Fuzzy Linguistic Decision Analysis for Web Server System Future Planning

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Abstract

Web administrators' prioritization of several upgrading alternatives with respect to multiple contradictory criteria involve fuzziness and impreciseness of human's subjective judgements in a Web server system. In this paper, fuzzy concepts are used to enhance the traditional Analytic Hierarchy Process (AHP) which are mainly applied in crisps decision environment. The entropy weight proposed by Don-Lin Mon[1] is implemented to evaluate the upgrading alternatives priority in a Web server system. Fuzzy numbers act as a reference to indicate the influence strength of each element in the hierarchy structure. α-cut-based method is utilized to prevent the controversial of fuzzy number ranking process where the fuzzy judgement matrix is reconstructed into an interval fuzzy judgement matrix. Fuzzy linguistic term approach is applied to capture the fuzziness and subjectiveness of Web administrators' judgements.

Keywords: Fuzzy Logic, Analytic Hierarchy Process, Decision Making, Shannon Entropy, Interval Arithmetic.

Introduction

The exponential growth of Internet web traffic slows the Web servers to a crawl. The Web based application, for instance electronics commerce, internet telephony, video conferencing, online distance learning etc. are the major contributors to the explosive World Wide Web population. The bursty characteristic [2,3] of the Web traffic has overwhelmed the Web servers where the frequent occurrence of load peaks cause the inefficieny of sizing the server capacity and bandwidth to maintenance the user unprecedented demands. Consequently, the Web server responsiveness degradation is a critical issue.

Many researches have been accomplished in order to overcome the web services performance bottlenecks. C. Yoshikawa [4] has migrated certain Web servers functionality to users via Applets. However, the client-based scheduling has caused additional traffic by the data transmission among client and servers. Ari Luotonen [5] claims that the caching feature in proxy servers show shorter response times after the first document fetch. Jeffery, C.L[6] proposed the design and implications of an extended proxy server that shares cache resources with near neighbors. Furthermore, a substantial reduction in internetwork load can be obtained from proxy sharing, with a corresponding increase in performance.

In workload distribution, mirrored or redundant Web Servers [7] is established where the document tree of certain Web site is replicated into *n* identical Web servers to prevent the highly demand requests. Round Robin DNS is one of the well-known methods that is applied in Web cluster load balancing and load sharing. However, for self similar [2] arrival of requests, traditional Round Robin method is not applicable as the method is practical only for the uniformly distributed arrival requests [8]. Additionally, the limited DNS scalability of the reached workload has failed to perform Web cluster optimal resources utilization. To overcome the drawback of traditional DNS approach, V. Cardellini et.al. proposed the adaptive TTL algorithms[8] to dynamically selecting the appropriate TTL value. G.D.H. Hunt invented Network Dispatcher [9] where incoming requests packets are forwarded to the selected server without IP head modification.

In favor of improve the Web service performance, Web server administrators facing difficulty to determine the most optimal solution upgrading their systems in the cost-effective way and significant improvement outcome of the system performance. To handle humans' subjective thought and judgement under complex circumstances, tremendous studies have been done to overcome the problem where the traditional Saaty's AHP [10] is facing a very unbalanced scale of estimations. Yiping Fan et al.[11] uses the fuzzy relation in the analytic hierarchy process(AHP) for solving the multiple vague criteria decision making by establishing the fuzzy relation between the vague criteria and some measurable items. Chung-Hsing et al.[12] proposed an algorithm for solving general fuzzy multi-criteria decision making problem involving fuzzy data expressed by means of linguistic terms. For handling human's subjective judgements, Don-Lin Mon [1] has proposed fuzzy AHP based on entropy weight to evaluate the a weapon systems which involves multiple criteria.

In this paper, Web server administrators judge upon the alternative such as the link bandwidth capacity to Internet, caching feature, redundant servers as well as intelligent workload handling methods to evaluate and select the alternatives priority for upgrading their system. Generally, due to the inconsistency of administrators' experiences, lack of experimental data as well as miscellaneous system condition, the subjective judgements given by the administrators are vague and imprecise. The implementation of fuzzy set theory in AHP to handle the multi-criterion problem is suitable to capture the subjectiveness and vagueness decisions. The subjective judgements, selection and preference are highly predominated the AHP result. Incorrect judgement given by the expert will degrade the decision accuracy. Fuzzy linguistic term with symmetrical triangular fuzzy number will be utilized to indicate the influence strength of the judgements in the hierarchy elements. Linguistic term approach is convenient for decision makers to express their assessment.

