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A Hybrid Methodology for Performance Assessment of Campus Network

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Abstract

In this paper, we propose a combined methodology of fuzzy analytic hierarchy process (FAHP) and data envelopment analysis (DEA) in order to apply it to multivariate analysis and integrated evaluation. With FAHP method, the relative importance levels of different available indicators are determined. And the DEA model is used to obtain the efficiency performances of the use case of network measurement. Finally network performance is evaluated by means of integrating available indicator weights with efficiency performances. It is quite important that the integrated methodology considers both personal preferences and objective relative efficiency for assessment simultaneously to avoid the bias of single methodology.

***Keywords**: performance assessment, fuzzy analytic hierarchy process, data envelopment analysis, campus network*

1. Introduction

Network performance refers to measures of service quality of a network product as seen by the users. With the wide application of cloud computing [1] and big data [2], network performance, which is critical to Internetware [3], gains increasing research focus in the network engineering field. It is a difficult issue to dynamic track and quantitative analyze network performance. Because network performance tend to have many measurement indicators (jitter, missing package rate, throughput, etc.), and the major challenge for benchmarking is how to effectively solve the multi-objective model to accurate assessment.

In traditional empirical studies, many benchmarking methods have been presented for network performance. However, most of these studies have focused on FAHP method which is used to provide a vector of weights expressing the relative importance for each criterion. Furthermore, FAHP method reflects the decision makers' preferences but ignores the internal relationship between measured data.

In this paper, we propose a novel network performance benchmarking method based on a combined methodology of FAHP/DEA. The FAHP is applied to determine the relative importance levels of different available indicators, and DEA is used to solve obtain the efficiency performances of the use case of network measurement. This paper is organized as follows. Section 2 reviews the related works pertinent to this research. The details of the proposed methodology are presented in Section 3. Section 4 provides a campus network example to demonstrate the efficiency of our proposed model. Conclusions are presented in Section 5.

2. Related Works

Previous researches mainly focus on the human preferences, using AHP or FAHP methodology to solve multi-objective evaluation as in [4]. It is useful for achieving the differentiated service network as in [5]. The need for correlation between indicators is introduced by [6] to weaken the impact of abnormal values. Meanwhile, many studies including [7-8] have been tried to contribute to designing the metrics to reflect the network quality.

However, none of these researches has considered the qualitative and quantitative variables for efficiency assessment. Scores with single AHP or FAHP method using the same

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weight vector only can express the experts' subjective preferences. We will apply the integrated FAHP/DEA approach to develop a framework for evaluating the performance of campus network as follows.

3. The Integrated DEA and FAHP Methodology

3.1 Execution Flow Chart

The combined methodology of FAHP/DEA is composed of six phases for assessing and prioritizing the relative scores of network performance. Figure 1 shows the schematic of the execution flow chart. In 1st phase the network system being studied is simulated and validated. The next step consists of the scenarios definition and formulation of a list of criteria used to compute the relative importance of criteria and alternatives. The 3rd phase extracts the data from simulation with respect to selected scenarios. The purpose of FAHP is to provide the criteria weights of network expressing the relative importance, and synthesize priorities of the alternative scenarios. The efficiency scores of network scenarios are measured by using the DEA approach. The final step aggregates the synthesize priorities and efficiency scores produced in 5th phase.

3.2 Fuzzy Analytic Hierarchy Process (FAHP)

FAHP was one ordering method and was aimed at coordinating decision-makers to solve complicated problems with fuzzy multiple attributes. In this part, criteria weights of the network performance variable are obtained by using Chang's extent FAHP method [9]. Although there are a number of FAHP methods to calculate weights, this method has an extensive usage in many studies because of its computational easiness and efficiency.

In this study, FAHP method is proposed as a tool for solving network assessment problem of multiple criteria. In order to determine the optimal scenario alternative, a three level hierarchical model is devised (Figure 2). The network performance can be described by two main criteria, which are anomaly and availability attributes. Under availability main criterion, four different criteria are produced while three sub-criteria are examined under anomaly main criterion.

