



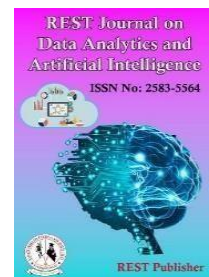
REST Journal on Data Analytics and Artificial Intelligence

Vol: 4(4), December 2025

REST Publisher; ISSN: 2583-5564

Website: <http://restpublisher.com/journals/jdaai/>

DOI: <https://doi.org/10.46632/jdaai/4/4/3>



Evaluation of SDN-Based Traffic Engineering in Data Center Networks Using the Weighted Product Method

*Manjula Selvam, Vidhya Prasanth, Devipriya Mani, M. Ramachandran

REST Labs, Kaveripattinam, Krishnagiri, Tamil Nadu, India.

Corresponding author email: manjulaselvam2016@gmail.com

Abstract: The meteoric rise of cloud computing has catalysed an explosion of data traffic within Data Centre Networks (DCNs), rendering traditional management approaches inadequate. In response to this overwhelming surge, advanced traffic management solutions have become imperative. This investigation delves into the realm of Software-Defined Networking (SDN)-based Traffic Engineering for DCNs, pinpointing the urgent necessity for network management strategies that are not only efficient but also adaptable and secure. The significance of this research is underscored by SDN's potential to transform DCN management fundamentally. With its capability for programmable, centralised control over network resources, SDN offers a promising paradigm shift. As DCNs grapple with mounting demands for heightened performance, unwavering reliability, and optimal energy efficiency, the exploration of diverse SDN-based routing alternatives takes on critical importance for the optimisation of network operations. Employing the Weighted Product Method (WPM), this study rigorously evaluates six routing alternatives: OSPF, ECMP, Hedera, MicroTE, Mahout, and ANS. This methodological approach is characterised by a thorough examination of pivotal performance metrics, including throughput, fault tolerance, network security, energy consumption, cost, and latency. Through the application of the WPM, the research presents a systematic comparison of these alternatives, unveiling insights into their relative efficacy within the unique context of DCNs. The findings illuminate a distinct hierarchy among the scrutinised routing options. Hedera emerges resplendently as the top contender, boasting a remarkable preference score of 0.946974, and showcasing unparalleled prowess across all evaluated criteria. In the ensuing ranks, OSPF routing and Mahout claim the second and third positions, respectively, demonstrating commendable performance in key areas such as latency optimisation and bolstered security. While Hedera asserts itself as the premier choice for SDN-based Traffic Engineering in DCNs, the selection of the most suitable routing alternative must be meticulously tailored to the specific demands of individual data centre environments. This study furnishes invaluable insights, steering the decision-making processes in network management and paving the way for more robust and efficient data centre networks amidst the burgeoning cloud computing landscape.

Keywords: Software-Defined Networking (SDN), Traffic Engineering, Data Center Networks (DCNs), Network Management, Routing Alternatives, Weighted Product Method (WPM), OSPF Routing and ECMP Routing.

1. INTRODUCTION

With the exponential rise in cloud computing services, a remarkable upsurge in data traffic has ensued within data centre networks (DCNs). This surge is not merely a statistic; it signifies a critical turning point, marked by a pronounced escalation in instances of congestion and the consequent loss of data packets that plague these networks. For network administrators tasked with the Herculean responsibility of navigating the intricate demands of cloud computing, a profound understanding of data packet transmission between diverse switches has become imperative [1]. At the heart of this complexity lies the traffic matrix (TM), a vital tool that encapsulates the dimensions and characteristics of network flows linking distinct source and destination nodes. Accurately estimating the TM within DCNs is essential; it empowers operators to proficiently manage network traffic, whether for resource allocation, orchestrating virtual machine migrations, or reinforcing security protocols. However, traditional methods of TM estimation often lean heavily on direct measurements or deductions derived from link counts via the Simple Network Management Protocol (SNMP). Such approaches, fraught with

limitations, may encounter pitfalls like exorbitant resource consumption or inadequate accuracy [2,3]. Moreover, acquiring the TM by measuring individual flows is not only prohibitively costly but also logistically unfeasible, as it requires substantial hardware instrumentation—a daunting task in sprawling networks like DCNs. Consequently, the quest for timely and precise TM estimates within real-world networks looms as a formidable challenge [4]. In the realm of data centre management, Software-Defined Networking (SDN) assumes a pivotal role, delineating its influence through two distinct paradigms: inter-data centre management, wherein SDN operates as a multi-layer controller that connects various data centres, and intra-data centre management, where SDN functions within a singular data centre. In this latter context, applications like Hadoop leverage a network of servers, each serving as data nodes, to facilitate the colossal transfer of data across interconnected servers and services [5]. Interestingly, traffic volume within data centres often eclipses that exchanged between end-users and the data centre itself. As files are introduced into the Hadoop ecosystem, substantial files are segmented into smaller parcels, each transmitted to the pertinent data nodes via the data centre network. This intricate process, especially regarding routing, is significantly bolstered by SDN, enhancing the efficiency of large file transfers within the Hadoop framework [6]. The SDN controller assumes the critical role of overseeing data movement among nodes, with the capacity to prioritise significant data streams to ensure the smooth operation of applications. Beyond merely optimising data flow, SDN harnesses traffic pattern analysis to redistribute workloads intelligently. This load balancing results in an equitable distribution of traffic across various pathways, culminating in swifter network processing times [7]. The operational sequences within DCNs can also be dynamically adjusted in real-time, utilising SDN to better manage workloads and improve efficiency. Yet, the optimisation of DCNs demands intelligent strategies that account for a multitude of network performance factors. This intricate challenge is ripe for the infusion of Artificial Intelligence (AI) methodologies [8]. As data centre capabilities expand, a strategic approach to energy consumption emerges as an undeniable necessity, leading to the urgent need for a novel and adaptable network architecture. This architecture should enable the seamless incorporation of new elements into the network—be it traffic coordination, innovative routing techniques, or the meticulous tracking of energy consumption. In pursuit of energy-efficient networking solutions, numerous strategies warrant consideration, and delving into potential enhancements to network topology presents a particularly captivating avenue for addressing these challenges [9]. Software-Defined Networking (SDN) has crystallised as a cornerstone in this enhancement initiative. By introducing a (virtually) centralised control hub, SDN amplifies network programmability and facilitates remote management across diverse infrastructures through a unified open protocol. This innovative framework fosters collaborative interactions between network and business applications, driven by analytics, and empowers the agile adaptation of network policies in response to shifting user experiences and application effectiveness [10,11]. While the network's configuration remains consistent, applications and systems transition into a more sophisticated state. SDN distinctly separates the data and control planes within packet-forwarding devices (switches), employing a logically centralised controller (control plane) that independently manages individual network flows by imposing customised flow directives on the switches responsible for routing (data plane) [12]. These regulations encompass detailed data flow information, coupled with a command section delineating the requisite actions for the flow, alongside trackers monitoring these statistics. OpenFlow epitomises the SDN concept, offering the allure of a centralised network view that facilitates the integration of various traffic management techniques and central control, thus presenting a compelling design alternative for data centre networks [13].