Fuzzy judgement matrix (**M**) where evaluation between each of the alternatives and the criteria is established according to Web administrator subjective judgments. A weighting vector (**V**) among the criteria will be predefined by the subjective judgements of the Web administrators. A total fuzzy judgement (**T**) is derived by multiplying the fuzzy judgement matrix (**M**) and the weighting vector(**V**). The series of pair wise comparison in traditional AHP is exempted where entropy weight [1] with the approaches of interval arithmetic, level fuzzy sets (α- cut) and the index of the decision maker optimism level (***b***), are employed to determine the desired alternative. α-level fuzzy sets is utilized to avoid the complexity and controversial fuzzy ranking since the predefined fuzzy number is in the obvious situations where the fuzzy number can confidently rank [13]. Different optimism index (***b***) will be used with its respective entropy weight depending on the decision maker optimism level. To examine the consistency of the fuzzy ranking, preceding of ***a*** is chosen to exhibit the reliability of the precedence alternative.

2. Hierarchy Structure

Analytic Hierarchy Process (AHP) method is widely used in complex and intangible decision-making problems in various areas of human requirement and interests. In traditional AHP [10], in order to obtain the optimal overall decisions, AHP requires structuring, weighting as well as synthesis procedures. In this paper, a hierarchy structure is established with four alternatives ($\boldsymbol{A_1}$, $\boldsymbol{A_2}$, $\boldsymbol{A_3}$ *and* $\boldsymbol{A_4}$) and two criteria ($\boldsymbol{C_a}$, $\boldsymbol{C_b}$) to select the greatest finite alternatives in favor of improve the Web server performance. Owing to the vagueness of human judgement and network fluctuating condition, fuzzy logic as well as entropy weighting approaches are the most appropriate candidates to derive the priority among the alternatives and choosing the desired preference. The hierarchy structure is described in Figure 1.

3. Shannon Entropy – Entropy Weight Derivation [1]

$$H = -\sum_{i=1}^{n} p_i \log(p_i) \qquad (1)$$

Basically, Shannon entropy is originally derived from thermodynamics studies [1]. Shannon entropy gives a measure of information and the information gain from an event is inversely related to its probability of occurrences. Shannon defined the *n*-state entropy function with *base-2* logarithm as:

where p_i is the relative frequency.

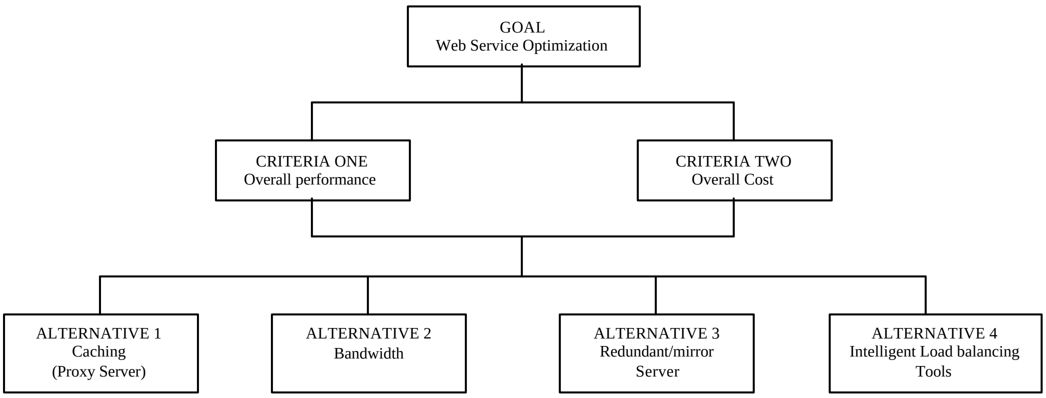

Figure 1: Hierarchy Structure Model of Web Server Upgrading Alternatives

The entropy weight [1] is shown as follows:

(a) Let V be a crisp judgement matrix where V is the n ´n matrix.

$$V = \begin{bmatrix} v_{11} & v_{12} & \ldots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & & \ddots & \vdots \\ v_{n1} & v_{n2} & \cdots & v_{nn} \end{bmatrix}$$

(b) The normalized matrix with elements represent the relative frequency is illustrated as follows:

$$\begin{bmatrix} \frac{v_{11}}{r_1} & \frac{v_{12}}{r_1} & \cdots & \frac{v_{1k}}{r_1} \\ \frac{v_{21}}{r_2} & \frac{v_{22}}{r_2} & \cdots & \frac{v_{2k}}{r_2} \\ \vdots & & \ddots & \vdots \\ \frac{v_{k1}}{r_k} & \frac{v_{k2}}{r_k} & \cdots & \frac{v_{kk}}{r_k} \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} & \ldots & f_{1k} \\ f_{21} & f_{22} & \cdots & f_{2k} \\ \vdots & & \ddots & \vdots \\ f_{k1} & f_{k2} & \cdots & f_{kk} \end{bmatrix}$$

where $\boldsymbol{R_i}$, with i =1, 2, 3, …, k, be the sum of the *i-th* row,

$\boldsymbol{f_{ij}}$ be the relative frequency $\boldsymbol{f_{ij}} = \boldsymbol{v}_{ij} / \boldsymbol{r_i}$,

$\boldsymbol{r_i}=\mathbf{S}_{j=1}^{k}\ \boldsymbol{a_{ij}}$.

(c) From equation (1), the entropy is determine as below:

$$H_1 = -\sum_{j=1}^{k} p_{1j} \log_2(p_{1j})$$

$$H_2 = -\sum_{j=1}^{k} p_{2j} \log_2(p_{2j}) \qquad (2)$$

$$H_k = -\sum_{j=1}^{k} p_{kj} \log_2(p_{kj})$$

The entropy weight is obtained by normalizing each element of entropy values in equation (2).

4. Fuzzy Approach in Subjective Judgement Matrix Evaluation

In this paper, fuzzy number with symmetrical triangular membership function is utilized to evaluate the influence strength of the alternatives in the hierarchy structure. A triangular membership function is confined by three parameters $\{x, y, z\}$ as follows:

$$Triangle(a\,; x, y, z) = \begin{cases} 0, & a \le x. \\ \frac{a-x}{y-x}, & x \le a \le y. \\ \frac{z-a}{z-y}, & y \le a \le z. \\ 0 & z \le a. \end{cases}$$

A level threshold ($0<\boldsymbol{a}<1$) of the fuzzy set is defined to avoid the complexity and unreliable fuzzy ranking. The definition of the symmetrical triangular fuzzy number with the interval confidence at level $\boldsymbol{a}$ can be determine as:

$$M_a = [x_a, z_a]$$

$$= [\ (y\text{-}x)\ \boldsymbol{a} + x,\ (y\text{-}z)\ \boldsymbol{a} + z\ ] \qquad \forall\ \boldsymbol{a} \in [0, 1] \qquad (3)$$

Table 1: Triangular Fuzzy Number Predefined Parameters

Triangular Parameters			Triangular Fuzzy number with α-level	
x	y	z	(y-x) α + x	(y-z) α + z
1	1	3	1	-2α+ 3
1	3	5	2α + 1	-2α+ 5
3	5	7	2α + 3	-2α+ 7
5	7	9	2α + 5	-2α+ 9
7	9	11	2α+ 7	-2α+ 11
9	11	11	2α + 9	11

For positive fuzzy numbers with the interval of confidence at level α, M_g and N_g the basic operations [13] are:

$M_a = [m^-_a , m^+_a]$, $N_a = [n^-_a , n^+_a]$
$\forall \gamma \in [0, 1]$ and $\forall m^-_a , n^-_a , m^+_a , n^+_a \in \hat{\mathbf{A}}$

$M_a / N_a = [m^-_a + n^-_a, m^+_a + n^+_a]$

$M_a \; 0 \; N_a = [m^-_a - n^-_a, m^+_a - n^+_a]$

$M_a \; 1 \; N_a = [m^-_a \times n^-_a, m^+_a \times n^+_a]$

$M_a \; 2 \; N_a = [m^-_a / n^-_a, m^+_a / n^+_a]$.

