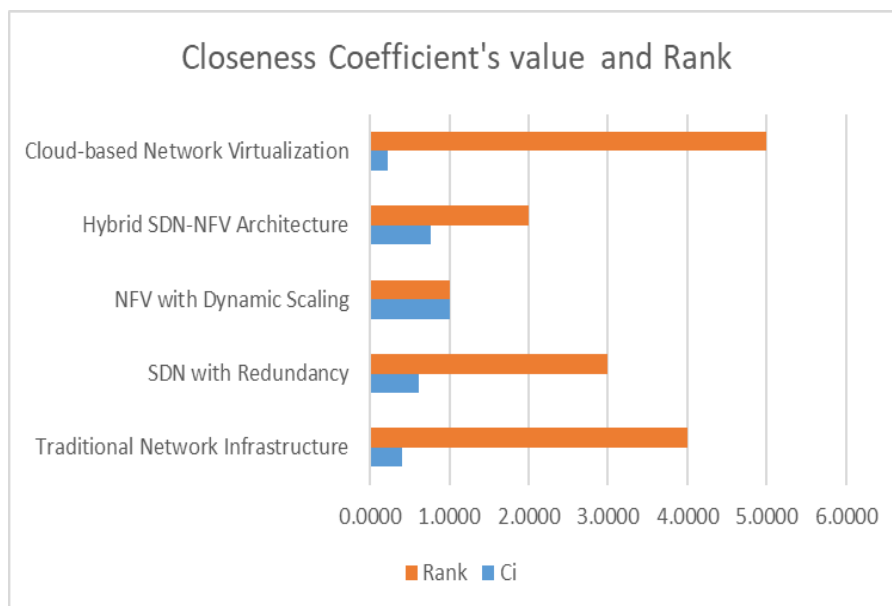


FIGURE 4.

Figure 4 displays the Closeness Coefficient values and respective rankings derived from TOPSIS analysis. NFV with Dynamic Scaling emerges as the top-performing infrastructure, attaining a perfect score of 1.0 and securing the first position. Following closely is Hybrid SDN-NFV Architecture, with a coefficient of 0.7642, placing second. SDN with Redundancy occupies the third spot with a coefficient of 0.6126. Traditional Network Infrastructure holds the fourth position with a coefficient of 0.4083, while Cloud-based Network Virtualization ranks fifth with the lowest coefficient of 0.2277. This evaluation suggests that NFV with Dynamic Scaling and Hybrid SDN-NFV Architecture are the most advantageous choices, while Cloud-based Network Virtualization demonstrates relatively weaker performance.

#### 4. CONCLUSION

Traditional network infrastructure, while simple, often falls short in fault recovery and scalability. SDN with redundancy offers improved fault recovery and scalability, albeit with higher costs. NFV with dynamic scaling strikes a balance between cost and agility but may involve moderate implementation complexity. The hybrid SDN-NFV architecture integrates the advantages of both approaches, aiming for a well-rounded performance. Cloud-based network virtualization stands out for its agility and security but requires careful consideration of latency issues. The NFV with Dynamic Scaling infrastructure emerges as the top-performing option, securing the highest rank with a perfect Closeness Coefficient value of 1.0. This infrastructure excels in critical areas such as scalability, cost-effectiveness, and fault recovery time, making it a highly attractive choice for organizations seeking agility, resilience, and cost optimization. However, it may require careful consideration of implementation complexity and security concerns associated with virtualized environments. The Hybrid SDN-NFV Architecture closely follows as the second-best option, with a Closeness Coefficient of 0.7642. This approach combines the strengths of both SDN and NFV technologies, delivering a well-rounded performance across various criteria, including scalability, cost-effectiveness, fault recovery time, and latency. While it may have moderate implementation complexity, the hybrid architecture offers a balanced solution for organizations seeking a robust and flexible network infrastructure. SDN with Redundancy ranks third, exhibiting strong performance in scalability, cost-effectiveness, and latency, but with average scores in other areas. This infrastructure may be suitable for organizations prioritizing scalability and performance while considering the moderate implementation complexity and security concerns. Traditional Network Infrastructure and Cloud-based Network Virtualization ranked fourth and fifth, respectively, highlighting their limitations in areas such as fault recovery time, scalability, and cost-effectiveness. While Traditional Infrastructure is economical and straightforward to implement, it lacks the agility and resilience demanded by modern network environments. Cloud-based Network Virtualization, although promising in fault recovery and security, may face trade-offs in scalability, cost-effectiveness, and implementation complexity. Ultimately, the choice of network infrastructure

will depend on the specific requirements and priorities of an organization, such as performance, resilience, agility, cost considerations, and the ability to address implementation complexities and security concerns effectively.

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