2. MATERIALS AND METHODS

The exploration of SDN-based Traffic Engineering within Data Centre Networks demands an intricate assessment of various methodologies, notably OSPF, ECMP, Hedera, MicroTE, Mahout, and ANS. This comprehensive evaluation navigates a myriad of variables: throughput, fault tolerance, network security, energy consumption, costs, and latency, all intricately woven through the lens of the MOORA method. OSPF, or Open Shortest Path First, emerges as a pivotal networking protocol employed in extensive networks such as data centres. It meticulously calculates the most efficient path for data packets, thereby ensuring a seamless flow of information. In contrast, ECMP—or Equal-Cost Multi-Path—represents a strategy that uniformly distributes network traffic across multiple paths with equivalent costs. This approach not only enhances network efficiency but also alleviates congestion, fostering an optimised environment for data transmission. Diving deeper, Hedera signifies a specialised technology or approach within the domain of SDN-centric Traffic Engineering, its specific utility contingent upon the broader contextual framework. Meanwhile, MicroTE, which stands for Micro Traffic Engineering, is dedicated to refining traffic routes with a focus on minimising delays and optimising the flow of data. It hones in on micro-level data patterns while simultaneously addressing broader traffic management strategies. The mention of Mahout likely refers to the Apache Mahout project, a robust machine learning library adept at facilitating tasks such as recommendation systems, clustering, and data categorisation within network scenarios. In the same vein, ANS, or the Alibaba Network Stack, emerges as a tailor-made tool developed by

Alibaba. It enhances network operations within their data centres, optimising packet processing efficiency and effectively reducing latency, all in pursuit of bolstering overall performance.

Throughput embodies the sheer volume of data that traverses a network or specific connection within a designated timeframe. In the realm of SDN-oriented Traffic Engineering, the quest to amplify throughput revolves around maximising efficient data transmission while simultaneously mitigating congestion, ultimately striving for elevated data transfer rates. Fault tolerance encompasses a network’s inherent capability to maintain operational integrity amidst various failures, be they hardware malfunctions or connectivity disruptions. Within the sphere of SDN-driven Traffic Engineering, fault tolerance ensures rapid adaptation and effective rerouting of traffic, thus preserving functionality during unforeseen breakdowns. Network security entails a robust set of strategies designed to safeguard data, devices, and communications within the network from unauthorised access, cyber threats, and potential breaches. In the context of SDN-centric Traffic Engineering, the integration of advanced security mechanisms is imperative to protect data centre networks against an array of vulnerabilities and threats. Energy usage reflects the total power consumed by network components and devices. In SDN-focused Traffic Engineering, the optimisation of energy consumption is crucial, involving the structuring and management of the network to reduce power usage while maintaining peak performance and reliability. Costs signify the financial commitments associated with establishing, maintaining, and operating network infrastructure. SDN-based Traffic Engineering endeavours to optimise resource allocation and traffic management, thereby minimising operational expenditures while adhering to performance standards. Latency denotes the temporal delay experienced as data journeys from source to destination within a network. In the landscape of SDN-oriented Traffic Engineering, minimising latency is of utmost importance, facilitating swift and responsive interactions among network elements—especially critical in applications such as online gaming, video streaming, and real-time data analysis. This nuanced analysis reflects the dynamic interplay of technologies and methodologies pivotal to the success of SDN-based Traffic Engineering, offering a comprehensive perspective on its multifaceted dimensions.

Weighted Product Method:

The Weighted Product Method (WPM) stands as a prominent and time-honoured technique within the realm of Multi-Criteria Decision Making (MCDM). It serves as a crucial ally for decision-makers navigating the intricate labyrinth of evaluating and ranking various alternatives through the lens of multiple criteria. In an era characterised by multifaceted decision-making landscapes, where a multitude of factors clamour for attention simultaneously, the significance of MCDM methods has surged. Notably, the WPM has garnered acclaim for its adeptness at tackling non-linear and incomparable criteria, rendering it applicable to a diverse spectrum of real-world challenges [14-15]. Delving into the theoretical foundations of the WPM, one discovers its roots intertwined with Bridgman's pioneering exploration of dimensionless numbers and their myriad applications across disciplines. Building upon this intriguing concept, Miller and Starr introduced the Weighted Product Model, a precursor to the WPM that has since flourished as a robust framework for addressing MCDM dilemmas. From its inception, the WPM has been subject to rigorous scrutiny, continual refinement, and broad application across an array of fields including engineering design, supply chain management, environmental management, energy planning, and healthcare [16-17]. The operational mechanics of the WPM unfold through a meticulous process: the multiplication of the normalised performance ratings for each alternative by their respective weights, creating a synergistic interplay of factors. This strategic approach ensures that the relative significance of each criterion is deftly woven into the fabric of the overall evaluation process. The methodology is anchored in the creation of a decision matrix, the determination of weight vectors, the normalisation of the decision matrix, the calculation of preference values for each alternative, and ultimately, the ranking of these alternatives based on their derived preference values [18-19].

