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Facility Location Selection Using Extent Fuzzy AHP

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Abstract: Facility location problems (FLP) are strategic decision making problems for selecting best geographical location to start the operations of a new facility or for expansion of existing facilities. These are long term investment decision involving many factors that may be conflicting in nature. Properly selected location provides better economical benefits and improved service to consumers. FLP is a multi-criteria decision making (MCDM) problem in which best location has to be selected from a set of alternatives. Taking into consideration a number of Criteria and sub-criteria. In this article Extent Fuzzy AHP based method has been proposed to solve a real time facility location problem.

Keyword: Facility location, Multi-criteria decision-making (MCDM), Fuzzy AHP, FAHP, Extent FAHP

I. INTRODUCTION

Facility location is a related to determination of geographical location to start, relocate or expand the operations of a firm in order to optimize at least one objective i.e. cost, profit, distances, service, or waiting time. It is not easy to change the location very often. Selecting the appropriate facility among a given set of alternatives is a difficult work requiring both qualitative and quantitative factors [1]. Facility location selection decisions affect several operational and logistical decisions of firms and have impact on operating costs and revenues of the firm. These decisions are costly and difficult to reverse, and they entail a long term commitment. Plant location is the function of determining location for a plant for maximum operating economy and efficiency [1].

Facility location decisions are observed to be of immense importance in long-term planning for the manufacturing organizations. The location of a big plant cannot be changed due to changes in demands, transportation, and raw material price. Once a mistake is made for the location of facility, it becomes extremely difficult and costly to change it especially in large facilities [2]. A bad facility location is a burden, and it may bankrupt the company. On the other hand, a good choice of location might result in optimum transportation costs, availability of qualified labor, adequate supplies of raw materials, or some similar condition that would give competitive edge to the company over competitors [3]. Therefore, decision makers must select not only a well performing facility for the current situation, but also a probable performing facility for the lifetime of the company [4].

Various important qualitative and quantitative criteria, such as availability of resources for production, investment cost, nearness of other facilities etc. are usually considered while selecting a facility location for a specific industrial application. Brown and Gibson [5] and Buffa and Sarin [6] proposed a facility location model for a multidimensional location problem based on critical factors, objective factors, and subjective factors. Fortenberry and Mitra [7] presented a model for the location-allocation problems considering both qualitative and quantitative factors. Kahne [8] considered 29 attributes and used a weighting model to determine the relative importance with uncertainty in attributes.

The success or failure of a manufacturing organization largely depends on the consideration of realistic criteria as they directly influence the organizational performance. Selection of a proper location involves consideration of multiple feasible alternatives. It is also observed that the selection procedure involves several objectives and it is often necessary to make compromise among the possible conflicting criteria [9]. For these reasons, multi-criteria decision making (MCDM) is found to be an effective approach to solve the facility location selection problems.

Randhawa and West [10] proposed a solution approach to facility location selection problems while integrating analytical and multi-criteria decision-making models. Sriniketha et. al [11] presented and an integrated decision-making methodology employing Analytical hierarchy process (AHP), and Preference ranking organization method for enrichment evaluations (PROMETHEE-II) in order to make the best use of information available, either implicitly or explicitly to solve the MCDM facility location problem. El-Santawy et al [12] proposed VIKOR based MCDM methodology for Ranking Facility Locations. Many researchers presented a number of MCDM approaches to solve the facility location problem [9-13].

The analytic hierarchy process (AHP) is an analytical approach used to solve complex problems. Some researchers used the AHP as a stand-alone methodology to make location decisions [14, 15]. The AHP enables the decision maker to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner with conflicting multiple criteria [16].

However, AHP is based on crisp theory and includes the vagueness of human beings, due to this reason the selection is often based on the vagueness of human being's

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thought, or personal judgement. Therefore, in this article we propose a fuzzy multi criteria decision making (MCDM) model by extending crisp AHP theory and analysis methods to fuzzy techniques for solving real-world problems.

