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A FUZZY AHP BASED APPROACH FOR SELECTING POTENTIAL RECOVERY FACILITIES IN A CLOSED-LOOP SUPPLY CHAIN

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ABSTRACT

In this paper, we employ fuzzy AHP methodology for selecting potential recovery facilities in a closed-loop supply chain. This methodology utilizes triangular fuzzy numbers for pair-wise comparisons and the extent analysis method for the synthetic extent value of the fuzzy pair-wise comparisons and principle of comparison of fuzzy numbers to derive the weight vectors to address the criticism traditional AHP often faces due to its unbalanced scale of judgments and inability to handle inherent uncertainty in carrying out pair-wise comparisons. A numerical example is considered to illustrate the methodology.

Keywords: Closed loop supply chain, strategic planning, fuzzy AHP, extent analysis.

1. INTRODUCTION

Economic incentives, government regulations and customer perspective on environmental consciousness (EC) are driving more and more companies into the product recovery business [1]. EC, enforced primarily by government regulations, has become an obligation to the society itself [2], [3], [4], [5]. Many original equipment manufacturers (OEM) these days are engaged in additional series of activities stemming from the reverse supply chain that involves retrieving used products from consumers and remanufacture (closed-loop) or recycle (open-loop) them to recover their left-over market value, at the same time, fulfilling the government regulations pertaining to the handling of used products. The combination of forward and reverse supply chains is called a closed-loop supply chain.

For a Closed-Loop Supply Chain (CLSC) to operate efficiently, its strategic planning (that involves selection of potential recovery facilities) is of paramount importance. Not many quantitative models in the literature deal with this aspect of designing a CLSC. Majority of the models assume each available facility is efficient enough to re-process the incoming used products, which is contrary to real-life situations. Pochampally and Gupta [6] address this drawback in a reverse supply chain and employ Analytic Hierarchy Process (AHP) in selecting potential recovery facilities in a reverse supply chain. However, traditional AHP is criticized for its unbalanced scale of judgment and failure to precisely handle the inherent uncertainty and vagueness in carrying out pair-wise comparisons.

With an objective to address these drawbacks, in this paper, we employ a fuzzy AHP based approach for selecting potential recovery facilities in a CLSC. This methodology utilizes triangular fuzzy numbers for pair-wise comparisons and the extent analysis method for the synthetic extent value of the fuzzy pair-wise comparisons and principle of comparison of fuzzy numbers to derive the weight vectors. We illustrate our methodology with a numerical example.

2. FUZZY AHP

Multi-Criteria analysis problems require the decision maker to make qualitative assessments regarding the performance of the decision alternatives with respect to each independent criterion and the relative importance of each independent criterion with respect to the overall objective of the problem. As a result, uncertain subjective data are present which make the decision making process complex [7].

The Analytic Hierarchy Process (AHP) is a multi-attribute decision making tool based on reasoning, knowledge and experience of experts in the field, supported by simple mathematics that enables the decision maker to weigh tangible and intangible criteria against each other for the purpose of resolving conflict or setting priorities. The process has been

formalized by Saaty [8] and is used in a wide variety of problem areas. AHP enables a person to make pair-wise judgments of importance between the independent criteria as well as the decision alternatives. However, traditional AHP is criticized for its unbalanced scale of judgment and failure to precisely handle the inherent uncertainty and vagueness in carrying out pair-wise comparisons. In order to address this drawback, we utilize triangular fuzzy numbers [9], [10] for pair-wise comparisons and utilize the extent analysis method [11], [12] for the synthetic extent value of the fuzzy pair-wise comparisons and principle of comparison of fuzzy numbers to derive the weight vectors.

Linguistic Values and Triangular Fuzzy Numbers

When dealing with factors with uncertain or imprecise values, people use linguistic values like “high”, “low”, “good”, “medium”, etc., to describe those factors. The fuzzy set theory is primarily concerned with quantifying vagueness in human perceptions and thoughts. The transition from vagueness to quantification is performed by the application of fuzzy set theory as shown in figure 1. A triangular fuzzy number (TFN) is a fuzzy set with three parameters (l, m, u), each representing a quantity of a linguistic value associated with a degree of membership of either 0 or 1. The parameters l, m, u denote the smallest possible, most promising and the largest possible quantity that describes the linguistic value.