Two vectors will be considered in Saaty's AHP for instance fuzzy judgement matrix (**M**) and weighting matrix (**V**). The **M** represents the fuzzy number's grade of each alternative which satisfies each criterion. Furthermore, a total fuzzy judgement matrix (**T**) is derived by using the interval arithmetic operation as well as the entropy weight. The fuzzy judgement matrix(**M**) for alternatives is represented by fuzzy linguistic terms as follows:

$$M = \begin{bmatrix} m_{11} & m_{12} & \dots & m_{1n} \\ m_{21} & m_{22} & \dots & m_{2n} \\ & & & \\ m_{n1} & m_{n2} & \dots & m_{nn} \end{bmatrix}$$

where each element(m_{ij}) in the matrix **M** represents the Web administrators' linguistic judgement of the strength influence of alternative A_i (i=1, 2, …, n) with respect to criterion C_j (j=1, 2, …, n). For instance, the alternative (A_i) respect to the C_a linguistic term set is assigned as:

{*Extremely Expensive (EEx), Expensive (Ex), Above Average (AA), Average (A), Economic(Ec), Very Economic(VEc)*}

Similarly, the alternative (A_i) respect to the C_b linguistic term set is defined as:

{*Very Poor (VP), Poor (P), Average (A), Above Average (AA), Good (G), Extremely Good (EG)*}

For the weighting matrix, the evaluation of the strength influence is represented by the linguistic term set as below:

{*Insignificant (I), Weak (W), Fair (F), Above Fair (AF), Strong(S),Extremely Strong(ES)* }

The predefined linguistic term sets and their respected fuzzy numbers are illustrated as follows:

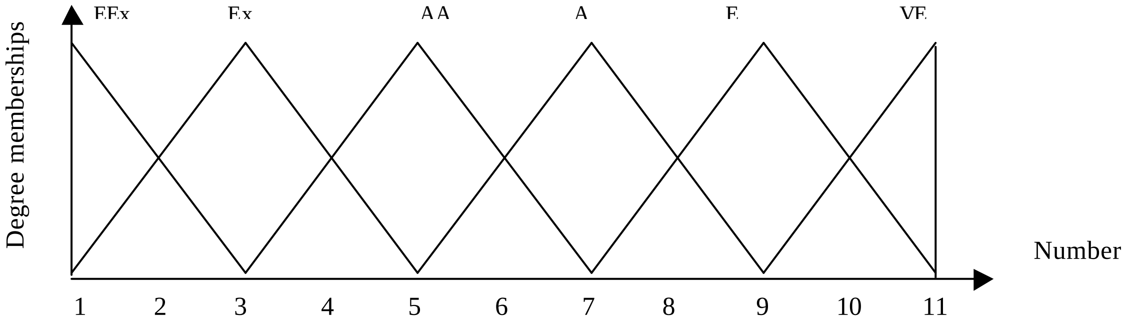

Figure 2: Linguistic Terms $\boldsymbol{C_a}$ in Fuzzy Judgement Matrix

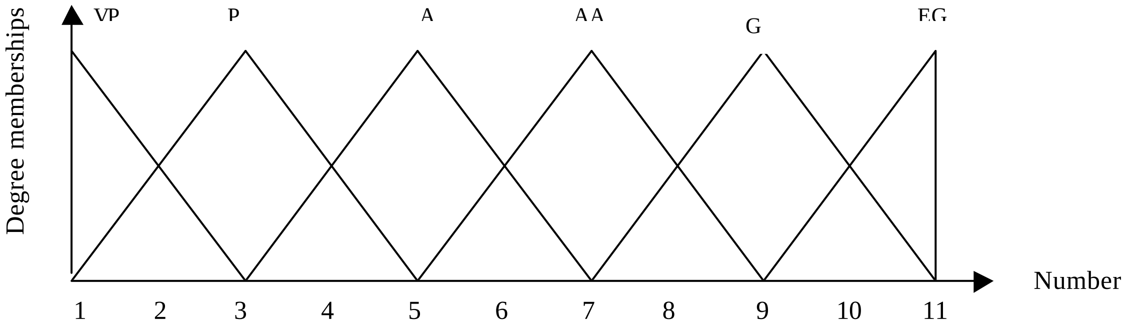

Figure 3: Linguistic Terms $\boldsymbol{C_b}$ in Fuzzy Judgement Matrix

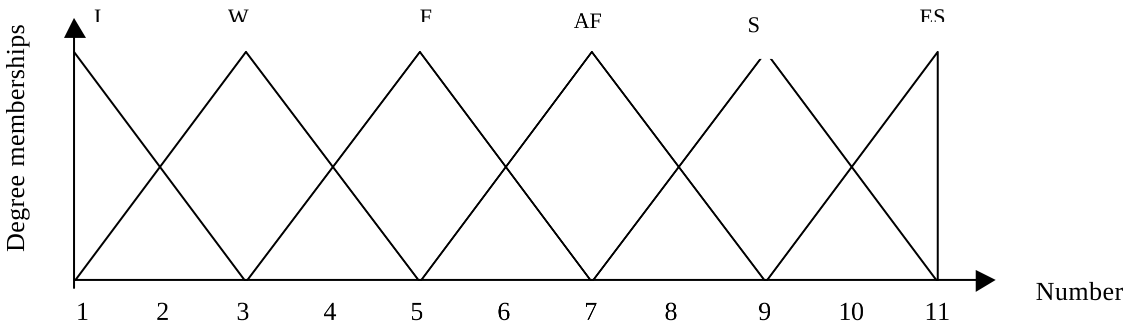

Figure 4: Linguistic Terms Strength Influence in Weighting Matrix

5. Numerical Evaluation

Consider a public accessible Web server on the Internet. The Web server system consists of two redundant servers to handle the large population of unknown users' accesses. The Web server is connected to a switch and a router that connects to the ISP then to the Internet. The backbone connected to Internet through a T1 link. Due to high demands of user demands, the provided Web site exhibits extremely slow response and traffic congestion. In order to overcome the congested Web traffic, Web server administrators have monitored the performance of the Web server and discovered several factors enormously influencing the Web server overall performance.

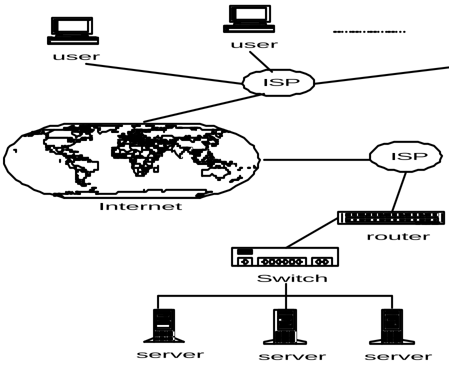

Figure 5: Web Server System and Internet Connectivity

The four alternatives upgrade features are caching **(**A_1**)**, link bandwidth **(**A_2**)**, redundant server **(**A_3**)** and intelligent load balancing approaches **(**A_4**)**. However, the priority of the selection within the four alternatives is governed by the most cost-effective ($\boldsymbol{C_a}$) and indicates the most significant Web server performance ($\boldsymbol{C_b}$) outcome as the two considerate criteria. To solve the multiple criteria decision making problem, fuzzy AHP approach is utilized to capture the vagueness of the descriptions and judgements among the Web server administrators. The evaluation of the alternatives is based on the follow descriptions:

(a) Caching ($\boldsymbol{A_1}$)

The purpose of caching [5] depends on the Web server administrators intentions such as caching for bandwidth conservation, performance, security purposes, access control, logging, monitoring, audit trail etc. In this paper, Web proxy server is considered as the caching tool which intends to improve the Web service performance by reducing the latency of data retrieving. Caching consideration includes the numbers and the capacity of the proxy servers.

