

Analysis of Green Computing Strategy in University: Analytic Network Process (ANP) Approach

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Abstract—Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis do not provide an analytical means to determine the importance of the identified factors of green computing strategy and implementation. Although the SWOT analysis successfully explores the factors, individual factors are usually described very generally. For this reason, SWOT analysis possesses deficiencies in the measurement and evaluation of green computing steps. Even though the analytic hierarchy process (AHP) technique eliminates these deficiencies, it does not allow for measuring the possible dependencies among the individual factors. The AHP method assumes that the green computing factors presented in the hierarchical structure are independent; however, this assumption may be inappropriate in light of certain situation. Therefore, it is important to utilize a form of SWOT analysis that calculates and takes into account the possible dependency among the factors. This paper demonstrates a process for quantitative SWOT analysis of green computing implementation that can be performed even when there is dependence among strategic factors. The proposed algorithm uses the analytic network process (ANP), which allows measurement of the dependency among the green computing implementation factors, as well as AHP, which is based on the independence between the factors. There are four alternatives: campus awareness program, computer procurement, increase in heat removal requirement, and increase in equipment power density for improving the implementation of green computing in campus. Dependency among the SWOT factors is observed to effect the strategic and sub-factor weights, as well as to change the strategy priorities. Based on ANC method, the best alternative for this implementation is computer procurement.

Keywords—; SWOT; ANP; green computing

I. INTRODUCTION

Universities build and employ strategies for improving efficiencies in IT-related asset utilization and process management. They also begin to understand the important opportunities that include cost savings and the decreased environmental impact from too much power consumption. Accurate IT management software solutions aligned with good executed strategies allow these universities to quickly execute and correctly identify its benefits. Going green in IT does not require a new technology investment. Implementation of enterprise IT management software can leverage new technology investments to achieve greater efficiencies faster and at lower costs. Many IT departments already have the tools for IT management in

place. The good results of applying software solutions for Green IT are cost savings, reduced environmental impact and good university management. Strategic management can be understood as the decisions and actions taken by management, in consultation within the organization, to determine the long-term activities of the organization [1]. Many approaches and techniques can be utilized to analyze strategic cases in the strategic management process [2]. Among them, Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, which evaluates the opportunities, threats, strengths and weaknesses of an organization condition and strategy, is the most common [3].

SWOT analysis is an important support tool for decision-making and is used to analyze an organization's internal and external environments [4, 5]. The university can make strategies of green computing implementation upon its strengths, eliminate its weaknesses, and exploit its opportunities or use them to counter the threats. The strengths and weaknesses are recognized by an internal environment appraisal while the opportunities and threats are recognized by an external environment appraisal [6]. SWOT analysis summarizes the most important of the internal and external factors that may possibly affect the organization's future, which are linked to as strategic factors [4]. The external and internal environments are composed of factors which are outside and inside the organization. The organization's management has no short-term effect on either type of factor [1]. Comprehensive environmental analysis is important in identification of the variety of internal and external forces organization should deal with. The attained information can be represented in a matrix [1, 2], SWOT can provide a good strategy formulation [7]. However, SWOT analysis is with no weak points in the measurement and evaluation steps [3]. In SWOT analysis, the level of the factors is not quantitatively measured to find out the effect of each factor on strategy or plan [8], or in the other world SWOT analysis does not give an analytical results to determine the relative weight of the factors [7]. Based on this reason, using of SWOT analysis cannot comprehensively appraise the strategic decision-making process [3]

A. AHP in SWOT

An initial study identified the multi-criteria decision technique, best known as the AHP, to be the most appropriate for solving complicated problems [9]. AHP was proposed as a method of solving socio-economic

decision-making problems and has been used to solve a wide range of decision-making problems [10]. AHP is a comprehensive framework which is designed to cope with the intuitive, the rational, and the irrational when multi-objective, multi-criterion, and multi-actor decisions are made, with or without certainty, for any number of alternatives. AHP can be used in functional independence of an upper part or cluster of the hierarchy from all its lower parts and the criteria or items in each level [9]. An hybrid method was first developed to eliminate the weaknesses in the measurement and evaluation steps of the SWOT analysis [5]. This technique of utilizing the Analytical Hierarchy Process in the SWOT analysis has also been referred to as A'WOT in subsequent studies [7]. The hybrid method was tested in connection with a Finnish case study on forest certification [5]. Similar with the previous method, there are some other studies that only deal with prioritization of the SWOT factors and sub-factors, and neither strategies nor alternatives are included in the hierarchical structures based on the strategic factors [7, 8].