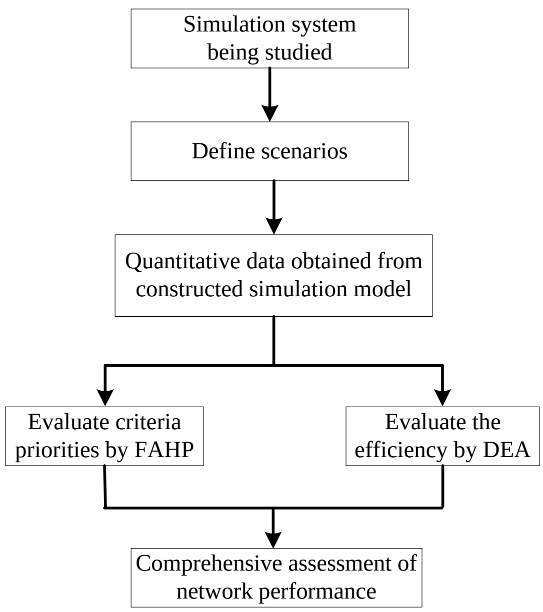

Figure 1. Execution flow chart

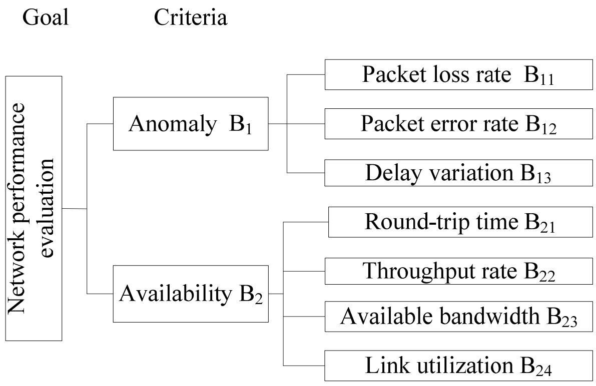

Figure 2. The hierarchical structure of the network performance assessment

Definition 1 (Fuzzy set).

Let X be a universe of discourse, $\tilde{A}$ is a fuzzy subset of X. such that for all $x \in X$, there is a number $\mu_{\tilde{A}}(X) \in [0,1]$, which is assigned to represent the membership of x to $\tilde{A}$, and $\mu_{\tilde{A}}(X)$ is called the membership function of $\tilde{A}$ [10-11].

Definition 2 (Triangular fuzzy number)

A triangular fuzzy number $\tilde{n}$ can be defined by a triplet (l,m,u). The membership function $\mu_{\tilde{n}}(X)$ is defined as

$$\mu_{\tilde{n}}(x) = \begin{cases} 0, & x < n_1, \\ \dfrac{x-l}{m-l}, & l \le x \le m, \\ \dfrac{u-x}{u-l}, & m \le x \le u, \\ 0, & x > n_3. \end{cases} \tag{1}$$

Where $l \le m \le u$, l and u stand for the lower and upper value of the support of $\tilde{n}$ respectively, and m for the modal value.

Consider two triangular fuzzy numbers $\tilde{a}$ and $\tilde{b}$, $\tilde{a} = (l_1, m_1, u_1)$ and $\tilde{b} = (l_2, m_2, u_2)$. Their operation laws are expressed as follows:

$$\lambda \otimes \tilde{a} = (\lambda l_1, \lambda m_1, \lambda u_1),\ \lambda \in R, \lambda \ge 0 \tag{2}$$

$$\tilde{a} \oplus \tilde{b} = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{3}$$

$$\tilde{a} \otimes \tilde{b} = (l_1 \times l_1, m_1 \times m_2, u_1 \times u_2) \tag{4}$$

$$\tilde{a}^{-1} = (\frac{1}{l_1}, \frac{1}{m_1}, \frac{1}{u_1}) \tag{5}$$

$$\tilde{a}^{1/n} = (l_1^{1/n}, m_1^{1/n}, u_1^{1/n}) \tag{6}$$

Definition 3 (Value of fuzzy synthetic extent)