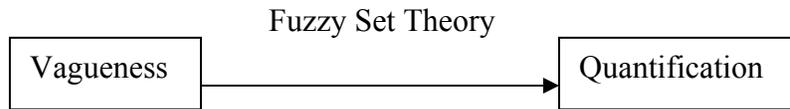


Figure 1

Extent Analysis Method to derive weight vectors

In the first step, triangular fuzzy numbers are used for pair-wise comparisons. Then, by using extent analysis method [11], [12] the synthetic extent value S_i of the pair-wise comparison is introduced and by applying the principle of the comparison of fuzzy numbers, the weight vectors with respect to each element under a certain criterion is calculated. The details of the methodology are presented in the following steps:

Let $X = \{x_1, x_2, \dots, x_n\}$ be an object set, and $U = \{u_1, u_2, \dots, u_m\}$ be a goal set. According to the method of Chang’s extent analysis, each object is taken and an extent analysis for each goal, g_i , is performed. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$M^1_{g_i}, M^2_{g_i}, \dots, M^m_{g_i}, i=1,2,\dots,n$, where all the $M^j_{g_i} (j=1,2,\dots,m)$ are TFN’s.

Step 1: The value of fuzzy synthetic extent with respect to the i th object is defined as

$$S_i = \sum_{j=1}^m M^j_{g_i} \otimes \left\{ \sum_{i=1}^n \sum_{j=1}^m M^j_{g_i} \right\}^{-1} \quad (1)$$

In order to obtain $\sum_{j=1}^m M^j_{g_i}$, perform the fuzzy addition operation of m extent analysis values for a particular matrix such

that

$$\sum_{j=1}^m M^j_{g_i} = \left(\sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j \right) \quad (2)$$

To obtain $\left\{ \sum_{i=1}^n \sum_{j=1}^m M^j_{g_i} \right\}^{-1}$, perform the fuzzy addition operation of $M^j_{g_i} (j=1,2,\dots,m)$ values such that

$$\sum_{i=1}^n \sum_{j=1}^m M^j_{g_i} = \left(\sum_{i=1}^n l_i, \sum_{i=1}^n m_i, \sum_{i=1}^n u_i \right) \quad (3)$$

and then compute the inverse of the vector.

Step 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is expressed as:
 $V(M_2 \geq M_1) = \text{hgt}(M_1 \geq M_2) = \{1, \text{ if } m_2 \geq m_1, 0, \text{ if } l_1 \geq u_2, (l_1 - u_2) / ((m_2 - u_2) - (m_1 - l_1))\}$ (4)
 To compare M_1 and M_2 both $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$ are required.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i ($i=1,2,\dots, k$) can be defined as:
 $V(M \geq M_1, M_2, \dots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \dots \text{ and } (M \geq M_k)]$
 $= \min V(M \geq M_i), i=1,2,\dots, k$ (5)

Let $d'(A_i) = \min V(S_i \geq S_k)$, for $k = 1,2,\dots,n; k \neq i$. Then the weight vector is given by:
 $W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T$ (6)

Step 4: The weight vector obtained in step 3 is normalized to get the normalized weights.

3. SELECTION OF EFFICIENT RECOVERY FACILITIES

We frame the problem of identifying efficient production facilities in a closed-loop supply chain as a four level hierarchy (figure 2). The first level contains the objective of evaluation of each available facility, the second level consists of the main criteria for evaluating the facilities, the third level contains the sub-criteria under each main criteria and the fourth level contains the different facilities available. We use a similar hierarchical structure and criteria/sub-criteria that was earlier detailed and used by Pochampally and Gupta [13].

Illustrative Example

Tables 1 and 2 show the linguistic weight conversion TFN's for the main criteria and sub-criteria and recovery facilities respectively.