B. ANP in Green Computing SWOT Analysis

AHP technique has the virtue by removing the deficiencies inherent in the measurement and evaluation steps of SWOT analysis, but AHP does not measure the possible dependencies among factors. This method is based on an assumption that the factors in the hierarchical structure are independent; yet this is not always a reasonable applied in many cases. The relationship and dependency among SWOT factors only can be evaluated by making internal and external environmental analyses. An organization can make good use of its opportunities in term of assets and capabilities in which it can convert to become superiority, otherwise opportunities are either lost before any benefit can be gained or are used by rivals. The ability to overcome the effects of threats depends on university's strengths; a strong university can use its strengths to eliminate the effects of these threats. The relationship between the strengths and weaknesses of an organization during the implementation of green computing strategy are such that an organization with more strengths would probably have fewer weaknesses, and therefore would be able to face situations arising from these weaknesses. Organizations have more weaknesses than their rivals are more vulnerable to the threats, then organizations should think about the relationship between their threats and weaknesses when establishing their strategies. Similarly, an institution with weaknesses may to use of its opportunities and benefit from this factor if it has sufficient assets and capabilities, but if it is not, such opportunities arising from the external environment may otherwise prove not useful [2].

In this green computing case study, SWOT analysis is performed by using the analytical network process (ANP) which measure and take the possible dependencies among factors into account. At the same time by assuming that the factors are independent, the AHP method is used in order to determine the factor weights and their effects on the selection of an green computing alternative strategy.

II. ANALYTIC NETWORK PROCESS

The Analytic Network Process (ANP), was introduced by Saaty, is a generalization of the AHP [11, 12]. The use of AHP is solving the problem of independence among alternatives or criteria, while the use of ANP is solving for

dependent side [9]. AHP models a decision making framework with a uni-directional hierarchical AHP relationship among decision level, the ANP allows for complex interrelationships among decision levels and attributes. Structuring a problem involving functional dependence that allows for feedback among clusters is considered to be a network system. The ANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower, dominant or subordinate, direct or indirect [13]. For instance, not only does the importance of the criteria determine the importance of the alternatives, as in a hierarchy, but the importance of the alternatives may also have an impact on the importance of the criteria [11]. In a network, there can be organized that include source clusters, intermediate clusters and sink clusters. Relationships in a network are represented by arcs, and the directions of arcs signify directional dependence [11, 12]. Interdependency between two nodes, called outer dependence, is represented by a two-way arrow, and inner dependencies among elements in a node are represented by a looped arc [12]. The ANP is composed of four major steps [12]:

Step 1:

Model construction and problem structuring: The problem should be declared clearly and be decomposed into a rational system, like a network. This network structure can be attained by decision-makers through brainstorming or other appropriate methods.

Step 2:

Pairwise comparison matrices and priority vectors: Similar to the comparisons performed in AHP, pairs of decision elements at each cluster are compared with respect to their importance towards their control criteria. The clusters themselves are also compared pairwise with respect to their contribution to the goal. Decision-makers are requested to respond to a series of pairwise comparisons of two clusters or two elements to be evaluated in terms of their contribution to their particular upper level criteria [13]. In addition, if there are interdependencies among elements of a cluster, comparisons also need to be created, the eigenvector can be obtained for each element to show the influence of other elements on it. The relative importance values are determined with a scale of 1 to 9 (Table1), where a score of 1 represents equal importance between the two elements and a score of 9 indicates the extreme importance of one element (row component in the matrix) compared to the other one (column component in the matrix)[13]. A reciprocal value is assigned to the inverse comparison, that is, $a_{ij}=1/a_{ji}$, where a_{ij} (a_{ji}) denotes the importance of the i th (j th) element. Like with AHP, pairwise comparison in ANP is executed in the framework of a matrix, and a local priority vector can be derived as an estimate of the relative importance associated with the elements (or clusters) being compared by solving the following equation:

$$A \times w = \lambda_{\max} \times w \quad (1)$$

where A is the matrix of pairwise comparison, w is the eigenvector, and λ_{\max} is the largest eigenvalue of A . Saaty [14] proposes several algorithms to approximate w .