This paper proposes a multi-criteria decision making (MCDM) methodology that is suitable for a location selection problem under conflicting in nature criteria environment. The main goal of this paper is to provide investors and managers with a more effective and efficient model for location selection decisions. The purpose of this paper is also to demonstrate how better location decisions can be made by the application of the extent fuzzy AHP (FAHP). Furthermore, a multi-attribute location with triangular fuzzy numbers model is discussed to give a clear indication about the location selection problem in real-world situations.

II. PROBLEM ENVIRONMENT

The case of an automobile manufacturing factory has been considered here. The firm wanted to identify a geographical location from which it can start the operations of a new facility for some new car models. The location has to be selected in such a way that initial investment and transportation cost can be minimised while effectiveness of the operations can be improved.

In the literature a number of authors have addressed the plant location selection problem by cost based models**.** However, the facility location also depends upon many other factors like business culture of the place, infrastructure available, availability of manpower etc.

Due to this reason in this article a MCDM approach based on extent Fuzzy analytical hierarchy process (EFAHP) has been proposed in this article. Four selection criteria and sixteen sub criteria are considered here to affect the location selection decision. The criteria and sub criteria considered in this article are as follows:

i. Proximity (C1)- This criteria is effected by four sub criteria:. Proximity to finished goods market(SC1), proximity to raw material market(SC2), proximity to a city(SC3) and proximity to region with skilled work force(SC4).
ii. Infrastructure (C2) – Availability of power supply (SC5), water source/supply (SC6) and road transport infrastructure (SC7), rail transport infrastructure (SC8).
iii. Economical factors (C3) : Cost of labor(SC9), Cost of land(SC10), tax rates(SC11) in the region, cost of power(SC12) i.e. electricity etc.
iv. Business environment (C4) –political environment (SC13), work culture(SC14), government policies(SC15), administrative system(SC16).

The company has identified four different geographical locations as alternatives from which the best location has to be selected. Figure 1 shows the hierarchy of the location problem.

III. THEORETICAL BACKGROUND

The concept of the fuzzy set theory was first introduced by Zadeh [17]. It has been used as a modelling tool for complex systems that are difficult to define precisely or with certainty, but can be operated and controlled by humans. By embedding the AHP method into fuzzy sets, another application area of the fuzzy logic is revealed. Decision markers usually find that it is more confident to give interval judgments than fixed value judgment. This is because they are usually unable to be explicit about their preferences due to the fuzzy nature of the comparison process [24].

There are many fuzzy AHP methods proposed by a number of researchers [18-23]. Due to relatively easier steps of Chang [19] extension than the other fuzzy AHP approaches and similarity to the crisp AHP, we use this approach in our proposed model.

IIIa. Fuzzy set and fuzzy number

Fuzzy set theory which is an extension of ordinary set theory was introduced by Zadeh [17] for dealing with uncertainty and imprecision associated with information. The preliminary of fuzzy set theory used for development of extent fuzzy TOPSIS method used in this article is as follows:

Definition 1 (Fuzzy Set)**.** In a universe of discourse X a fuzzy set ã is characterised by a membership function $\mu_{\tilde{a}}(x)$ which associate each element x in X, a real number in the interval [0, 1]. Membership function $\mu_{\tilde{a}}(x)$ is termed as the grade of membership of x in ã [17].

$$\tilde{a} = \{x, \mu_{\tilde{a}}(x) \mid x \in X\} \qquad \ldots(1)$$

Definition 2 (Fuzzy number)**.** A fuzzy number is a quantity whose value is imprecise, rather than exact as is the case with "ordinary" (single-valued) numbers. Any fuzzy number can be thought of as a function whose domain is a specified set usually the set of real numbers, and whose range is the span of non-negative real numbers between, and including, 0 and 1. Each numerical value in the domain is assigned a specific "grade of membership" where 0 represents the smallest possible grade, and 1 is the largest possible grade.