Consider a comprehensive decision matrix, denoted as:

$$D = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

In this formulation, D) embodies the various alternatives, represented across multiple criteria. The corresponding weight vector can be succinctly articulated as:

$$w_j = [w_1 \quad \dots \quad w_n]$$

with the crucial condition that the summation of the weights adheres to:

$$\sum_{j=1}^n (w_1 \cdots w_n) = 1$$

To enhance the comparability of the alternatives, we must normalise the decision matrix, defined mathematically as follows:

$$n_{ij} = \begin{cases} \frac{x_{ij}}{\max. x_{ij}} & | j \in B \\ \frac{\min. x_{ij}}{x_{ij}} & | j \in C \end{cases}$$

Here, n_{ij} signifies the normalised value for the i^{th} alternative corresponding to the j^{th} criterion. Notably, $\max. x_{ij}$ and $\min. x_{ij}$ refer to the maximum and minimum values found within the j^{th} column, specifically for benefit (denoted as B) and cost criteria (denoted as C), respectively.

Next, we elevate our normalised decision matrix through the application of weights, yielding:

$$W_{n_{ij}} = (n_{ij})^{w_j}$$

Ultimately, the alternatives demand an orderly ranking, represented by the scoring function:

$$S_i^{WPM} = \prod_{j=1}^n (n_{ij})^{w_j}$$

In this equation, S_i^{WPM} denotes the ranking score assigned to the i^{th} alternative, while w_j represents the weight of the j^{th} criterion. The alternatives are then systematically ranked in descending order, with the highest S_i^{WPM} receiving the premier rank.

Among its myriad advantages, the WPM shines brightly for its capacity to accommodate non-linear and incomparable criteria, positioning itself as an invaluable asset in complex decision-making scenarios. Moreover, it deftly incorporates the relative importance of criteria through judicious weight assignments, empowering decision-makers to prioritise specific factors grounded in their expertise or preferences. The method, too, boasts a user-friendly design, facilitating comprehension and application among decision-makers hailing from diverse backgrounds [20-22]. The versatility inherent in the Weighted Product Method has rendered it applicable to a wide-ranging spectrum of decision-making challenges. Fields such as engineering design, supply chain management, environmental stewardship, energy planning, and healthcare have all benefited from its insights. Additionally, the WPM affords opportunities for sensitivity analysis, enabling decision-makers to probe how fluctuations in criterion weights influence the ranking of alternatives [23-24]. Nevertheless, the Weighted Product Method is not without its limitations and avenues for enhancement. Its compensatory nature, coupled with the subjective weight assignment and the potential for rank reversal, highlights areas for critical reflection. In pursuit of addressing these challenges, researchers have embarked on explorations of extensions and modifications to the WPM. Notable innovations include the integration of fuzzy logic, the amalgamation with other MCDM techniques, and the crafting of hybrid approaches to bolster its efficacy [25].

3. ANALYSIS AND DISCUSSION

TABLE 1. Data

Alternative	Throughput (Gbps)	Fault Tolerance	Network Security (score)	Energy Consumption (kWh)	Cost (in 1000 \$)	Latency (ms)
OSPF routing	150	9	8.5	450	120	2.5
ECMP routing	130	8	8.2	500	110	3.1
Hedera	180	9.5	8.9	400	130	2.8
MicroTE	120	7.5	8	520	105	3.5
Mahout	160	8.5	8.6	470	115	2.6
ANS	140	8.8	8.3	490	112	3.2

The data encapsulated in Table 1 presents a fascinating snapshot of the performance metrics across six distinct routing alternatives, each evaluated on crucial parameters such as throughput, fault tolerance, network security, energy consumption, cost, and latency. These factors are pivotal in assessing not only the efficiency of the network but also its overall performance. When we delve into throughput, Hedera emerges as the clear frontrunner,

boasting an impressive figure of 180 Gbps. Close behind, Mahout registers a commendable 160 Gbps, while OSPF routing, though slightly trailing at 150 Gbps, still showcases robust capabilities. In stark contrast, MicroTE finds itself at the bottom of the spectrum with a throughput of merely 120 Gbps, casting doubt on its suitability for applications demanding substantial bandwidth. The metrics for fault tolerance and network security reveal further layers of complexity in determining the reliability of these routing options. Hedera not only achieves the highest fault tolerance rating of 9.5 but also garners a notable security score of 8.9. This combination underscores its aptitude for environments where resilience and security are non-negotiable. OSPF routing and Mahout follow suit with solid fault tolerance ratings of 9 and 8.5, respectively, while MicroTE struggles with a lower score of 7.5, signalling potential vulnerabilities. Turning our gaze to energy consumption, MicroTE again leads the pack—albeit in a less desirable capacity—by consuming a staggering 520 kWh. In sharp contrast, Hedera demonstrates a more efficient energy profile with consumption at 400 kWh. Cost considerations also come into play; MicroTE is the most budget-friendly option at \$105, while Hedera’s higher price tag of \$130 may cause some trepidation among budget-conscious decision-makers. Latency, a critical determinant of responsiveness, is another area where OSPF routing shines, delivering the lowest latency at just 2.5 ms.