Let $X=\{x_1,x_2,\cdots x_n\}$ be an object set, and $U=\{u_1,u_2,\cdots,u_m\}$ be a goal set. Therefore, we can get m extent analysis values for each object, with the following signs:

$$M_{gi}^1, M_{gi}^2, \cdots, M_{gi}^m,\ i=1,2,\cdots,n \quad (7)$$

Let $M_{gi}^j (j=1,2,\cdots,m)$ be values of extent analysis of the object for m goals. Then the value of fuzzy synthetic extent with respect of the i-th object is defined as [11]

$$S_i=\sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} \quad (8)$$

$$\sum_{j=1}^{m} M_{gi}^j=(l_i,m_i,u_i)=(\sum_{j=1}^{m} l_j,\sum_{j=1}^{m} m_j,\sum_{j=1}^{m} u_j) \quad (9)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j=(\sum_{i=1}^{n} l_i,\sum_{i=1}^{n} m_i,\sum_{i=1}^{n} u_i) \quad (10)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1}=\left(\frac{1}{\sum_{i=1}^{n} u_i},\frac{1}{\sum_{i=1}^{n} m_i},\frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (11)$$

In order to evaluate the importance of the main criteria and sub-criteria of Network performance, the relative importance by triangular fuzzy number scale is given in Table 1.

Table 1. Ambiguous semantics scale of relative importance

Triangular Fuzzy Numbers	Ambiguous Semantics
(1/2, 1, 3/2)	Equally important
(1, 3/2, 2)	Weakly more important
(3/2, 2, 5/2)	Strongly more important
(2, 5/2, 3)	Very strongly more important
(5/2, 3, 7/2)	Absolutely more important

Definition 4.

The degree of possibility of $M_1 \geq M_2$ (M_1 and M_2 *are triangular numbers) is defined as*

$$V(M_1 \geq M_2)=\sup_{x\geq y}[\min(\mu_{M_1}(x),\mu_{M_2}(y))] \quad (12)$$

And can be equivalently expressed [12] as follows:

$$V(M_2 \geq M_1)=hgt(M_1 \cap M_2)=\mu_{M_2}(d)$$

$$=\begin{cases} 0 & \text{if } l_1 \geq u_2 \\ 1 & \text{if } m_2 \geq m_1 \\ \dfrac{l_1-u_2}{(m_2-u_2)-(m_1-l_1)} & \text{otherwise} \end{cases} \quad (13)$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}.

Definition 5.

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i(i=1,2,\cdots,k)$ can be defined by

$$\begin{aligned} & V(M \geq M_1, M_2, \cdots, M_k) \\ & = V[(M \geq M_1)\ and\ (M \geq M_2)\ and \cdots and\ (\mathrm{M} \geq \mathrm{M}_k)] \\ & = \min\ \mathrm{V}(\mathrm{M} \geq \mathrm{M}_i) \end{aligned} \quad (14)$$

Definition 6.

Let $d^{'}(A_i) = \min\ V(S_i \geq S_k)$, *weight vector can be defined by*

$$W^{'} = (d^{'}(A_1), d^{'}(A_2), \cdots, d^{'}(A_n))^T \quad (15)$$

where $S_k(k=1,2,\cdots,n;\ k \neq i)$ *is the fuzzy synthetic extent of k-th object, and* $A_i(i=1,2,\cdots,n)$ *are* n *elements.*

Via normalization, we get the normalized weight vector

$$W = (d(A_1), d(A_2), \cdots, d(A_n))^T \quad (16)$$

After the fuzzy judgment matrix has been identified, we employ Chang's FAHP method to calculate the weight vector for index.