Step 3:

Arranged supermatrix formation: The supermatrix concept is similar to the Markov chain process [11]. To obtain global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix. As a result, a supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two clusters in a system. Let the clusters of a decision system be $C_k, k = 1; 2; \dots; n$, and each cluster k has m_k elements, denoted by $e_{k1}; e_{k2}; \dots; e_{kmk}$. The local priority vectors attained in Step 2 are grouped and located in the appropriate positions in a supermatrix based on the flow of influence from one cluster to another, or from a cluster to itself, as in the loop.

TABLE 1. SAATY'S 1-9 SCALE FOR AHP PREFERENCE [11]

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one over another
5	Strong importance	Experience and judgment strongly favor one over another
7	Very strong importance	Activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	Used to represent compromise between the priorities listed above

A. ANP Literature

Over the years, ANP, a comprehensive multi-purpose decision method, has been widely used by both researchers and practitioner in solving many complicated decision-making problems. In two studies, ANP was used in a methodology they developed to evaluate logistic strategies and to improve production speed [15]. Also in other research ANP was used in the interdependent information system project selection process, and project priorities found in these study is taken as restraints in the 0-1 goal programming model [9]. ANP was used in a quality function deployment process [16]. In addition to these studies, other studies where ANP was used include: a model he developed for the purpose of strategic supplier selection [17], supplier selection [18], evaluating alternative research-development projects [15], selection of logistics service provider [19], selecting knowledge management strategies [20], and a model they developed for a product mixture [12].

B. ANP Model for SWOT

The hierarchy and network model used in this case study for SWOT analysis for green computing implementation is composed of four levels, as shown in Fig. 1 [21]. The goal (the best green computing strategy) is indicated in the first level, the criteria (SWOT factors) and subcriteria (SWOT sub-factors) are found in the second and third levels respectively, and the last level is composed of the alternatives (alternative strategies). The supermatrix of a SWOT hierarchy with four levels is as follows:

$$W = \begin{matrix} \text{goal} & \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & W_{32} & 0 & 0 \\ 0 & 0 & W_{43} & I \end{bmatrix} \\ \text{SWOT factor} \\ \text{SWOT sub-factors} \\ \text{alternatives} \end{matrix}$$

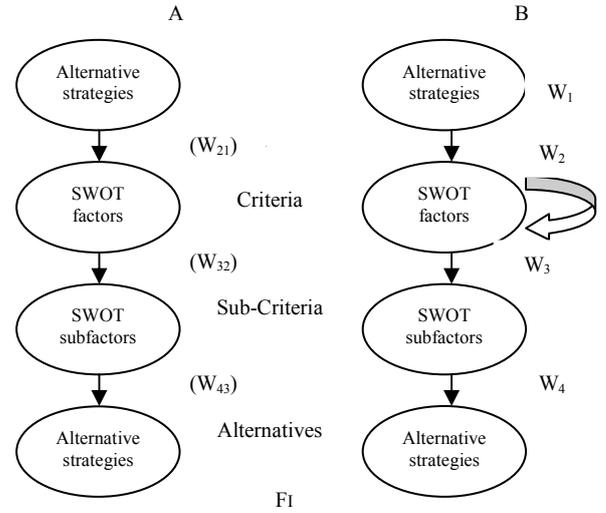


FIGURE 1. (A) THE HIERARCHICAL REPRESENTATION OF THE SWOT MODEL. (B) THE NETWORK REPRESENTATION OF THE SWOT MODEL.