In this article triangular fuzzy numbers are used. In general, a triangular membership function is described by a triplet ã (l, m, u) as shown in fig .2 .
A triangular fuzzy number ã (l, m, u) is defined by the following membership function:

$$\mu_{\tilde{a}}(x) = \begin{cases} 0, & x \le a, \\ \dfrac{x-l}{m-l}, & l < x \le m, \\ \dfrac{u-x}{u-m}, & m < x \le u, \\ 0, & x > u, \end{cases} \qquad \ldots(2)$$

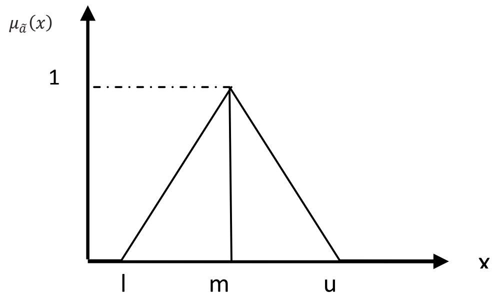

Figure 2. The membership function of a triangular fuzzy number $\tilde{a} = (l, m, u)$.

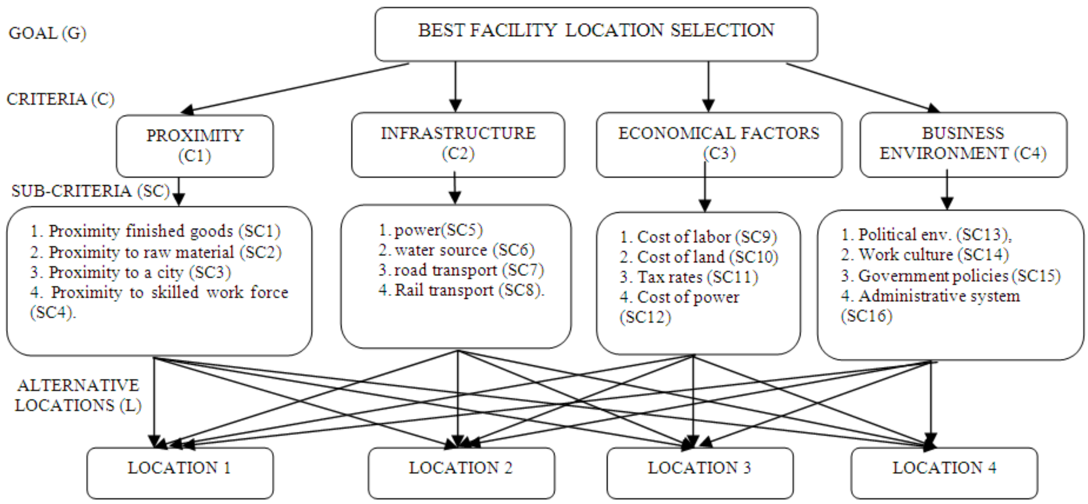

Fig. 1. General six sigma project evaluation model

IIIb. Extent Fuzzy Analytic Hierarchy Process (EFAHP)

Consider a triangular fuzzy comparison matrix expressed by:

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} (1,1,1) & (l_{12},m_{12},u_{12}) & \cdots & (l_{1n},m_{1n},u_{1n}) \\ (l_{21},m_{21},u_{21}) & (1,1,1) & \cdots & (l_{2n},m_{2n},u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (l_{n1},m_{n1},u_{n1}) & (l_{n2},m_{n2},u_{n2}) & \cdots & (1,1,1) \end{bmatrix} \quad (3)$$

where, $a_{ij} = (l_{ij}, m_{ij}, u_{ij}) = a_{ji}^{-1} = \left(\frac{1}{u_{ji}}, \frac{1}{m_{ji}}, \frac{1}{l_{ji}}\right)$

for $i, j = 1, \ldots\ldots, n$ and $i \neq j$.

To calculate a priority vector of the above triangular fuzzy comparison matrix, Chang [19] suggested an extent analysis method, which is summarized as follows.

Step 1: Sum up each row of the fuzzy comparison matrix A by fuzzy arithmetic operations:

$$RS_i = \sum_{j=1}^{n} a_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right) \quad (4)$$
$i = 1, \ldots\ldots, n.$

Step 2: Normalize the above row sums by:

$$S_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right) \quad (5)$$
$$i = 1, \ldots\ldots, n$$

Step 3: Compute the degree of possibility of $S_i \geq S_j$

$$V(S_i \geq S_j) = f(x) = \begin{cases} 1, & if\, m_i \geq m_j, \\ \frac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, & if\, l_j \leq u_i, \quad i, j = 1, \ldots, n; j \neq i \\ 0, & others, \end{cases} \quad (6)$$

where, $S_i = (l_i, m_i, u_i)$ and $S_j = (l_j, m_j, u_j)$. The definition of possibility degree is shown in Fig. 3.