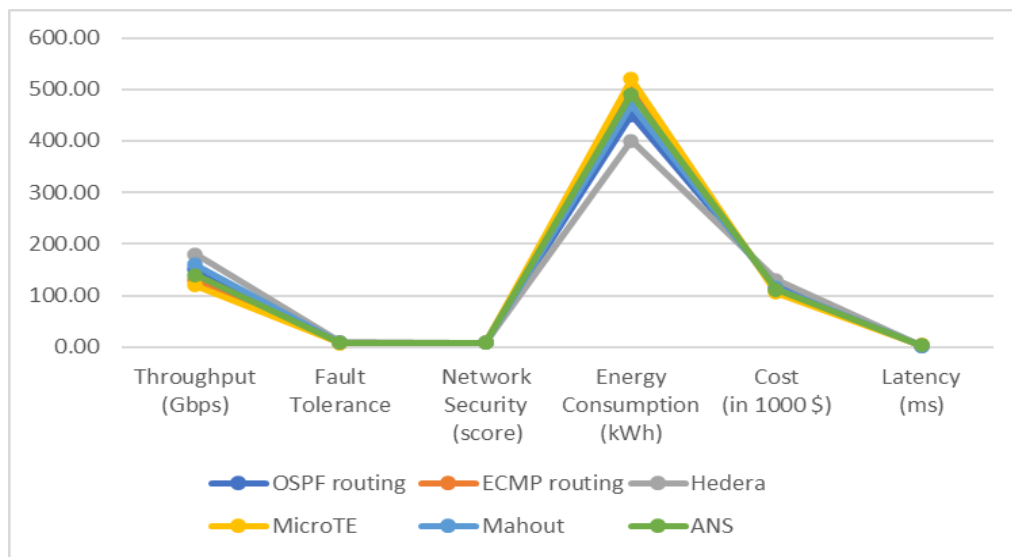


FIGURE 1. Data Set

The data showcased in Figure 1 presents a captivating tapestry of performance metrics for six distinct routing alternatives, each vying for supremacy in key domains: throughput, fault tolerance, network security, energy consumption, cost, and latency. This comprehensive evaluation scrutinises various pivotal factors, integral to discerning the performance and efficiency of network operations. Diving into throughput, Hedera stands out as the champion, boasting an impressive throughput of 180 Gbps. Hot on its heels is Mahout, clocking in at 160 Gbps, while OSPF routing, though slightly trailing with a respectable 150 Gbps, demonstrates commendable capabilities. Meanwhile, MicroTE languishes at the bottom with a mere 120 Gbps, casting doubt on its suitability for bandwidth-intensive applications. Fault tolerance and network security ratings are equally paramount, shedding light on the reliability of these routing contenders. Here, Hedera once again claims the throne with a remarkable fault tolerance score of 9.5, complemented by an impressive security rating of 8.9. This duo of high scores signifies its readiness for environments where resilience and security are non-negotiable. OSPF routing and Mahout follow suit, recording fault tolerance ratings of 9 and 8.5, respectively, while MicroTE lags with a score of 7.5, revealing vulnerabilities in its reliability. Energy consumption is another critical dimension to consider. MicroTE, alas, emerges as the energy guzzler, consuming a hefty 520 kWh, starkly contrasted by Hedera's more streamlined consumption of 400 kWh. On the financial front, MicroTE shines as the budget-friendly option, priced at \$105, yet Hedera, with its premium price of \$130, could pose challenges for budget-conscious decision-makers. Lastly, examining latency reveals that OSPF routing excels with a mere 2.5 ms latency, establishing itself as the most responsive option among the contenders, making it a worthy choice for those prioritising speed and efficiency.

TABLE 2. Performance Values

OSPF routing	0.83333	0.94737	0.95506	0.88889	0.87500	1.00000
ECMP routing	0.72222	0.84211	0.92135	0.80000	0.95455	0.80645
Hedera	1.00000	1.00000	1.00000	1.00000	0.80769	0.89286
MicroTE	0.66667	0.78947	0.89888	0.76923	1.00000	0.71429

Mahout	0.88889	0.89474	0.96629	0.85106	0.91304	0.96154
ANS	0.77778	0.92632	0.93258	0.81633	0.93750	0.78125

The performance values detailed in Table 2 illuminate the results derived from evaluating an array of routing alternatives through the lens of the Weighted Product Method. This approach accentuates a multitude of criteria: throughput, fault tolerance, network security, energy consumption, cost, and latency. By scoring each alternative against these factors, a nuanced and thorough comparison of their performance is rendered. In this landscape, Hedera distinctly rises to prominence, attaining flawless scores across all assessed criteria. Such exemplary performance underscores its unparalleled prowess in areas such as throughput, fault tolerance, network security, and energy efficiency. Coupled with its reasonable figures for cost and latency, Hedera showcases an exceptional ability to harmonise these pivotal performance metrics, solidifying its status as an extraordinarily effective contender in the realm of network routing. Conversely, MicroTE lags behind, particularly faltering in throughput and latency. Despite its commendable performance concerning cost, these deficiencies significantly undermine its overall efficiency. OSPF routing and Mahout display a more balanced performance spectrum; notably, Mahout shines in fault tolerance and network security, yet both alternatives trail behind Hedera in terms of throughput and energy efficiency. ECMP routing and ANS further contribute to the competitive performance landscape, with ECMP routing highlighting a robust focus on fault tolerance and cost-effectiveness. Meanwhile, ANS, though scoring lower in throughput, exhibits a commendable capability in fault tolerance and network security. This comparative analysis accentuates the diverse strengths and weaknesses inherent in each routing alternative, emphasising the necessity of a customised approach when determining the most suitable solution for specific network demands.

TABLE 3. Weight

OSPF routing	0.166667	0.166667	0.166667	0.166667	0.166667	0.166667
ECMP routing	0.166667	0.166667	0.166667	0.166667	0.166667	0.166667
Hedera	0.166667	0.166667	0.166667	0.166667	0.166667	0.166667
MicroTE	0.166667	0.166667	0.166667	0.166667	0.166667	0.166667
Mahout	0.166667	0.166667	0.166667	0.166667	0.166667	0.166667
ANS	0.166667	0.166667	0.166667	0.166667	0.166667	0.166667

Table 3 unveils a nuanced comparative analysis of six distinct routing alternatives, meticulously examining a multitude of performance criteria: throughput, fault tolerance, network security, energy consumption, cost, and latency. The alternatives under scrutiny—namely OSPF routing, ECMP routing, Hedera, MicroTE, Mahout, and ANS—demonstrate a curious uniformity in their score distribution across these pivotal criteria, each attribute receiving an equal weight of 0.1667. This equal weighting inherently posits that all six alternatives are being evaluated with the underlying assumption that every criterion bears the same degree of importance in the intricate decision-making labyrinth. Such a consistent distribution of weights reflects a balanced, albeit somewhat rigid, approach to performance evaluation. It empowers stakeholders to navigate the decision-making landscape without unduly privileging any single criterion. In multi-criteria decision-making scenarios, where a diverse array of performance attributes clamours for attention, this methodology fosters a sense of comprehensiveness. By granting equal importance to all criteria, the analysis champions transparency and fairness, thus enabling decision-makers to appraise each routing alternative with a critical yet objective lens. Yet, one must tread cautiously; while this egalitarian approach boasts its merits, it may inadvertently overlook contexts where certain criteria naturally demand a heavier emphasis. For instance, within the confines of high-security environments, the pressing need for robust network security could far outweigh concerns like cost or latency. Thus, although the equal distribution of weights lays the groundwork for an initial comparative analysis, it beckons a re-evaluation of the weighting scheme. Such recalibration would ensure it mirrors the specific contexts and priorities that stakeholders hold dear, ultimately refining the decision-making process to better reflect the realities of diverse operational landscapes.