where w_{21} is a vector which represents the impact of the goal on the criteria, w_{32} is a matrix that represents the impact of the criteria on each of the sub-criteria, w_{43} is a matrix that represents the impact of the sub-criteria on each of the alternatives, and I is the identity matrix. A hierarchical representation of the SWOT model is given in Fig. 1a and its network representation is presented in Fig. 1b. The network model illustrates the case of green computing hierarchy with inner dependence within clusters but no feedback. Here, factors, sub-factors and strategies are used in the representation of criteria, sub-criteria and alternatives, respectively, and the SWOT factors have inner dependencies. The procedure of this ANP model for SWOT can be summarized as follows. First step is the identification of the SWOT factors, SWOT sub-factors and alternatives. The importance of the SWOT factor, which corresponds to the first step of the matrix manipulation concept of the ANP, is determined based on the method developed by Lee and Kim [9], and Saaty and Takizawa [22]. Then, according to the inner dependencies among the SWOT factors, the inner dependency matrix, weights of SWOT sub-factors and priority vectors for alternative green computing strategies based on the SWOT sub-factors are determined in given order. The letters in parentheses in Fig. 1b correspond to the relationship that will be signified by sub-matrices for supermatrix evaluation of the relative importance weights. Based on the schematic representation of Fig. 1b, the general sub-Matrix notation for the SWOT model used in analysis is as follows:

$$W = \begin{matrix} \text{goal} & \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & W_3 & 0 & 0 \\ 0 & 0 & W_4 & I \end{bmatrix} \\ \text{SWOT factor} \\ \text{SWOT sub-factors} \\ \text{alternatives} \end{matrix}$$

where w_1 is a vector that represents the impact of the goal, namely, selecting the best strategy according to SWOT factors, w_2 is a matrix that represents the inner

dependence of the SWOT factors, w_3 is a matrix that denotes the impact of the SWOT factor on each of the SWOT sub-factors, and w_4 is a matrix that denotes the impact of the SWOT sub-factors on each of the alternatives. Using matrix operations is preferred in order to show the details of the calculations in this algorithm. To apply the ANP to matrix operations in order to determine the overall priorities of the alternative strategies identified with SWOT analysis, the proposed algorithm is as follows:

Step 1: Identify SWOT sub-factors and determine the alternative strategies according to SWOT sub-factors.

Step 2: Assume that there is no dependence among the SWOT factors; determine the importance degrees of the SWOT factors with a 1–9 scale (i.e. calculate w_1)

Step 3: Determine, with a 1–9 scale, the inner dependence matrix of each SWOT factor with respect to the other factors by using the schematic representation of inner dependence among the SWOT factors: (i.e. calculate w_2)

Step 4: Determine the interdependent priorities of the SWOT factors (i.e. calculate $w_{\text{factors}} = w_2 \times w_1$)

Step 5: Determine the local importance degrees of the SWOT sub-factors with a 1–9 scale (i.e. calculate $w_{\text{sub-factors(local)}}$)

Step 6: Determine the global importance degrees of the SWOT sub-factors (i.e. calculate $w_{\text{sub-factors(global)}} = w_{\text{factors}} \times w_{\text{sub-factors(local)}}$)

Step 7: Determine the importance degrees of the alternative strategies with respect to each SWOT sub-factor with a 1–9 scale (i.e. calculate W_4)

Step 8: Determine the overall priorities of the alternative strategies, reflecting the interrelationships within the SWOT factors (i.e. calculate $w_{\text{alternatives}} = w_4 \times w_{\text{sub-factors(global)}}$)

III. IMPLEMENTATION OF GREEN COMPUTING USING SWOT ANALYSIS

This section presents an illustration of the proposed approach summarized in the previous section. In the following case study, SWOT analysis utilizing the ANP is performed on an implementation of green computing strategy in University.

A. Implementation of the proposed ANP Model

In this study, first an external environment analysis is performed by doing a literature review and real observation. In this way, those SWOT sub-factors which affect the success of the organization but cannot be controlled by the organization are identified and analyzed. SWOT sub-factors, SWOT matrix and alternative strategies based on these sub-factors are presented (Table 2). Based on Table 2, it can be seen that the organization has four alternative strategies.

