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MULTI-CRITERIA ANALYSIS OF POTENTIAL RECOVERY FACILITIES IN A REVERSE SUPPLY CHAIN

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ABSTRACT

Analytic Hierarchy Process (AHP) has been employed by researchers for solving multi-criteria analysis problems. However, AHP is often criticized for its unbalanced scale of judgments and failure to precisely handle the inherent uncertainty and vagueness in carrying out the pair-wise comparisons. With an objective to address these drawbacks, in this paper, we employ a fuzzy approach in selecting potential recovery facilities in the strategic planning of a reverse supply chain network that addresses the decision maker's level of confidence in the fuzzy assessments and his/her attitude towards risk. A numerical example is considered to illustrate the methodology.

Keywords: Reverse supply chain, strategic planning, fuzzy AHP, Fuzzy numbers, Multi-Criteria 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.

For a Reverse Supply Chain (RSC) 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 RSC. 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] 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 this criticism that AHP often faces, in this paper, we employ a fuzzy approach in selecting potential recovery facilities in the strategic planning of a reverse supply chain. This approach addresses issues such as decision maker's confidence in the fuzzy assessments and his/her attitude towards risk, which, traditional AHP does not address.

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 the concept of fuzzy extent analysis is applied to solve the fuzzy reciprocal matrix for determining the criteria importance and alternative performance. The α -cut concept [11] is used to transform the fuzzy performance matrix representing the overall performance of all alternatives with respect to each criterion into an interval performance matrix. An overall performance index for each alternative across all criteria that incorporates the decision maker's attitude towards risk is obtained by applying the concept of similarity to the ideal solution [12] using the vector matching function.

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 (a, b, c), each representing a quantity of a linguistic value associated with a degree of membership of either 0 or 1. The parameters a, b, c denote the smallest possible, most promising and the largest possible quantity that describes the linguistic value.

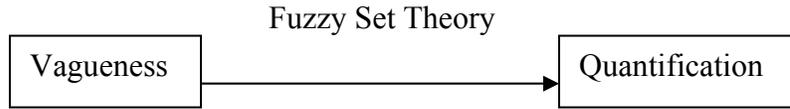


Figure 1

Steps involved in the Fuzzy AHP process

The alternative selection process starts with determining the criteria of importance and alternative performance. By using triangular fuzzy numbers, a fuzzy reciprocal matrix for criteria importance (W) or alternative performance with respect to a specific criterion (C_j) can be determined as

$$W \text{ or } C_j = \begin{bmatrix} \overline{a_{11}} & \overline{a_{12}} & \dots & \overline{a_{1k}} \\ \overline{a_{21}} & \overline{a_{22}} & \dots & \overline{a_{2k}} \\ \dots & \dots & \dots & \dots \\ \overline{a_{k1}} & \overline{a_{k2}} & \dots & \overline{a_{kk}} \end{bmatrix} \quad (1)$$

Where

$$\overline{a_{ls}} = \begin{cases} 1, 3, 5, 9, l < s, \\ 1, l = s, l, s = 1, 2, \dots, k; k = m, \text{ or } n, \\ 1/\overline{a_{sl}}, l > s, \end{cases} \quad (2)$$

By applying fuzzy extent analysis on (1), the corresponding criteria weights (w_j) or alternative performance ratings (x_{ij}) with respect to a specific criterion C_j can be determined as

$$x_{ij} \text{ or } w_j = \frac{\sum_{s=1}^k \overline{a_{ls}}}{\sum_{l=1}^k \sum_{s=1}^k \overline{a_{ls}}} \quad (3)$$

where $i=1, 2, \dots, n; j=1, 2, \dots, m$ and $k=m$ or n depending on whether the reciprocal judgment matrix is for assessing the performance ratings of alternatives or weights of criteria involved.

The decision matrix (X) and the weight vector (W) can be respectively determined as

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (4)$$

$$W = (w_1, w_2, \dots, w_m) \quad (5)$$

where x_{ij} represents the resultant fuzzy performance assessment of alternative $A_i (i = 1, 2, \dots, n)$ with respect to criterion C_j and w_j is the resultant fuzzy weight of criterion $C_j (j = 1, 2, \dots, m)$ with respect to the overall goal of the problem.

A fuzzy performance matrix Z representing the overall performance of all alternatives with respect to each criterion is obtained by multiplying the weight vector by the decision matrix. The arithmetic operation on fuzzy numbers is based on [13].

$$Z = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \dots & w_m x_{1m} \\ w_1 x_{21} & w_2 x_{22} & \dots & w_m x_{2m} \\ \dots & \dots & \dots & \dots \\ w_1 x_{n1} & w_2 x_{n2} & \dots & w_m x_{nm} \end{bmatrix} \quad (6)$$

An interval performance matrix (7) is derived by using a α -cut on the performance matrix (6), where $0 \leq \alpha \leq 1$. The value of α represents the decision maker's degree of confidence in his/her fuzzy assessments regarding the alternative ratings and criteria weights. The larger the value of α , the more confident the decision maker is about the fuzzy assessments i.e., the assessments are closer to the most possible value a_2 of the triangular fuzzy number (a_1, a_2, a_3) .

$$Z_\alpha = \begin{bmatrix} [z_{11l}^\alpha, z_{11r}^\alpha] & [z_{12l}^\alpha, z_{12r}^\alpha] & \dots & [z_{1ml}^\alpha, z_{1mr}^\alpha] \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ [z_{n1l}^\alpha, z_{n1r}^\alpha] & [z_{n2l}^\alpha, z_{n2r}^\alpha] & \dots & [z_{nm1}^\alpha, z_{nmr}^\alpha] \end{bmatrix} \quad (7)$$