Step 4: Calculate the degree of possibility of S_i over all the other $(n-1)$ fuzzy numbers by:

$$V(S_i \geq S_j | j = 1, \ldots, n; j \neq i) = min_{j\in\{1,\ldots,n\}, j\neq i} V(S_i \geq S_j), i=1,\ldots\ldots, n. \quad (7)$$

Step 5: Define the priority vector $W = (w_1, \ldots\ldots, w_n)^T$ of the fuzzy comparison matrix A as:

$$w_i = \frac{V(S_i \geq S_j | j = 1,\ldots,n; j \neq i)}{\sum_{k=1}^{n} V(S_k \geq S_j | j = 1,\ldots,n; j \neq k)}, \quad i = 1, \ldots\ldots, n. \quad (8)$$

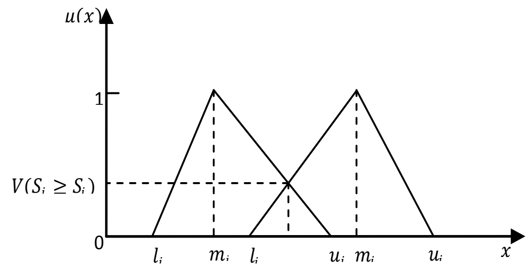

Fig. 3. Definition of the degree of possibility of $V(S_i \geq S_j)$

IV. ILLUSTRATIVE EXAMPLE

In this study, a case of automobile industry is taken. Due to increase in the demand of product and boom in the automobile sector, the company was trying to identify a location to start a new plant. There was no formal, established decision-making procedure or criteria for evaluating the importance of different locations within the company.

Top management realised the threat the company is facing from its competitors and thus accentuated the identification of location that could have a higher impact on the business financially and strategically. Thus, this paper aims to propose a formal approach for the selection of facility location by the application of EFAHP.

IVa. Facility location Selection Using EFAHP:

After the discussion with the top management and experts, author analyzed numerous dimensions for selecting the right facility location. In this study, we categorized those dimensions under four criteria and each criteria has four sub-criteria and a total of 16 sub-criteria. The general evaluation model of facility location selection is given in Figure 1.

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IVb. Development of Fuzzy Comparison Matrix

In order to take the vagueness of assessment on pair wise comparison into consideration, triangular numbers A_1, A_3, A_5, A_7, &A_9 are used to represent the assessment for "Equal, Moderately, Strongly, Very Strongly, and Extremely", respectively. Fig. 4 shows the triangular fuzzy numbers $A_t = (l_t, m_t, u_t)$, where t = 1, 2, ..., 9 and l_t, m_t, &u_t are the lower, middle and upper values of fuzzy number A_t. Table 1 shows the results of pair wise comparisons of various criteria at individual level.

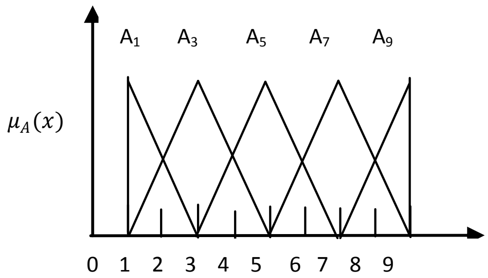

Figure 4. The membership function of the triangular numbers

Table 1: Pair wise comparison for various criteria at individual level

	C1	C2	C3	C4
C1	(1, 1, 3)	(1, 3, 5)	(1/5,1/3,1/1)	(3, 5, 7)
C2	(1/5,1/3,1/1)	(1, 1, 3)	(3, 5, 7)	(1/7,1/5,1/3)
C3	(1, 3, 5)	(1/7,1/5,1/3)	(1, 1, 3)	(1/7,1/5,1/3)
C4	(1/7,1/5, 1/3)	(3, 5, 7)	(3, 5, 7)	(1, 1, 3)