TABLE 4. Weighted Normalized Matrix

OSPF routing	0.97007	0.99103	0.99237	0.98056	0.97799	1.00000
ECMP routing	0.94721	0.97176	0.98644	0.96349	0.99228	0.96478
Hedera	1.00000	1.00000	1.00000	1.00000	0.96503	0.98129
MicroTE	0.93466	0.96137	0.98239	0.95721	1.00000	0.94546
Mahout	0.98056	0.98163	0.99430	0.97348	0.98495	0.99348
ANS	0.95898	0.98732	0.98843	0.96674	0.98930	0.95969

Table 4 presents a meticulously crafted weighted normalized matrix, the product of the Weighted Product Method (WPM), which serves as a pivotal tool for evaluating a spectrum of six distinct routing alternatives: OSPF routing,

ECMP routing, Hedera, MicroTE, Mahout, and ANS. This matrix is rich with diverse performance criteria, encompassing throughput, fault tolerance, network security, energy consumption, cost, and latency. Each alternative is rigorously assessed across these multifaceted metrics, with values normalised to foster an unambiguous comparison. Diving into the data, it becomes evident that Hedera emerges as a frontrunner, boasting the highest normalized scores across all evaluated criteria, a testament to its remarkable performance prowess. Achieving a perfect score of 1 in crucial areas—throughput, fault tolerance, and network security—Hedera distinctly outshines its competitors. Following closely in the rankings are OSPF routing and Mahout, where OSPF routing reveals commendable performance, particularly excelling in latency, while Mahout showcases its strengths in both throughput and network security. In this competitive landscape, ECMP routing and ANS also present formidable scores, especially in terms of cost and energy consumption, underscoring their efficiency and practicality. Yet, MicroTE lags slightly, registering lower performance across most criteria, suggesting it may not represent the optimal choice among these alternatives. The application of the Weighted Product Method not only amplifies the decision-making process but also provides a vivid illustration of each alternative's unique strengths and weaknesses. By normalising the scores, this analysis empowers stakeholders to pinpoint the most suitable routing alternative based on a thorough and nuanced evaluation of performance metrics. This, in turn, facilitates informed decisions meticulously tailored to meet the specific demands of the network environment, allowing for a strategic alignment of resources and priorities.

TABLE 5. Preference Score and Rank

Alternative	Preference Score	Rank
OSPF routing	0.914893	2
ECMP routing	0.837505	5
Hedera	0.946974	1
MicroTE	0.798876	6
Mahout	0.911686	3
ANS	0.85899	4

Table 5 unveils a detailed panorama of performance scores and rankings for six distinct routing alternatives, meticulously assessed through the Weighted Product Method (WPM). This table does not merely present numbers; it encapsulates the essence of each alternative's effectiveness, as measured against weighted criteria, illuminating their relative standings in the hierarchy of routing options. At the pinnacle of this assessment is Hedera, triumphantly clinching the top spot with a remarkable preference score of 0.9469. This impressive figure is not just a statistic; it signifies Hedera's exceptional prowess across the evaluated criteria, hinting at its unparalleled suitability for the intricate network demands at play. Its stellar performance suggests a balanced approach that optimally integrates throughput, fault tolerance, and network security, all while judiciously managing energy consumption, costs, and latency—elements that are often at odds in the pursuit of efficiency. Not far behind, OSPF routing claims the second position with a commendable preference score of 0.9149. This substantial score indicates that OSPF is not merely a contender but a robust option, particularly noted for its stellar performance in critical metrics like latency and security. Meanwhile, Mahout secures the third place with a preference score of 0.9117, reflecting a solid performance, albeit slightly trailing behind OSPF. In stark contrast, the lower ranks are populated by ECMP routing, ANS, and MicroTE, with preference scores of 0.8375, 0.8590, and a modest 0.7989, respectively. These scores reveal a reality: while these alternatives hold potential, they undeniably lag behind their higher-ranked counterparts in overall effectiveness. MicroTE, in particular, languishes at the bottom, raising flags about its efficacy in the pivotal performance dimensions scrutinised.