Table 1. Linguistic Weight Conversion Table for Criteria and Sub-Criteria

Linguistic Weight	TFN
Very High (VH)	(0.7, 0.9, 1.0)
High (H)	(0.5, 0.7, 0.9)
Medium (M)	(0.3, 0.5, 0.7)
Low (L)	(0.1, 0.3, 0.5)
Very Low (VL)	(0.0, 0.1, 0.3)

Table 2. Linguistic Weight Conversion Table for Recovery Facilities

Linguistic Weight	TFN
Very Good (VG)	(7, 10, 10)
Good (G)	(5, 7, 10)
Fair (F)	(2, 5, 8)
Poor (P)	(1, 3, 5)
Very Poor (VP)	(1, 1, 3)

Table 3 shows the normalized weight vectors of the main criteria obtained after carrying out pair-wise comparisons among them and applying the steps of extent analysis method described above.

Table 3. Weights of Main Criteria

Criteria	Weight
ECD	0.008351847
ECM	0.093393234
AMT	0.158907973
POT	0.22579517
COS	0.253366077
CSE	0.260185699

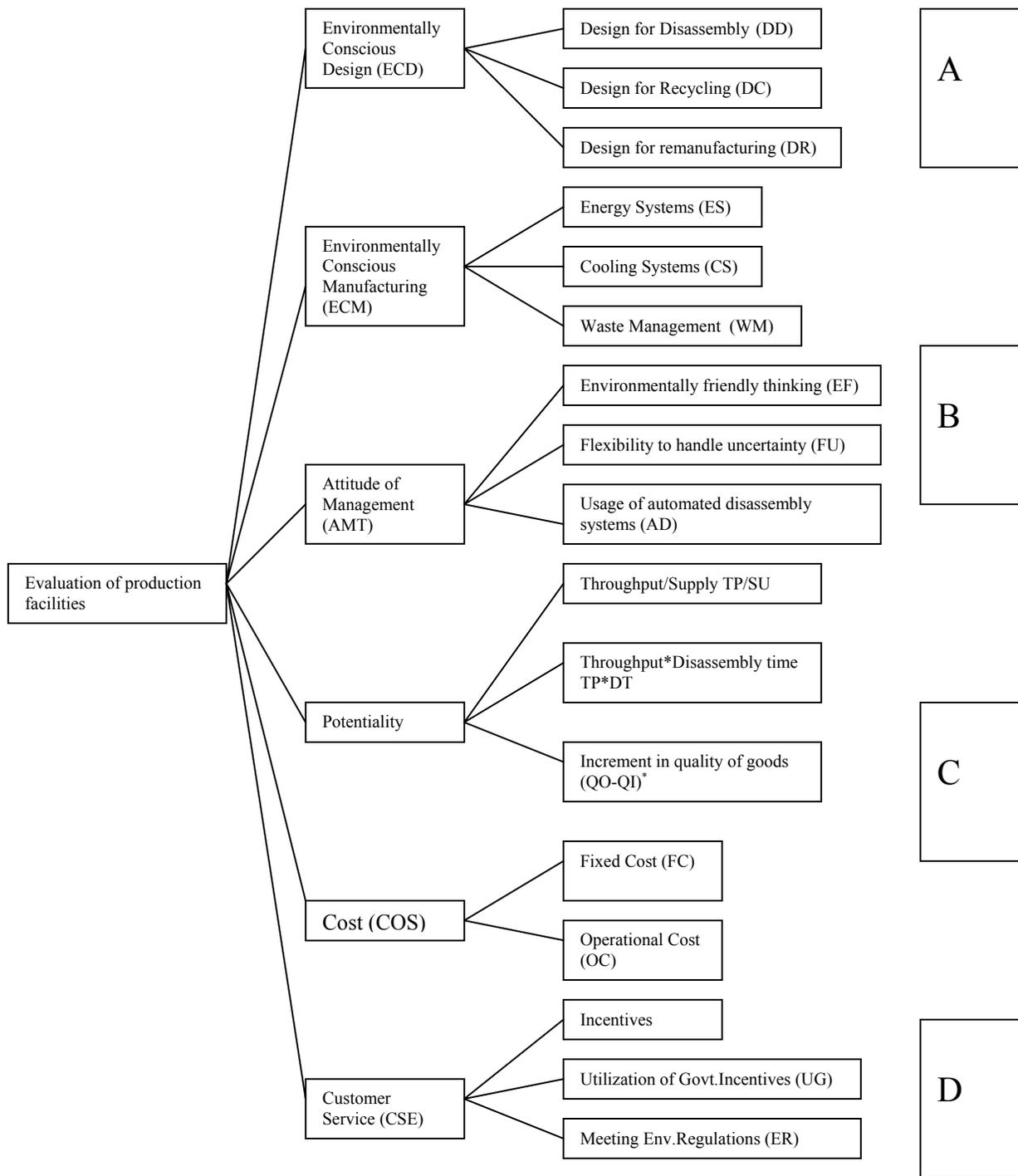


Figure 2. Levels of Hierarchy

Table 4 shows normalized weight vectors of each sub-criteria with respect to its main criteria obtained after carrying out pair-wise comparisons among them and applying the steps of extent analysis method described above. For pair-wise

comparison, the question asked to the decision maker is ‘what is the relative impact of sub-criteria a on main criteria X compared to sub-criteria b in evaluating each available production facility?’

Table 4. Weights of Sub-Criteria with respect to Main Criteria

Sub-Criteria	Weight
DD	0.365181452
DC	0.332675525
DR	0.302143023
ES	0.05687219
CS	0.29054319
WM	0.65258462
EF	0.06678159
FU	0.33525506
AD	0.59796335
TP/SU	0.13614722
TP*DT	0.33686398
QO-QI	0.5269888
FC	0.12134932
OC	0.87865068
Incentives	0.09669799
UG	0.47671802
ER	0.426584

Similarly, pair-wise comparisons are carried out between the decision alternatives with respect to sub-criteria and main criteria. Tables 5 and 6 show the resulting normalized weight vectors.

Table 5. Weights of Alternatives with respect to Sub-criteria

Sub-Criteria	A	B	C	D
DD	0.263028215	0.25637619	0.241718731	0.238876864
DC	0.263695249	0.250633282	0.241695093	0.243976375
DR	0.263028215	0.25637619	0.241718731	0.238876864
ES	0.25956884	0.256182303	0.240613325	0.243635531