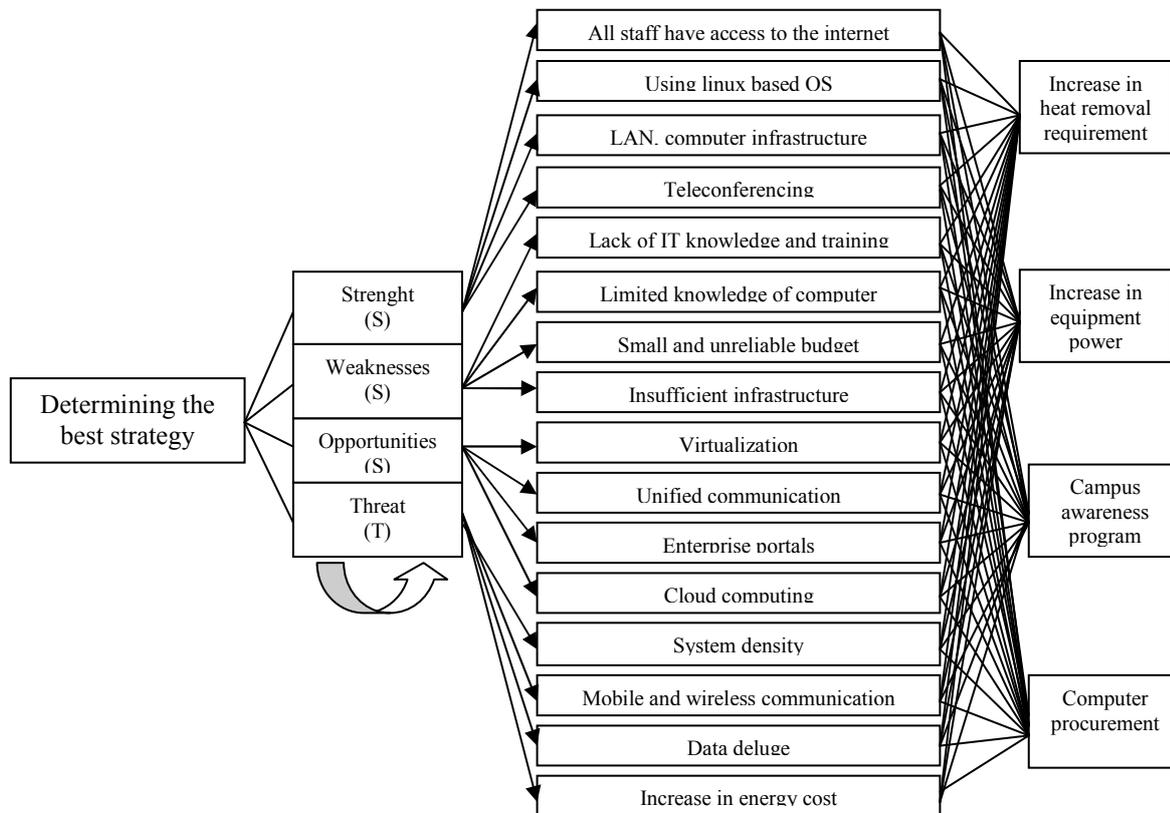


FIGURE 2. ANC SWOT MODEL

The strategy identified as SO exploits the opportunities by using the existing strengths of the organization. The WO strategy seeks to get benefit from the opportunities created by the external environmental factors by considering the weaknesses of the organization. Similarly, ST is the strategy associated with using the organization's strengths to remove or reduce the effects of threats. The last strategy is WT, in which the organization tries to minimize the effects of its threats by taking its weaknesses into account. In this study, the aim of the SWOT analysis is to determine the priorities of the green computing strategies and to determine the best strategy for the organization.

Step 1: The problem is converted into a hierarchical structure in order to transform the sub-factors and alternative strategies into a state in which they can be measured by the ANP technique. The schematic structure established is shown in Fig. 2. The aim of "choosing the best strategy" is placed in the first level of the ANP model and the SWOT factors (Strengths, Weaknesses, Opportunities, Threats) are in the second level. The SWOT sub-factors in the third level include four sub-factors for every SWOT factor. Four alternative green computing strategies developed for this study are placed in the last level of the model. As presented in the SWOT matrix, these alternatives are as follows (Table 2):

- Campus awareness program (SO);
- Computer procurement (WO);
- Increase in heat removal requirement (ST);
- Increase in equipment power density (WT).