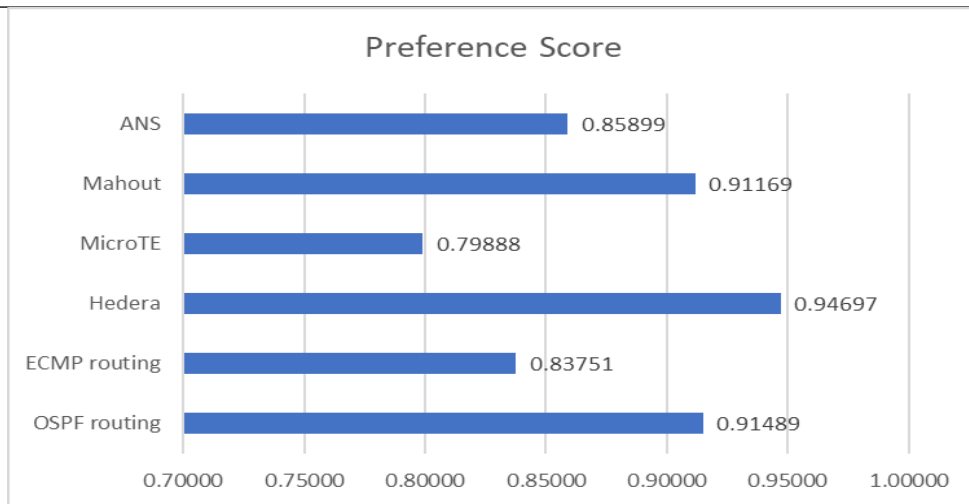


FIGURE 2. Preference Score

The visual representation depicted in Chart 2 vividly encapsulates the preference scores assigned to six routing alternatives, meticulously derived from the Weighted Product Method. Each alternative emerges as a horizontal bar, creating an intuitive platform for comparative analysis, illuminating the performance spectrum across diverse routing options based on their meticulously calculated scores. Dominating this landscape, Hedera emerges as the unequivocal frontrunner, boasting an impressive preference score of 0.94697. This remarkable figure underscores its exceptional efficacy when scrutinised against the myriad criteria evaluated, establishing it as the premier choice for network routing within the context of this analysis. Such stellar performance can be ascribed to its robust capabilities in essential domains, including throughput, fault tolerance, and network security. Trailing closely behind, OSPF routing secures a commendable second place with a preference score of 0.91489. This outcome reflects OSPF's reliability as a routing alternative, shining particularly in the realms of latency and security. Consequently, it emerges as a formidable contender for decision-makers in search of optimal routing solutions. Not to be overlooked, Mahout claims the third position with a score of 0.91169. While it showcases a commendable level of performance, it falls just short of OSPF routing. Close on its heels, ANS occupies the fourth spot with a preference score of 0.85899. Although its performance remains satisfactory, it lags behind the upper echelon of alternatives, signalling potential areas for enhancement. In stark contrast, ECMP routing and MicroTE languish at the bottom of the ranking, with preference scores of 0.83751 and 0.79888, respectively. These figures indicate a marked deficiency in competitiveness concerning the evaluated criteria, suggesting that these alternatives may not be the most desirable options in the intricate tapestry of network routing scenarios.

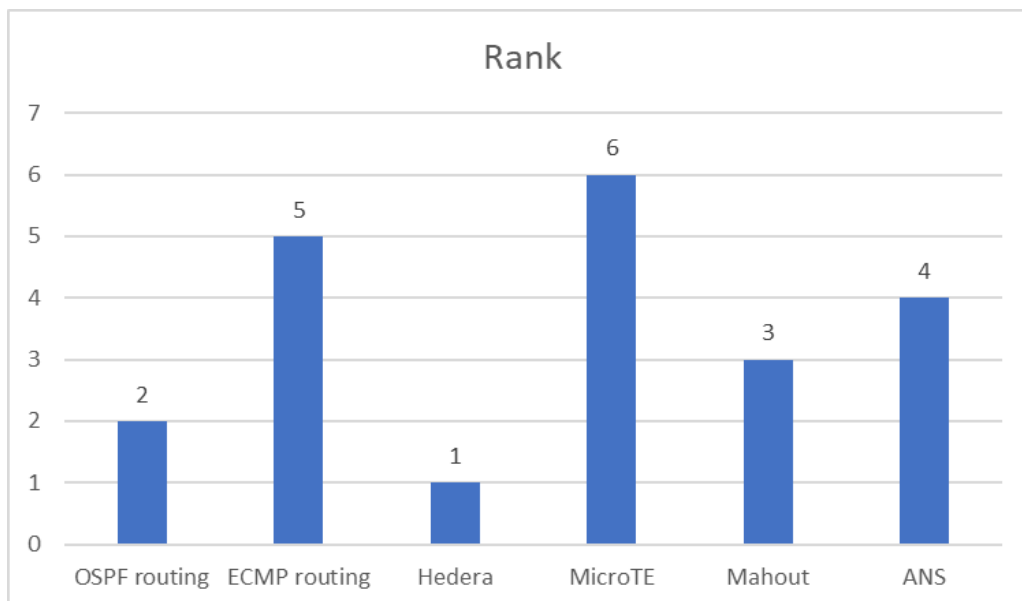


FIGURE 3. Rank

Figure 3 vividly illustrates the hierarchy of six distinct routing alternatives, all meticulously assessed through the lens of the Weighted Product Method (WPM). This visual representation sheds light on the nuanced performance dynamics of each contender in the intricate realm of decision-making. The alternatives scrutinised encompass OSPF routing, ECMP routing, Hedera, MicroTE, Mahout, and ANS. Each ranking unfurls a tapestry of insights, revealing which alternatives emerge as the most potent choices according to the criteria meticulously applied during analysis. In a striking display of prowess, Hedera claims the coveted top position, asserting itself as the paramount alternative. This prestigious ranking underscores Hedera's status as the most advantageous option among the contenders, illuminating its exceptional performance across vital metrics such as throughput, fault tolerance, and network security. Such a high standing not only marks it as a leader in the field but also positions it as the quintessential candidate for optimal network routing solutions. Trailing closely, OSPF routing secures the second spot. This strategic placement signals that OSPF is also a formidable player, particularly shining in areas like latency and security. Its commendable performance solidifies its status as a trustworthy alternative, even if it slightly lags behind the frontrunner, Hedera. In the third slot, Mahout emerges, hinting at its solid overall performance. However, it fails to reach the heights achieved by the top two contenders, illustrating a gap in capability that could influence decision-making. Following Mahout, ANS holds the fourth position. While it remains a viable alternative, its performance does not match the strength of the leading options, indicating a potential compromise for stakeholders. At the lower end of the spectrum, ECMP routing and MicroTE find themselves in fifth and sixth positions, respectively. This ranking starkly illustrates that both alternatives may struggle to meet the rigorous performance criteria expected in the competitive landscape of routing solutions. Their diminished desirability in routing decisions becomes apparent as a result. In summary, Hedera's first-place ranking signifies its preeminence based on the assessed performance criteria, encompassing throughput and fault tolerance. OSPF routing, in its second-place standing, showcases reliability, particularly in terms of latency and security. Mahout, while securing third place, suggests a commendable but lesser performance compared to the frontrunners. ANS, in fourth, remains a feasible choice yet is less competitive. Meanwhile, ECMP routing and MicroTE, languishing in fifth and sixth ranks, reflect relative underperformance when juxtaposed with their peers. Collectively, these rankings afford stakeholders a lucid perspective on the most suitable routing solutions, empowering informed decision-making rooted in thorough evaluations.