(b) Link Bandwidth ($\boldsymbol{A_2}$)

Normally, LANs connect to WANs with different speeds such as ISDN 1 BRI (128k), T1 (1.544Mbps), T3 (45Mbps), etc. High speed alternatives for link bandwidth [7] to Internet for instance Fast Ethernet(100Mbps), ATM-OC-3 (15.5Mbps) or ATM-OC-12(62.2Mbps), etc. Web administrators have to consider the adequate link bandwidth where, generally, the bandwidth performance is proportional to the speed as well as the cost and the maintenance cost.

(c) Redundant/Cluster Server ($\boldsymbol{A_3}$)

Replication of redundant servers [7] approach such as Redundant Array of Inexpensive Computers (RAIC) is one of the considerations to improve a Web sites serving reliability instead of a single server. The important judgement is the number of replication server as well as the server hardware performance such as CPU power, capacity, etc.

(d) Intelligent Redistribution Approaches($\boldsymbol{A_4}$)

Intelligent Redistribution Approaches are such as RRDNS with adaptive TTL algorithm [8], network dispatcher [9], etc to improve the Web servers responsitivity. The judgement should place emphasis on the system's environment such as topology, size and popularity before select a most appropriate intelligent system.

Based on the above consideration, Web administrators with the expert's subjective judgements have compromised a fuzzy judgement matrix(**M**) of four alternatives($\boldsymbol{A_1}$, $\boldsymbol{A_2}$, $\boldsymbol{A_3}$ and $\boldsymbol{A_4}$) which associated on criteria ($\boldsymbol{C_a}$, $\boldsymbol{C_b}$). Symmetrical fuzzy numbers are used to denote the hierarchy structure elements' influence strength. The linguistic fuzzy judgement matrix(**M**) is described as:

$$
\mathbf{M} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}
\begin{array}{c} \begin{array}{cc} C_a & C_b \end{array} \\
\begin{bmatrix} AA & AA \\ Ex & AA \\ Ex & A \\ A & G \end{bmatrix} \end{array}
$$

Based on Table 2, the linguistic terms are represented by the numerical values as follows:

$$
\mathbf{M} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}
\begin{array}{c} \begin{array}{cc} C_a & C_b \end{array} \\
\begin{bmatrix} 5 & 7 \\ 3 & 7 \\ 3 & 5 \\ 7 & 9 \end{bmatrix} \end{array}
$$

And the precedence of the influence, the two criteria, cost-effectivity and performance improvement outcome are illustrated by the weighting vector as follow:

$$
\mathbf{V} = [\ AF \quad S\ ] = [\ 9 \quad 7\ ]
$$

The total value fuzzy matrix **Mt** is obtained by multiplying the two matrix:

$$
Mt = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}
\begin{array}{c} \begin{array}{cc} C_a & C_b \end{array} \\
\begin{bmatrix} 9\text{´}5 & 7\text{´}7 \\ 9\text{´}3 & 7\text{´}7 \\ 9\text{´}3 & 7\text{´}5 \\ 9\text{´}7 & 7\text{´}9 \end{bmatrix} \end{array}
$$

Fuzzy number arithmetic and the Shannon entropy rules are used to determine the entropy weight. From *equation(2)* and Table 1, the total weighting vector with respect to the a-level(0.15) and defined optimism index, b=0.5 (where the b is proportional to the optimism level) is obtained as below:

$$
\mathbf{Mt} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_3 \end{array}
\begin{array}{c} \begin{array}{cc} C_a & C_b \end{array} \\
\begin{bmatrix}
[7.30, 10.70] \times [3.30, 6.70] & [5.30, 8.70] \times [5.30, 8.70] \\
[7.30, 10.70] \times [1.00, 2.70] & [5.30, 8.70] \times [5.30, 8.70] \\
[7.30, 10.70] \times [1.30, 4.70] & [5.30, 8.70] \times [3.30, 6.70] \\
[7.30, 10.70] \times [5.30, 8.70] & [5.30, 8.70] \times [7.30, 10.70]
\end{bmatrix} \end{array}
$$

$$
\mathbf{Mt} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}
\begin{array}{c} \begin{array}{cc} C_a & C_b \end{array} \\
\begin{bmatrix}
[24.09, 71.69] & [28.09, 75.69] \\
[7.30, 28.89] & [28.09, 75.69] \\
[9.49, 50.29] & [17.49, 58.29] \\
[38.69, 93.09] & [38.69, 93.09]
\end{bmatrix} \end{array}
$$