Algorithm 1. Computing relative weight vector

Input: Fuzzy judgment matrix $\tilde{A} = (a_{ij})_{n \times n}$, *Index set* $M = (M_1, M_2, \cdots M_n)$

Output: Normalized weight vector $W_{FAHP} = (d_{M_1}, d_{M_2}, \cdots, d_{M_n})^T$

1. FOR all $M_i \in M(i \in [1,n])$ DO
2. $s_{M_i} = fse(A)$

/*calculate the values of extent analysis of every index*/

3. END FOR
4. FOR all $M_i, M_j \in M(i \in [1,n], j \in [1,n]\ and\ j \neq i)$ DO
5. $V_{M_i M_j} = \sup(s_{M_i}, s_{M_j})$

/*calculate the degree of possibility of $s_{M_i} \geq s_{M_j}$ */

6. END FOR
7. FOR all $M_i, M_j \in M(i \in [1,n], j \in [1,n]\ and\ j \neq i)$ DO
8. $d'_{M_i} = \min calculate(\mathrm{V}_{M_i M_j})$

/*calculate the degree possibility for a convex fuzzy number to be greater than $n-1$ convex fuzzy numbers $M_i(i=1,2,\cdots,k)$ */

9. END FOR
10. FOR all $d'_{M_i}(i \in [1,n])$ DO
11. $d_{M_i} = normalize(d'_{M_i})$

/*normalize d'_{M_i} */

12. END FOR
13. $W_{FAHP} = \{d_{M_i} \mid i \in [1,n]\}$
14. RETURN W_{FAHP}

3.3 Data Envelopment Analysis (DEA)

DEA developed by Charnes, Cooper , and Rhodes in 1978 is a efficiency evaluation module [13]. Compared with AHP method, without any weight assuming is the most prominent characteristic of DEA. Recently, DEA has gained successful benchmarking applications in financial, industrial process, network engineering etc. DEA used enveloping theory to map the multiple inputs and outputs of all the evaluated Decision-Making Unit (DMU) into space, so that the observation value and relative efficiency of the organization could be calculated.

CCR module [13], proposed by Charnes et al., is a performance module of multiple input and output. Suppose that there is a set of n DMUs which is to be analyzed. And we assume there are m inputs and s outputs for each DMU. The inputs and outputs are aggregated into an average input and an average output by using input and output weights (u and v vectors, respectively). Let $k(k=1,\cdots,n)$ denotes the k-th DMU is assigned the highest possible efficiency score. The optimal weights for the outputs and inputs are chose from the available data by solving the mathematical programming problem. The following formula shows the measurement of relative efficiency, where u^T is the weight vector of output y_k, and v^T is the weight vector of input x_k.

$$(P)\begin{cases} \max h_k = u^T y_k \\ s.t. v^T x_j - u^T y_j \geq 0, j=1,2,\cdots,n \\ v^T x_k = 1 \\ u \geq 0, v \geq 0 \end{cases} \quad (17)$$

The basic understanding of inputs and outputs of network indicator model is that the less inputs the better and the larger outputs the better in the view of performance. If the k-th DMU receives the maximal value h_k ($\theta = 1$), then it is efficient, but if $\theta < 1$, it is inefficient, since with its optimal weights, another DMU receives the maximal efficiency. There are two types of CCR modules. One version is the input oriented model in which the inputs are maximized. The other is the output-oriented model in which the outputs are maximized. This paper employs the output-oriented CCR model, because the focus is on maximizing multiple outputs (good indicators of network performance).

3.4 Combined Methodology

Definition 7

The evaluation scores of network performance with FAHP are determined as the followed formulation:

$$E' = \sum_{i=1}^{n} (w_i \times s_i) \quad (18)$$

w_i is weight of i-th criterion, n is the number of criteria and here is set to 7, while s_i is the quantitative datum related to i th criterion.