4. CONCLUSION

Software-Defined Networking (SDN) has risen to prominence as a revolutionary paradigm in network management, particularly in the intricate realm of Traffic Engineering for Data Centre Networks (DCNs). By disentangling the control plane from the data plane, SDN ushers in an era of heightened flexibility, programmability, and efficiency in network operations. In the context of DCNs, where traffic patterns proliferate in both volume and complexity, SDN-enabled Traffic Engineering unfolds innovative avenues for performance optimisation, security enhancement, and operational cost reduction. This investigation delves into a meticulous analysis of diverse SDN-driven routing alternatives for DCNs, encompassing OSPF, ECMP, Hedera, MicroTE, Mahout, and ANS. Employing the Weighted Product Method (WPM), we meticulously evaluate these alternatives against pivotal performance metrics: throughput, fault tolerance, network security, energy consumption, cost, and latency. Our analysis uncovers a pronounced hierarchy among the scrutinised routing alternatives. Hedera ascends to the pinnacle of performance, showcasing exceptional prowess across all evaluated criteria. Its impressive preference score of 0.946974 underscores its capacity to deftly balance the multifaceted demands of contemporary DCNs, particularly in maximising throughput while ensuring robust fault tolerance and stringent network security. Meanwhile, OSPF routing and Mahout closely follow, securing the second and third positions respectively, with commendable performances in specialised domains such as latency optimisation and security enhancement. The implications of these findings resonate deeply with network administrators and decision-makers navigating the labyrinth of data centre management. Hedera's stellar performance suggests a formidable solution for DCNs aspiring to refine their traffic engineering methodologies. However, the robust capabilities exhibited by OSPF routing and Mahout reveal their continued relevance, especially in scenarios where their unique strengths resonate with specific network priorities. As data centre networks evolve, grappling with ever-growing demands, the significance of effective SDN-based Traffic Engineering solutions becomes paramount. This study enriches the ongoing discourse by presenting a data-driven comparison of routing alternatives, delivering critical insights to inform decision-making processes in network management. In summation, while Hedera clearly emerges as the premier option, selecting the most suitable routing alternative necessitates a careful alignment with the distinct requirements and constraints of each data centre environment. Future inquiries in this domain should aim to refine these solutions further and investigate novel strategies to tackle the dynamic landscape of data centre networking.

REFERENCES

- [1]. Bastam, Mostafa, Masoud Sabaei, and Ruhollah Yousefpour. "A scalable traffic engineering technique in an SDN-based data center network." *Transactions on Emerging Telecommunications Technologies* 29, no. 2 (2018): e3268.
- [2]. Han, Yoonseon, Sin-seok Seo, Jian Li, Jonghwan Hyun, Jae-Hyoung Yoo, and James Won-Ki Hong. "Software defined networking-based traffic engineering for data center networks." In *The 16th Asia-Pacific Network Operations and Management Symposium*, pp. 1-6. IEEE, 2014.
- [3]. Liu, Guiyan, Songtao Guo, Bin Xiao, and Yuanyuan Yang. "SDN-based traffic matrix estimation in data center networks through large size flow identification." *IEEE Transactions on Cloud Computing* 10, no. 1 (2019): 675-690.
- [4]. Amaral, Pedro, Paulo F. Pinto, Luis Bernardo, and Fábio Silva. "SDN based traffic engineering without optimization: A centrality based approach." In *2017 IEEE International Conference on Communications (ICC)*, pp. 1-7. IEEE, 2017.
- [5]. Kanumarlapudi, P. K. "Improving Data Market Implementation Using Gray Relational Analysis in Decentralized Environments." *Journal of Artificial intelligence and Machine Learning* 2, no. 1 (2024): 1-7.
- [6]. Thota, Sandeep Kumar, Kumari Gubbala, Ashok Polavarapu, Vikram Narayandas, Hari Suresh Babu Gummadi, Narendra Chennupati, Sreedhar Babu Seshagani, Shivakrishna Deepak Veeravalli, and Manisha Guduri. "Adversarial Training with Attention-Guided DCGAN for Robust Lung Segmentation in Medical Imaging." In *2025 IEEE Region 10 Symposium (TENSYMP)*, pp. 1-6. IEEE, 2025.
- [7]. Nayeemuddin, . and Salma, Umme, Analysis of a Drilling Hybrid Aluminum Metal Matrix Composites by Using SPSS (May 7, 2023). *Int. J. Adv. Res.* 11(01), 82-91, 2023, Available at SSRN: <https://ssrn.com/abstract=4440349>
- [8]. Pilimon, Artur, Angelos Mimidis Kentis, Sarah Ruepp, and Lars Dittmann. "Analysis of traffic engineering capabilities for SDN-based data center networks." In *2018 Fifth International Conference on Software Defined Systems (SDS)*, pp. 211-216. IEEE, 2018.
- [9]. Paliwal, Manish, and Deepti Shrimankar. "Effective resource management in SDN enabled data center network based on traffic demand." *IEEE Access* 7 (2019): 69698-69706.
- [10]. Shirmarz, Alireza, and Ali Ghaffari. "Performance issues and solutions in SDN-based data center: a survey." *The Journal of Supercomputing* 76, no. 10 (2020): 7545-7593.
- [11]. Benzaoui, Nihel, José Manuel Estarán, Eric Dutisseuil, Haïk Mardoyan, Guilhem de Valicourt, Arnaud Dupas, Q. Pham Van et al. "CBOSS: bringing traffic engineering inside data center networks." *Journal of Optical Communications and Networking* 10, no. 7 (2018): B117-B125.
- [12]. Bastam, Mostafa, Keyvan RahimiZadeh, and Ruhollah Yousefpour. "Design and performance evaluation of a new traffic engineering technique for software-defined network datacenters." *Journal of Network and Systems Management* 29, no. 4 (2021): 38.
- [13]. Kulakov, Yurii, Alla Kohan, and Sergii Kopychko. "Traffic orchestration in data center network based on software-defined networking technology." In *Advances in Computer Science for Engineering and Education II*, pp. 228-237. Springer International Publishing, 2020.
- [14]. Wang, Yao-Chun, Ying-Dar Lin, and Guey-Yun Chang. "SDN-based dynamic multipath forwarding for inter-data center networking." *International Journal of Communication Systems* 32, no. 1 (2019): e3843.
- [15]. Pang, Junjie, Gaochao Xu, and Xiaodong Fu. "SDN-based data center networking with collaboration of multipath TCP and segment routing." *IEEE Access* 5 (2017): 9764-9773.
- [16]. Charalampou, Paris, and Efstathios D. Sykas. "An SDN focused approach for energy aware traffic engineering in data centers." *Sensors* 19, no. 18 (2019): 3980.
- [17]. San Cristóbal Mateo, José Ramón, and José Ramón San Cristóbal Mateo. "Weighted sum method and weighted product method." *Multi criteria analysis in the renewable energy industry* (2012): 19-22.
- [18]. Aminudin, Nur, Eni Sundari, K. Shankar, P. Deepalakshmi, Rita Irviani Fauzi, and Andino Maselena. "Weighted Product and its application to measure employee performance." *International Journal of Engineering & Technology* 7, no. 2.26 (2018): 102-108.
- [19]. Manjula selvam, Vimala Saravanan, M. Ramachandran, Ramya Sharama, "Evaluating the criteria for Crime against Women in India based on DEMATEL approach", *Journal on Innovations in Teaching and Learning*, 3(1), March 2024, 36-46.
- [20]. , Sridhar Reddy, Praveen Kumar Kanumarlapudi, and Sudhakara Reddy Peram. "Performance Metrics and Defect Rate Prediction Using Gaussian Process Regression and Multilayer Perceptron." *Information Technology and Management* 15, no. 1 (2024): 37-53.
- [21]. Peram, S. R. "Automated Label Detection and Recommendation System Using Deep Convolution Neural Networks and SPSS-Based Evaluation." *International Journal of Computer Science and Data Engineering* 1, no. 2 (2024): 258.
- [22]. Kakulavaram, S. R. "Performance Measurement of Test Management Roles in 'A'Group through the TOPSIS Strategy." *International Journal of Artificial intelligence and Machine Learning* 1, no. 3 (2023): 276.
- [23]. Kanumarlapudi, Praveen Kumar, and S. Ballamudi. "Enhancing Generative AI Shopping Assistants through Advanced Multi-Attribute Decision Making Technique." *Journal of Artificial Intelligence and Machine Learning* 3, no. 2 (2025): 1-7.
- [24]. Nayeemuddina Umme Salma, Green Fabrication of Nio Nano Particles Doped PS-PVDF Nanocomposite Films: Structural, Morphology and Electrical Studies, *Journal of Information Systems Engineering and Management*, 10(23), 2025, 794-800.
- [25]. Wang, Mingxi, Shulin Liu, Shouyang Wang, and Kin Keung Lai. "A weighted product method for bidding strategies in multi-attribute auctions." *Journal of Systems Science and Complexity* 23, no. 1 (2010): 194-208.
- [26]. Khairina, Dyna Marisa, Muhammad Reski Asrian, and Heliza Rahmania Hatta. "Decision support system for new employee recruitment using weighted product method." In *2016 3rd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE)*, pp. 297-301. IEEE, 2016.