TABLE II. SWOT MATRIX

External factors	Internal factors	
	Strengths (S)	Weaknesses (W)
	LAN and computer infrastructure (S1) All staff have access to the internet (S2) Using Linux based OS (S3) Teleconferencing (S4)	Small and unreliable budget (W1) Insufficient supporting infrastructure (W2) Lack of IT knowledge (W3) Limited knowledge of computer programming (W4)
Opportunities (O)	SO Strategy	WO Strategy
Unified communication (O1) Enterprise portals (O2) Virtualization (O3) Cloud computing (O4)	Campus awareness program	Computer procurement
Threats (T)	ST Strategy	WT Strategy
Data deluge (T1) Increase in energy cost (T2) System density (T3) Mobile and wireless communication (T4)	Increase in heat removal requirement	Increase in equipment power density

Step 2: Assuming that there is no dependence among the SWOT factors, pairwise comparison of the SWOT factors using a 1-9 scale is created with respect to the goal. The comparison results are shown in Table 3 and the following eigenvector is attained.

$$x \begin{bmatrix} S \\ W \\ O \\ T \end{bmatrix} = \begin{bmatrix} 0.445 \\ 0.283 \\ 0.165 \\ 0.107 \end{bmatrix}$$

TABLE 3. PAIRWISE COMPARISON OF SWOT FACTORS BY ASSUMING THAT THERE IS NO DEPENDENCE AMONG THEM

	(S)	(W)	(O)	(T)	Relative importance weights
Strengths (S)	1	2	3	3	0.445
Weaknesses (W)	0.500	1	2	3	0.283
Opportunities (O)	0.333	0.500	1	2	0.165
Threats (T)	0.333	0.333	0.5	1	0.107

Step 3: Inner dependence among the SWOT factors is determined by analyzing the impact of each factor on every other factor using pairwise comparisons. The introduction section mentioned that it is not always possible to assume the SWOT factors to be independent. More optimum results can likely be obtained by combining both SWOT analysis and the ANP technique. Using the analysis of both the internal and external environments of the organization, the dependencies among the SWOT factors, which are depicted schematically in Fig. 3, are determined. Based on the inner dependencies presented in Fig. 3, pairwise comparison matrices are formed for the factors (Tables 4-6). The following question, "What is the relative importance of strengths when compared with threats on controlling weaknesses?" may arise in pairwise comparisons and lead to a value of 7 (very strong importance) as denoted in Table 5. The resulting eigenvectors are presented in the last column of Tables 4-6. Using the computed relative importance weights, the inner dependence matrix of the SWOT factors (W_2) is formed. As opportunities are affected only by the Strengths, no pairwise comparison matrix is formed for opportunities

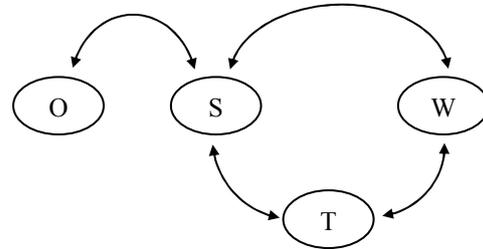


FIGURE 3. INNER DEPENDENCE AMONG SWOT FACTORS.

TABLE 4. THE INNER DEPENDENCE MATRIX OF THE SWOT FACTORS WITH RESPECT TO "STRENGTHS"

Strengths	W	O	T	Relative importance weight
Weaknesses (W)	1.000	0.143	0.250	0.080
Opportunities (O)	7.000	1.000	3.000	0.656
Threats (T)	4.000	0.333	1.000	0.265

TABLE 5. THE INNER DEPENDENCE MATRIX OF THE SWOT FACTORS WITH RESPECT TO "WEAKNESSES"

Weaknesses	S	T	Relative importance weight
Strengths (S)	1.000	7.000	0.875
Threats (T)	0.143	1.000	0.125

TABLE 6. THE INNER DEPENDENCE MATRIX OF THE SWOT FACTORS WITH RESPECT TO "THREATS"

Threats (T)	S	W	Relative importance weight
Strengths (S)	1.000	5.000	0.833
Weaknesses (W)	0.200	1.000	0.167

$$W_2 = \begin{bmatrix} 1.000 & 0.857 & 1.000 & 0.833 \\ 0.080 & 1.000 & 0.000 & 0.167 \\ 0.656 & 0.000 & 1.000 & 0.000 \\ 0.265 & 0.125 & 0.000 & 1.000 \end{bmatrix}$$