IVc. Determination of Priority Vector for Facility Location Selections

Using equation (4) RS_i is enumerated as,

$RS_1 = \sum_{j=1}^{n} a_{1j} = (1,1,1) + (1,3,5) + (1/5,1/3,1) + 3,5,7$=$(4.343, 6.53, 11.333)$,

$RS_2 = \sum_{j=1}^{n} a_{2j} = (1/5,1/3,1) + (1,1,3) + (3,5,7) + 1/7, 1/5, 1/3$=$(4.343, 6.53, 11.333)$,

$RS_3 = \sum_{j=1}^{n} a_{3j} = (1,3,5) + (1/7,1/5,1/3) + (1,1,3) + 1/7,1/5,1/3$= $(2.286, 4.40, 8.667)$,

$RS_4 = \sum_{j=1}^{n} a_{4j} = (1/7,1/5,1/3) + (3,5,7) + 3,5,7+1,1,3$=$(7.143, 11.20, 17.333)$,

Using Step 2 RS_i, is normalized,

$RS_1 + RS_2 + RS_3 + RS_4 = (4.343, 6.53, 11.333) + (2.286, 4.40, 8.667) + (7.143, 11.20, 17.333) = (18.971, 31.466, 53.333)$

$$[RS_1 + RS_2 + RS_3 + RS_4]^{-1} = \left(\frac{1}{53.33}, \frac{1}{31.47}, \frac{1}{18.97}\right)$$

= (0.0188, 0.0318, 0.053)

$S_1 = RS_1 \times [RS_1 + RS_2 + RS_3 + RS_4]^{-1}$
$= (4.343, 6.53, 11.333)x(0.0188, 0.0318, 0.053)$
$= (0.179, 0.340, 0.661)$

Similarly, S_2= (0.0814, 0.2076, 0.597389558)
S_3= (0.0428, 0.1398, 0.456827309)
S_4= (0.1339, 0.3559, 0.913654618)

Now, in Step 3 degree of possibility of $S_i \geq S_j$ are enumerated using equation (6) as,

$V(S_1 \geq S_2) = 1$; $V(S_1 \geq S_3) = 1$;
$V(S_1 \geq S_4) = 0.923$;
$V(S_2 \geq S_3) = 1$; $V(S_2 \geq S_4) = 0.758$;
$V(S_2 \geq S_1) = 0.849$;
$V(S_3 \geq S_4) = 0.599$; $V(S_3 \geq S_1) = 0.696$;
$V(S_3 \geq S_2) = 0.847$;
$V(S_4 \geq S_1) = 1$; $V(S_4 \geq S_2) = 1$;
$V(S_4 \geq S_3) = 1$.

In Step 4 the the degree of possibility of S_i over all the other $(n-1)$ fuzzy numbers by is calculated by using equation (7).

$$V(S_1 \geq S_j | j = 2,3,4) = 0.923;$$
$$V(S_2 \geq S_j | j = 3,4,1) = 0.758;$$
$$V(S_3 \geq S_j | j = 4,1,2) = 0.599;$$
$$V(S_4 \geq S_j | j = 1,2,3) = 1$$

The priority vector $W = (w_1, \dots\dots, w_n)^T$ of the fuzzy comparison matrix A as is calculated in Step 5 using equation (8) as,

$$w_1 = \frac{V(S_1 \geq S_2)}{V(S_1 \geq S_2) + V(S_2 \geq S_1) + V(S_3 \geq S_2) + V(S_4 \geq S_2)} = 0.2814;$$
$$w_2 = \frac{V(S_2 \geq S_1)}{V(S_1 \geq S_2) + V(S_2 \geq S_1) + V(S_3 \geq S_2) + V(S_4 \geq S_2)} = 0.2310;$$
$$w_3 = \frac{V(S_3 \geq S_2)}{V(S_1 \geq S_2) + V(S_2 \geq S_1) + V(S_3 \geq S_2) + V(S_4 \geq S_2)} = 0.1827;$$
$$w_4 = \frac{V(S_4 \geq S_2)}{V(S_1 \geq S_2) + V(S_2 \geq S_1) + V(S_3 \geq S_2) + V(S_4 \geq S_2)} = 0.3049$$