Using linear convex combination(*equation(3)*), the **Mt** is a crisp judgement matrix. The Moderate Web Administrator entropy weighting determination of the four alternatives A_1, A_2, A_3 and A_4 is evaluated with three different level a, (0.15, 0.50 and 0.95)

From Table 3,4 and 5, the priority of the upgrading alternatives are in the order of intelligent load balancing approaches(A_4), caching(A_1), redundant server(A_3) and link bandwidth(A_2). Regardless of the variety of a value , the result shown in Table 3, Table 4 and Table 5 are consistent with the priority of A_4, A_1, A_3 followed by A_2. To examine the consistency and reliability of the fuzzy ranking, preceding value of a is chosen with three different level of optimism such as b=0.1, b=0.5 and b=0.9 depends on the optimism level of the Web administrator. The results are illustrated in Figure 6, Figure 7 and Figure 8 where different levels of Web administrators' optimism level have no influence on the consistency of the alternatives priority. The consistency of the result assures the acceptable and correctness of the selected alternative.

Table 3: Moderate Entropy Weighting with α-level=0.15

Alternative	Linear convex combination		$-\sum p_i \, LOG2(p_i)$		Entropy weighting	Priority
	C_a	C_b	C_a	C_b		
A_1	47.89	51.89	0.5083	0.4906	0.2619	2
A_2	18.10	51.89	0.5046	0.3200	0.2162	4
A_3	29.89	37.89	0.5209	0.4690	0.2600	3
A_4	65.89	65.89	0.5000	0.500	0.2622	1

Table 4: Moderate Entropy Weighting with α-level=0.50

Alternative	Linear convex combination		$-\sum p_i \, LOG2(p_i)$		Entropy weighting	Priority
	C_a	C_b	C_a	C_b		
A_1	46.00	50.00	0.5086	0.4902	0.2667	2
A_2	14.00	50.00	0.4796	0.2782	0.2024	4
A_3	28.00	36.00	0.5218	0.4669	0.2640	3
A_4	64.00	64.00	0.5000	0.5000	0.2670	1

Table 5: Moderate Entropy Weighting with α-level=0.95

Alternative	Linear convex combination		$-\sum p_i \, LOG2(p_i)$		Entropy weighting	Priority
	C_a	C_b	C_a	C_b		
A_1	45.01	49.01	0.5088	0.4899	0.2755	2
A_2	9.46	49.01	0.4351	0.2133	0.1761	4
A_3	27.01	35.01	0.5223	0.4657	0.2725	3
A_4	63.01	63.01	0.5000	0.5000	0.2759	1

6. Conclusion

In this paper, fuzzy linguistic term of Web administrators assessment is used to capture the fuzziness and subjectiveness of priority upgrading alternatives selection in a multicriteria decision making problem in a Web server system. The predefined fuzzy number with the certain confidence of level(α-*cut-method*) is able to avoid the conflict and unreliability of the fuzzy ranking problem. The fuzzy approach in AHP has demonstrated the consistency of confidence in decision making since the different levels of optimism and α-levels have no influence in the evaluation outcome.

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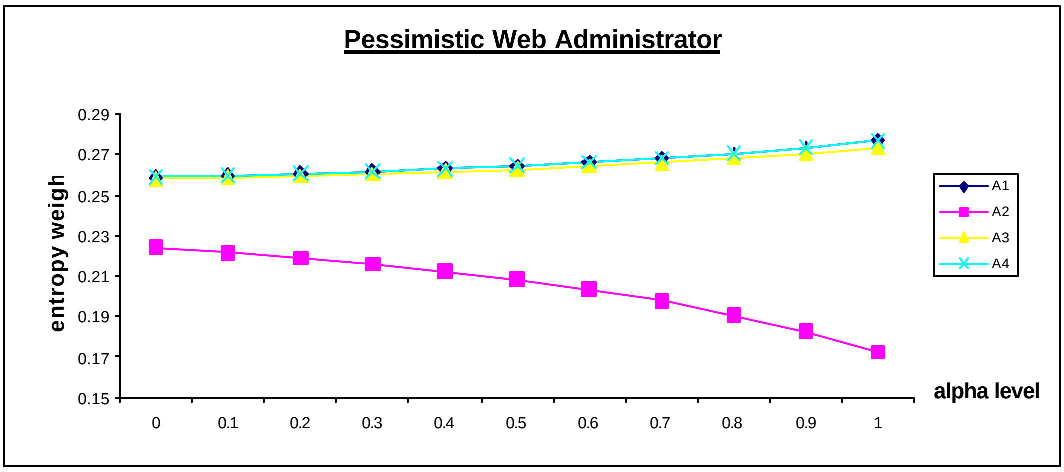