-
- [27]. Supriyono, Heru, and Chintya Purnama Sari. "Developing decision support systems using the weighted product method for house selection." In *AIP conference proceedings*, vol. 1977, no. 1. AIP Publishing, 2018.
- [28]. Ahsan, M., and N. Indawati. "Implementation weighted product method to determine multiple intelligence child." In *Journal of Physics: Conference Series*, vol. 1375, no. 1, p. 012038. IOP Publishing, 2019.
- [29]. Sabandar, Vederico Pitsalitz. "Sistem Pendukung Keputusan Penentuan Produk Terbaik Menggunakan Weighted Product Method." *Jurnal Ilmiah Computer Science* 1, no. 2 (2023): 58-68.
- [30]. Rahayu, Dewi, and Siti Mukodimah. "Decision Support System of achieved students using Weighted product method." *IJISCS (International Journal of Information System and Computer Science)* 3, no. 2 (2019): 72-77.
- [31]. Stanujkic, Dragisa, Gabrijela Popovic, Darjan Karabasevic, Ieva Meidute-Kavaliauskiene, and Alptekin Ulutaş. "An integrated simple weighted sum product method—WISP." *IEEE Transactions on Engineering Management* 70, no. 5 (2021): 1933-1944.
- [32]. Peram, S. R. "Advanced Network Traffic Visualization and Anomaly Detection Using PCA-MDS Integration and Histogram Gradient Boosting Regression." *Journal of Artificial Intelligence and Machine Learning* 1, no. 3 (2023): 281.
- [33]. Yi, Sora, and Yong-Chul Jang. "Analysis of recommended mobile selection using the weighted product method." *International Journal of Informatics and Information Systems* 5, no. 4 (2022): 167-174.
- [34]. Sinaga, Ardiles, and Disma Maulana. "Implementation of weighted product method for evaluating performance of technicians." *International Journal of Modern Education and Computer Science* 11, no. 4 (2022): 30.
- [35]. Wardhani, Anindya Khrisna, and Erba Lutfina. "Application Culinary decision support system in Kudus city with weighted product method based on mobile phone." *Journal of Computer Science and Engineering (JCSE)* 1, no. 1 (2020): 10-16.
- [36]. Chinnasami Sivaji, Vidhya Prasanth, Ramya sharma, M. Ramachandran, "Evaluating Project Alternatives for Transportation System Sustainability: Through the WSM Methodology", *Building Materials and Engineering Structures* 2(1), March 2024, 23-31
- [37]. Abhinav, E. Meher, Sai Naveen Kavuri, Thota Sandeep Kumar, Maragani Thirupathi, M. Chandra Mohan, and A. Suresh Reddy. "Analysis of molecular single-electron transistors using silicene, graphene and germanene." In *Proceedings of the Second International Conference on Computer and Communication Technologies: IC3T 2015, Volume 1*, pp. 77-84. New Delhi: Springer India, 2015.
- [38]. Kakulavaram, S. R. "Strategic Insights into Healthcare Waste Management through the DEMATEL Approach." *Journal of Business Intelligence and Data Analytics* 1, no. 3 (2024): 255.