The difference of positive and reverse criteria should be paid attention to. There are three positive criteria, throughput rate, available bandwidth, link utilization. On the contrary, the reverse criteria are composed of packet loss rate, packet error rate, delay variation, round-trip time. The weight of reverse criterion is determined as $-w$.

In order to make comparison between scenarios easier, evaluation scores of scenarios are normalized, converting scores to values between 0 and 1, formulation is presented as follow:

$$E = \frac{E' - m'}{M' - m'} \quad (19)$$

M' is the maximum value and m' is the minimal value of E'.

Definition 8

The comprehensive evaluation score of network performance with FAHP/DEA can be defined as follow:

$$CE = \alpha \times E + (1-\alpha) \times \theta \quad (20)$$

α is the favorite parameter, θ the relative efficiency. Obviously, different value of α will affect the result of comprehensive evaluation. This paper set α to 0.5, because subjective evaluation of experts and objective data reflects the efficiency of scenarios are equally important.

4. Empirical Analysis

4.1 Data Preparation

In this paper, we simulated a campus network by OPNET and collected quantitative data related to network performance based on measurement factors, which is in turn composed of such elements as packet loss rate, packet error rate, delay variation, round-trip time, throughput rate, available bandwidth, and link utilization. Table 2 exhibits the quantitative data related to a node of campus backbone with 10 scenarios.

To avoid the possible negative influences by associated physical dimension of criteria, this paper employs dimensionless method, converting quantitative criteria to values between 0 and 1, and shown in following equations. Then, the result is shown in Table 3.

$$x_{ij} = \frac{v_{ij}}{\overline{v}_j} \quad (21)$$

Where v_{ij} is the criterion value of scenario i, $\overline{v}_j$ the average number of criterion j, and x_{ij} the normalization value.

Table 2. Quantitative data related to criteria values

Time	B_{11}	B_{12}	B_{13}	B_{21}	B_{22}	B_{23}	B_{24}
1T	1.33	0.78	0.16	2.08	14421.33	79.86	9.25
2T	5.60	2.90	0.33	1.58	199281.78	82.19	15.02
T3	13.71	2.00	0.20	0.73	103253.33	80.40	12.23
4T	6.47	0.40	0.51	5.17	96483.56	88.08	8.84
5T	16.77	3.07	5.05	14.81	32369.78	84.40	5.65
6T	8.47	1.65	0.22	4.15	83285.33	90.81	1.45
7T	3.18	2.20	0.28	2.94	53134.22	63.65	30.02
8T	19.54	0.57	0.09	5.65	78961.78	75.18	17.23
9T	9.06	1.90	3.33	8.53	71054.22	69.09	28.15
10T	6.74	3.46	1.10	0.47	117361.78	74.39	12.46

Table 3. Dimensionless criteria values

Time	B_{11}	B_{12}	B_{13}	B_{21}	B_{22}	B_{23}	B_{24}
1T	0.15	0.41	0.14	0.45	0.17	1.01	0.66
2T	0.62	1.53	0.30	0.34	2.35	1.04	1.07
3T	1.51	1.06	0.18	0.16	1.22	1.02	0.87
4T	0.71	0.21	0.46	1.12	1.14	1.12	0.63
5T	1.85	1.62	4.48	3.21	0.38	1.07	0.40
6T	0.93	0.87	0.19	0.90	0.98	1.15	0.10
7T	0.35	1.16	0.25	0.64	0.63	0.81	2.14
8T	2.15	0.30	0.08	1.23	0.93	0.95	1.23
9T	1.00	1.00	2.96	1.85	0.84	0.88	2.01
10T	0.74	1.83	0.97	0.10	1.38	0.94	0.89

4.2 Calculating Criteria Weights with FAHP

After determining the network performance criteria (Figure 2), we consult an expert group for evaluating the relative importance of each measure with pair-wise comparisons. The importance of main and sub-criteria are provided in Table 3, 4 and 5. Meanwhile, the triangular fuzzy conversion scale (Table 1) is employed in order to determine the relative importance of each criterion.