Step 4: In this step, the interdependent priorities of the SWOT factors are calculated as follows:

$$W_{\text{factors}} = W_2 \times W_1 = \begin{bmatrix} 1.000 & 0.857 & 1.000 & 0.833 \\ 0.080 & 1.000 & 0.000 & 0.167 \\ 0.656 & 0.000 & 1.000 & 0.000 \\ 0.265 & 0.125 & 0.000 & 1.000 \end{bmatrix} \times$$

$$\begin{bmatrix} 0.445 \\ 0.283 \\ 0.165 \\ 0.107 \end{bmatrix} = \begin{bmatrix} 0.491 \\ 0.175 \\ 0.248 \\ 0.086 \end{bmatrix}$$

Significant differences are observed in the results obtained for the factor priorities (w1, Table 3) when the interdependent priorities of the SWOT factors (W_{factors}) and dependencies are ignored. The results change from 0.445 to 0.491, 0.283 to 0.175, 0.165 to 0.248, and 0.107 to 0.086 for the priority values of factors S, W, O and T, respectively.

Step 5: In this step, local priorities of the SWOT sub-factors are calculated using the pairwise comparison matrix. The pairwise comparison matrices are detailed in Appendix A. Priority vectors obtained by analyzing the pairwise comparison matrices shown below.

$$W_{\text{sub-factors(strengths)}} = \begin{bmatrix} 0.482 \\ 0.272 \\ 0.158 \\ 0.088 \end{bmatrix} \quad W_{\text{sub-factors(weaknesses)}} = \begin{bmatrix} 0.520 \\ 0.268 \\ 0.141 \\ 0.071 \end{bmatrix}$$

$$W_{\text{sub-factors(strengths)}} = \begin{bmatrix} 0.466 \\ 0.277 \\ 0.161 \\ 0.096 \end{bmatrix} \quad W_{\text{sub-factors(weaknesses)}} = \begin{bmatrix} 0.482 \\ 0.272 \\ 0.138 \\ 0.088 \end{bmatrix}$$

TABLE 7. OVERALL PRIORITY OF THE SWOT SUB-FACTORS

SWOT factors	Priority of the factors	SWOT subfactors	Priority of the sub-factors	Overall priority of the sub Factors
S	0.491	LAN and computer infrastructure (S1)	0.482	0.237
		All staff have access to the internet (S2)	0.272	0.134
		Using Linux based OS (S3)	0.158	0.078
		Teleconferencing (S4)	0.088	0.043
W	0.175	Small and unreliable budget (W1)	0.520	0.091
		Insufficient supporting infrastructure (W2)	0.268	0.047
		Lack of IT	0.141	0.025

SWOT factors	Priority of the factors	SWOT subfactors	Priority of the sub-factors	Overall priority of the sub Factors
O	0.248	knowledge (W3)		
		Limited knowledge of computer programming (W4)	0.071	0.012
		Unified communication (O1)	0.466	0.116
		Enterprise portals (O2)	0.277	0.069
T	0.086	Virtualization (O3)	0.161	0.040
		Cloud computing (O4)	0.096	0.024
		Data deluge (T1)	0.482	0.041
		Increase in energy cost (T2)	0.272	0.023
		System density (T3)	0.158	0.014
		Mobile and wireless communication (T4)	0.088	0.008

In this step, the overall priorities of the SWOT sub-factors are calculated by multiplying the interdependent priorities of SWOT factors found in Step 4 with the local priorities of SWOT sub-factors obtained in Step 5. The computations are provided in Table 7. The W_{sub-factors(global)} vector, obtained by using the overall priority values of the sub-factors in the last column of Table 7, is provided below.