Figure 6: Pessimistic Web Administrator with the optimism index, b=0.1.

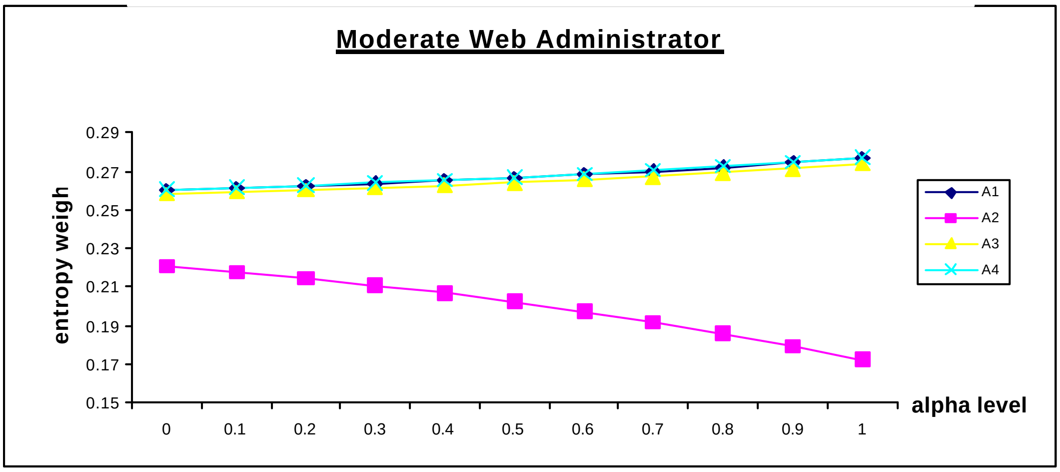

Figure 7: Moderate Web Administrator with the optimism index, b=0.5.

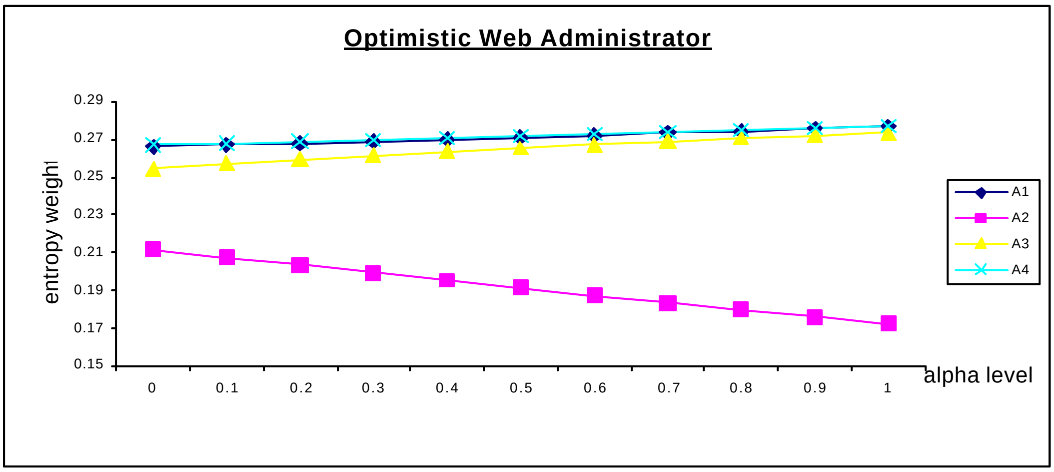

Figure 8: Optimistic Web Administrator with the optimism index, b=0.9.