Table 4. The relative importance of main criteria

	B_1	B_2
B_1	(1,1,1)	(1/2,2/3,1)
B_2	(1,3/2,2)	(1,1,1)

Table 5. The relative importance of sub-criteria of anomaly

	B_{11}	B_{12}	B_{13}
B_{11}	(1,1,1)	(1/2,1,3/2)	(2/5,1/2,2/3)
B_{12}	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)
B_{13}	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)

Table 6. The relative importance of sub-criteria of availability

	B_{21}	B_{22}	B_{23}	B_{24}
B_{21}	(1,1,1)	(1/2,1,3/2)	(3/2,2,5/2)	(1/2,1,3/2)
B_{22}	(2/3,1,2)	(1,1,1)	(3/2,2,5/2)	(1/2,1,3/2)
B_{23}	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1/2,2/3,1)
B_{24}	(2/3,1,2)	(1,3/2,2)	(1,3/2,2)	(1,1,1)

Using formulas (7) through (16), synthesis values respect to main criteria are calculated as follows:

$$S_{B_1} = (1.5, 1.67, 2) \otimes \left(\frac{1}{5}, \frac{1}{4.17}, \frac{1}{3.5} \right) = (0.3, 0.4, 0.57)$$

$$S_{B_2} = (2, 2.5, 3) \otimes \left(\frac{1}{5}, \frac{1}{4.17}, \frac{1}{3.5} \right) = (0.4, 0.6, 0.86)$$

Using these vectors, possibilities of fuzzy numbers comparison are computed:

$$V(S_{B_1} \geq S_{B_2})$$

$$= \frac{0.4 - 0.57}{(0.4 - 0.57) - (0.6 - 0.4)} = 0.46$$

$$V(S_{B_2} \geq S_{B_1}) = 1$$

Then, the normalized weight vector of main criteria (Table 7) is calculated. According to these weights, the main criterion availability is seen more important than the anomaly. In a similar way, the normalized weight vectors of sub-criteria are calculated.

$$d'(B_1) = 0.46$$

$$d'(B_2) = 1$$

$$W' = (0.46, 1)^T$$

$$W = (0.32, 0.68)^T$$

Table 7. unified weights of criteria

Main criteria	Local weights	Sub-criteria	Local weights
B_1	0.32	B_{11}	0.18
		B_{12}	0.28
		B_{13}	0.54
B_2	0.68	B_{21}	0.31
		B_{22}	0.31
		B_{23}	0.06
		B_{24}	0.31

4.3 Relative Efficiency Analysis with DEA

Under general DEA benchmarking, we have to classify network performance criteria into “inputs” and “outputs” in order to apply a proper DEA analysis. However, these criteria do not actually represent inputs and outputs at all, in the standard notion. Packet loss rate, packet error rate, delay variation, round-trip time compose input criteria, because their values are the smaller the better. On the contrary, there are three output criteria, throughput rate, available bandwidth, link utilization, because their values are the bigger the better.

Using software DEAP and CCR module (section 3.3), relative efficiency (θ) and corresponding weight vectors are obtained (Table 8).

Table 8. DEA Scores and weights of various scenarios

DMU	θ	u_1	u_2	u_3	u_4	v_1	v_2	v_3
1	**1**	1	0	0	0	0	0	0
2	**1**	0	1	0	0	0	0	0
3	0.90	0.21	0.29	0	0	0	0	0
4	**1**	0	0	0	1	0	0	0
5	0.91	2.64	0	0	1.80	0	0	0
6	**1**	0	0	0	0	0	0	0
7	**1**	0	0	0	0	0	1	0
8	**1**	0	0	0	0	0	0	1
9	**1**	0	0	0	0	0	0	0
10	0.56	0.31	0.54	0	0.02	0	0	0.04