$$W_{\text{sub-factors(global)}} = \begin{bmatrix} 0.237 \\ 0.134 \\ 0.078 \\ 0.043 \\ 0.091 \\ 0.047 \\ 0.025 \\ 0.012 \\ 0.116 \\ 0.069 \\ 0.040 \\ 0.024 \\ 0.041 \\ 0.023 \\ 0.014 \\ 0.008 \end{bmatrix}$$

$$W_{\text{sub-factors(global)}} =$$

Step 7: In this step we calculate the importance degrees of the alternative strategies with respect to each SWOT sub-factors. The eigenvectors are computed by analyzing these matrices and the W₄ matrix:

$$\begin{bmatrix} 0.058 & 0.204 & 0.267 & 0.225 & 0.071 & 0.057 & 0.463 & 0.100 & 0.268 & 0.220 & 0.269 & 0.079 & 0.026 & 0.071 & 0.026 & 0.020 \\ 0.264 & 0.276 & 0.285 & 0.272 & 0.268 & 0.600 & 0.200 & 0.229 & 0.493 & 0.490 & 0.299 & 0.466 & 0.180 & 0.241 & 0.160 & 0.123 \\ 0.024 & 0.026 & 0.108 & 0.113 & 0.280 & 0.145 & 0.059 & 0.178 & 0.077 & 0.126 & 0.163 & 0.265 & 0.217 & 0.268 & 0.237 & 0.270 \\ 0.123 & 0.116 & 0.060 & 0.060 & 0.132 & 0.129 & 0.245 & 0.432 & 0.029 & 0.079 & 0.027 & 0.175 & 0.446 & 0.220 & 0.466 & 0.220 \end{bmatrix}$$

Step 8: Finally, the overall priorities of the alternative strategies, reflecting the interrelationships within the SWOT factors, are calculated as follows:

$$W_{\text{alternatives}} = \begin{bmatrix} SO \\ WO \\ ST \\ WT \end{bmatrix} = W_4 \times W_{\text{sub-factors(global)}} = \begin{bmatrix} 0.250 \\ 0.421 \\ 0.169 \\ 0.160 \end{bmatrix}$$

The ANP analysis results indicate that WO is the best strategy with an overall priority value of 0.421.

B. Comparing the AHP and ANP results

According to the ANP analysis, alternative strategies are ordered as WO–SO–ST–WT. The same example is analyzed with the hierarchical model given in Fig. 3a by assuming there is no dependence among the factors.

TABLE 8. WEIGHT AND RANKING OF STRATEGIES

	SO	WO	ST	WT
Weights in AHP	0.227	0.418	0.178	0.176
Ranking in AHP	2	1	3	4
Weights in ANP	0.250	0.421	0.169	0.160
Ranking in ANP	2	1	3	4

The overall priorities computed for the alternative strategies are presented below. The same pairwise comparison matrices are used to compute the AHP priority values.

$$W_{\text{alternatives(AHP)}} = \begin{bmatrix} \text{SO} \\ \text{WO} \\ \text{ST} \\ \text{WT} \end{bmatrix} = \begin{bmatrix} 0.227 \\ 0.418 \\ 0.178 \\ 0.176 \end{bmatrix}$$

In the AHP analysis, the WO strategy is found to be the best alternative, with an overall priority value of 0.418. The priority ordering of the alternative strategies is WO–SO–ST–WT. The results obtained from the AHP and ANP analyses are comparatively listed in Table 8. In cases where the dependency among SWOT factors and sub-factors is established, ANP analysis can be performed in order to determine the alternative priorities so that firms are able to make strategically correct decisions. AHP analysis can be used in situations where

there is no dependency among SWOT factors and subfactors or where the level of this dependency can be neglected.

IV. CONCLUSION

In SWOT analysis, strategic alternatives for implementing green computing are selected in the light of the strengths, weaknesses, threats and, opportunities of the university as determined through internal and external environment analysis. However, SWOT analysis is not capable of quantitatively determining the weights and effects of the strategic factors on the alternatives of green computing implementation. In this study, we sought to demonstrate, with a implementation of green computing example, that it is possible to perform a quantitative SWOT analysis wherein the possible dependencies among SWOT factors are included. The ANP technique is utilized in this work for measuring inter-factor dependencies by transforming all the factors from the SWOT analysis and the alternative strategies. The first four levels of the ANP model consist of the goal, the SWOT factors, SWOT sub-factors and, four alternative green computing strategies. The AHP method is also used in this case to measure the effects of the dependency among the SWOT factors on prioritizing the alternative green computing strategies and on the SWOT sub-factors weights. The dependency or independency of SWOT factors affects the factor weights of the SWOT and affects both the green strategy selection and priority order. Future research may also consider the using of fuzzy method in the AHP or ANP to analyze some cases having greater uncertainty.

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