CS	0.257930031	0.253614435	0.24647209	0.241983444
WM	0.25956884	0.256182303	0.240613325	0.243635531
EF	0.259720696	0.250784065	0.246232019	0.24326322
FU	0.262650151	0.256492921	0.228013024	0.252843903
AD	0.259720696	0.250784065	0.246232019	0.24326322
TP/SU	0.259140373	0.252511572	0.249839508	0.238508547
TP*DT	0.251069599	0.269977124	0.243457646	0.235495631
QO-QI	0.259140373	0.252511572	0.249839508	0.238508547
FC	0.263038183	0.233644102	0.255567969	0.247749745
OC	0.263038183	0.233644102	0.255567969	0.247749745
Incentives	0.258579582	0.251015757	0.250905462	0.239499199
UG	0.264945605	0.24701762	0.238842536	0.249194239
ER	0.258579582	0.251015757	0.250905462	0.239499199

Table 6. Weights of Alternatives with respect to Main Criteria

Main criteria	A	B	C	D
ECD	0.263250121	0.254465665	0.241710867	0.240573347
ECM	0.259092695	0.255436227	0.24231555	0.243155529
AMT	0.260702811	0.252697988	0.240124009	0.246475193
POT	0.25642162	0.258395087	0.247689689	0.237493604
COS	0.263038183	0.233644102	0.255567969	0.247749745
CSE	0.26161438	0.249109773	0.245154848	0.244121

Multiplying the matrix obtained in table 6 with the normalized weight vectors obtained in table 3, we get the normalized ranks for the recovery facilities: Rank_A = 0.26; Rank_B = 0.248; Rank_C = 0.245; Rank_D = 0.242. Facility A's overall weighted index is the largest; hence, the decision maker would choose facility A.

4. CONCLUSIONS

In this paper, in order to address the drawbacks that traditional AHP faces due to its unbalanced scale of judgments and inability to handle inherent uncertainty in carrying out pair-wise comparisons, we employ a fuzzy AHP based approach for selecting potential recovery facilities in the strategic planning of a CLSC. This methodology utilizes triangular fuzzy numbers for pair-wise comparisons and the extent analysis method for the synthetic extent value of the fuzzy pair-wise comparisons and principle of comparison of fuzzy numbers to derive the weight vectors. We illustrated our methodology with a numerical example.

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