4.4 Result Comparisons of FAHP, DEA and FAHP/DEA

We have analyzed relative weights of network performance criteria with single FAHP (Table 7). Using formulas (18) and (19), we determine the FAHP scores of 10 network scenarios given in Table 9. Meanwhile, to determine the comprehensive scores with FAHP/DEA, formula (20) is employed. Table 9 presents the comparison of scores and the ranks of various scenarios with three methods in roughly the same form. It can be known from the analysis results that scenarios at time 5T, 9T, 10T did comparatively poor in performance, and the score records should be sent to the network administrator.

Table 9. Comparison of scores with FAHP, DEA and comprehensive method

Time	FAHP	DEA	FAHP/DEA
1T	0.66	**1**	0.83
2T	0.72	**1**	0.86
3T	0.67	0.90	0.78
4T	0.64	**1**	0.82
5T	0.18	0.91	0.46
6T	0.60	**1**	0.80
7T	0.70	**1**	0.85
8T	0.64	**1**	0.82
9T	0.38	**1**	0.69
10T	0.59	0.56	0.58

As this study took the performance evaluations of network, we can conduct evaluations on all the campus network scenarios by differentiating all the samples in good or bad condition. Dividing by the comprehensive score of 0.7 as well, 7 scenarios with score more than 0.7 are in good condition while 3 scenarios with score lower than 0.7 are out of order. Meanwhile, Scores with single DEA method lack discrimination, because 7 scenarios get the same score. The above mentioned results are illustrated more intuitive in Figure 3.

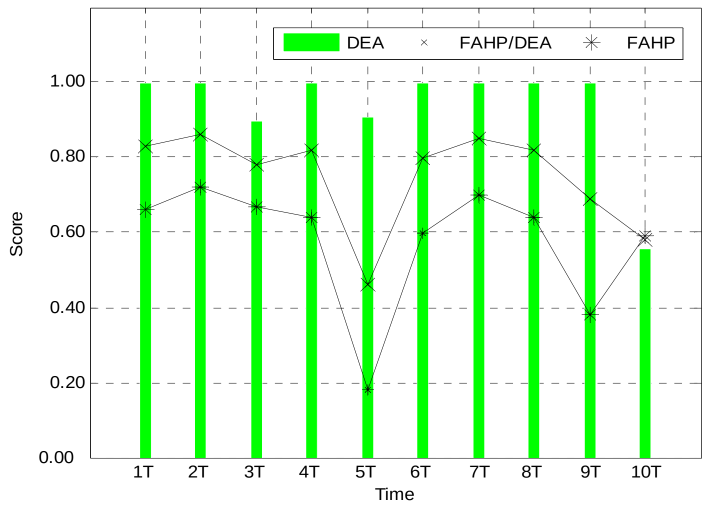

Figure 3. Comparison of scores with FAHP, DEA and FAHP/DEA

5. Conclusions and Future Work

It is difficult to analyze the complex network performance with single analytical method, because every method has its own bias. This paper presented a unique integrated approach for performance evaluation of network with complex limitation which requires both qualitative and quantitative assessment. The data in various scenarios are collected and analyzed in a simulated campus network. The network performance can be measured in terms of comprehensive scores by using 2-stage multi-criteria decision making approach which uses the FAHP and DEA model approach. FAHP effectively reflects the experts' preferences and the assessment problem of network performance is decomposed into a hierarchy of sub-problems to be easy analyzed. In addition, for multivariate assessment of the alternatives by DEA, the data of network availability and anomaly features are considered from previous study simulation. Experimental results show that the proposed integrated methodology achieves a good result of dealing with multi-objective network performance evaluation.

We will apply the current illustrated methodology in Gridjack [14, 15] network computing platform to improve the network performance. Moreover, the integrated modeling approach presented in this paper can be used to solve other similar problems in real world.

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