That is, weight vectors of various criteria are:
$w_{C1} = 0.2814$; $w_{C2} = 0.2310$; $w_{C3} = 0.1827$; $w_{C4} = 0.3049$

Similarly, by using Step 1 to Step 5 the weight vectors for various sub-criteria calculated:

w_{sc1}= 0.240; w_{sc2}= 0.165; w_{sc3}= 0.311;
w_{sc4}= 0.283; w_{sc5}= 0.264; w_{sc6}= 0.031;
w_{sc7}= 0.407; w_{sc8}= 0.297; w_{sc9}= 0.041;
w_{sc10}= 0.279; w_{sc11}= 0.305; w_{sc12}= 0.374;
w_{sc13}= 0.349; w_{sc14}= 0.283 w_{sc15}= 0.122;
w_{sc16}= 0.245;

Similarly, the weight vectors for the various locations with respect to each sub-criteria is shown in Table 2.

Now, the total weights of the facility locations can be derived by multiplying the alternative location weight with criteria weight and sub-criteria weights (equation 9). The multiplied values are depicted in Table 3.

$$W_{Ln} = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{t} W_{Ci} * W_{scj} * W_{Ljk} \quad (9)$$

Where,
$i = 1, \dots\dots, n$
$j = 1, \dots\dots, m$
$k = 1, \dots\dots, t$

As it is shown in Table 3, Location 3 gains the best score among all the alternative projects.

Table 2: Weight vectors for the various projects for each sub-criteria

	L1	L2	L3	L4
SC1	0.43437	0.3438	0.13	0.0919
SC2	0.39786	0.3101	0.106	0.186
SC3	0.27101	0.2676	0.2096	0.2518

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SC4	0.25406	0.2541	0.2541	0.2378
SC5	0.28884	0.2888	0.1224	0.2999
SC6	0.28853	0.2885	0.1214	0.3015
SC7	0.10916	0.1425	0.343	0.4053
SC8	0.15254	0.1754	0.2527	0.4193
SC9	0.1353	0.2371	0.2211	0.4065
SC10	0.39476	0.2404	0.0765	0.2884
SC11	0.15076	0.3516	0.1291	0.3686
SC12	0.31218	0.0616	0.2939	0.3323
SC13	0.31218	0.0616	0.2939	0.3323
SC14	0.3559	0.0227	0.2823	0.3391
SC15	0.33712	0.0182	0.2688	0.3759
SC16	0.25736	0.1823	0.3274	0.2329

Table 3: Total weights of each alternative location corresponding to each sub-criteria

	TOTAL WEIGHTS			
	L1	**L2**	**L3**	**L4**
SC1	0.02937	0.0232	0.0088	0.0062
SC2	0.01854	0.0145	0.0049	0.0087
SC3	0.0237	0.0234	0.0183	0.022
SC4	0.02025	0.0203	0.0203	0.019
SC5	0.01762	0.0176	0.0075	0.0183
SC6	0.00208	0.0021	0.0009	0.0022
SC7	0.01027	0.0134	0.0323	0.0381
SC8	0.01048	0.0121	0.0174	0.0288
SC9	0.00102	0.0018	0.0017	0.0031
SC10	0.02019	0.0123	0.0039	0.0147
SC11	0.0084	0.0196	0.0072	0.0205
SC12	0.02132	0.0042	0.0201	0.0227
SC13	0.03325	0.0066	0.0313	0.0354
SC14	0.03069	0.002	0.0243	0.0292
SC15	0.0126	0.0007	0.01	0.0141
SC16	0.01925	0.0136	0.0245	0.0174
SUM	**0.27904**	**0.1872**	**0.2333**	**0.3004**

V. CONCLUSION

In this article an extent fuzzy analytical hierarchy (EFAHP) has been proposed to solve the multi-criteria decision making problem of facility location selection. The problem is presented in form of a hierarchy. Four criteria and sixteen sub-criteria which are conflicting in nature are identified to select best location from a set of four probable locations for establishing a new facility. The indirect evaluation of AHP is used to eliminated the decision makers biasness and fuzzy is incorporated to remove the vagueness of decision makers from the solution. The location selected is expected to provide best operational and financial efficiency to the company and may give the company competitive edge over its competitors.

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