An overall crisp performance matrix (8) that incorporates the decision maker's attitude towards risk, using an optimism index λ ($\lambda = 1$ implies the decision maker has an optimistic view, 0 implies a pessimistic view and 0.5 implies a moderate view), is calculated, where $z_{ij\alpha}^\lambda = \lambda z_{ijr}^\alpha + (1 - \lambda) z_{ijl}^\alpha, \lambda \in [0, 1]$.

$$z_\alpha^\lambda = \begin{bmatrix} z_{11\alpha}^\lambda & z_{12\alpha}^\lambda & \dots & z_{1m\alpha}^\lambda \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ z_{n1\alpha}^\lambda & z_{n2\alpha}^\lambda & \dots & z_{nm\alpha}^\lambda \end{bmatrix} \quad (8)$$

A normalized performance matrix (10) with respect to each criterion is calculated from (8) by using (9):

$$z_{ij\alpha}^\lambda = z_{ij\alpha}^\lambda \div \sqrt{\sum_{i=1}^n (z_{ij\alpha}^\lambda)^2} \quad (9)$$

$$Z_\alpha = \begin{bmatrix} z_{11\alpha}^\lambda & z_{12\alpha}^\lambda & \dots & z_{1m\alpha}^\lambda \\ z_{21\alpha}^\lambda & z_{22\alpha}^\lambda & \dots & z_{2m\alpha}^\lambda \\ \dots & \dots & \dots & \dots \\ z_{n1\alpha}^\lambda & z_{n2\alpha}^\lambda & \dots & z_{nm\alpha}^\lambda \end{bmatrix} \quad (10)$$

Zeleny [12] introduced the concept of ideal solution in multi-attribute decision analysis that was further extended by Hwang and Yoon [14] including negative solution to avoid the worst decision outcome. In line with this concept, the positive and negative ideal solutions $A_{\alpha}^{\lambda+}$, $A_{\alpha}^{\lambda-}$ can be determined by selecting maximum and minimum value across all alternatives with respect to each criterion by (11).

$$A_{\alpha}^{\lambda+} = (z_{1\alpha}^{\lambda+}, z_{2\alpha}^{\lambda+}, \dots, z_{m\alpha}^{\lambda+}) \quad (11)$$

$$A_{\alpha}^{\lambda-} = (z_{1\alpha}^{\lambda-}, z_{2\alpha}^{\lambda-}, \dots, z_{m\alpha}^{\lambda-})$$

where

$$z_{j\alpha}^{\lambda+} = \max(z_{1j\alpha}^{\lambda}, z_{2j\alpha}^{\lambda}, \dots, z_{nj\alpha}^{\lambda}), \quad (12)$$

$$z_{j\alpha}^{\lambda-} = \min(z_{1j\alpha}^{\lambda}, z_{2j\alpha}^{\lambda}, \dots, z_{nj\alpha}^{\lambda})$$

By applying the vector matching function, the degree of similarity between each alternative and the positive and negative ideal solutions can be calculated, respectively as:

$$S_{i\alpha}^{\lambda+} = A_{i\alpha}^{\lambda} A_{\alpha}^{\lambda+} / \max(A_{i\alpha}^{\lambda} A_{i\alpha}^{\lambda}, A_{\alpha}^{\lambda+} A_{\alpha}^{\lambda+}) \quad (13)$$

$$S_{i\alpha}^{\lambda-} = A_{i\alpha}^{\lambda} A_{\alpha}^{\lambda-} / \max(A_{i\alpha}^{\lambda} A_{i\alpha}^{\lambda}, A_{\alpha}^{\lambda-} A_{\alpha}^{\lambda-})$$

where $A_{i\alpha}^{\lambda} = (z_{i1\alpha}^{\lambda}, z_{i2\alpha}^{\lambda}, \dots, z_{im\alpha}^{\lambda})$ is the i th row of the overall performance matrix in (10) that represents the corresponding performance of alternative A_i ($i \in \{1, 2, \dots, n\}$) with respect to criterion C_j ($j = 1, 2, \dots, m$). The larger the value of $S_{i\alpha}^{\lambda+}$, $S_{i\alpha}^{\lambda-}$, the higher the degree of similarity between each alternative and the positive ideal and negative ideal solution [15].

A preferred alternative should have a higher degree of similarity to the positive ideal solution and a lower degree of similarity to the negative ideal solution. Hence, an overall performance index for each alternative with the decision maker's α level of confidence and λ degree of optimism towards risk can be determined as:

$$P_{i\alpha}^{\lambda} = S_{i\alpha}^{\lambda+} / (S_{i\alpha}^{\lambda+} + S_{i\alpha}^{\lambda-}), i = 1, 2, \dots, n. \quad (14)$$

The larger the performance index, the most preferred the alternative.

3. SELECTION OF POTENTIAL RECOVERY FACILITIES

We frame the problem of identifying potential recovery facilities in a reverse supply chain by extending the three level hierarchical structure that was earlier detailed and used by Pochampally and Gupta [16] to 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.

Illustrative Example

For brevity purpose, we show only few calculation results.

Table 1 shows the normalized weight vectors of the main criteria obtained after carrying out pair-wise comparisons among them and applying the steps of fuzzy AHP method described above.

Table 1. Triangular Fuzzy Weights of Main Criteria

Criteria			
CO	0.159203	0.371862649	0.774805358
CS	0.108258	0.231740492	0.540015856
QO-QI	0.09861	0.217368988	0.472933141
TP/SU	0.067342	0.136683262	0.297623646
DT*TP	0.018633	0.042344608	0.126786331

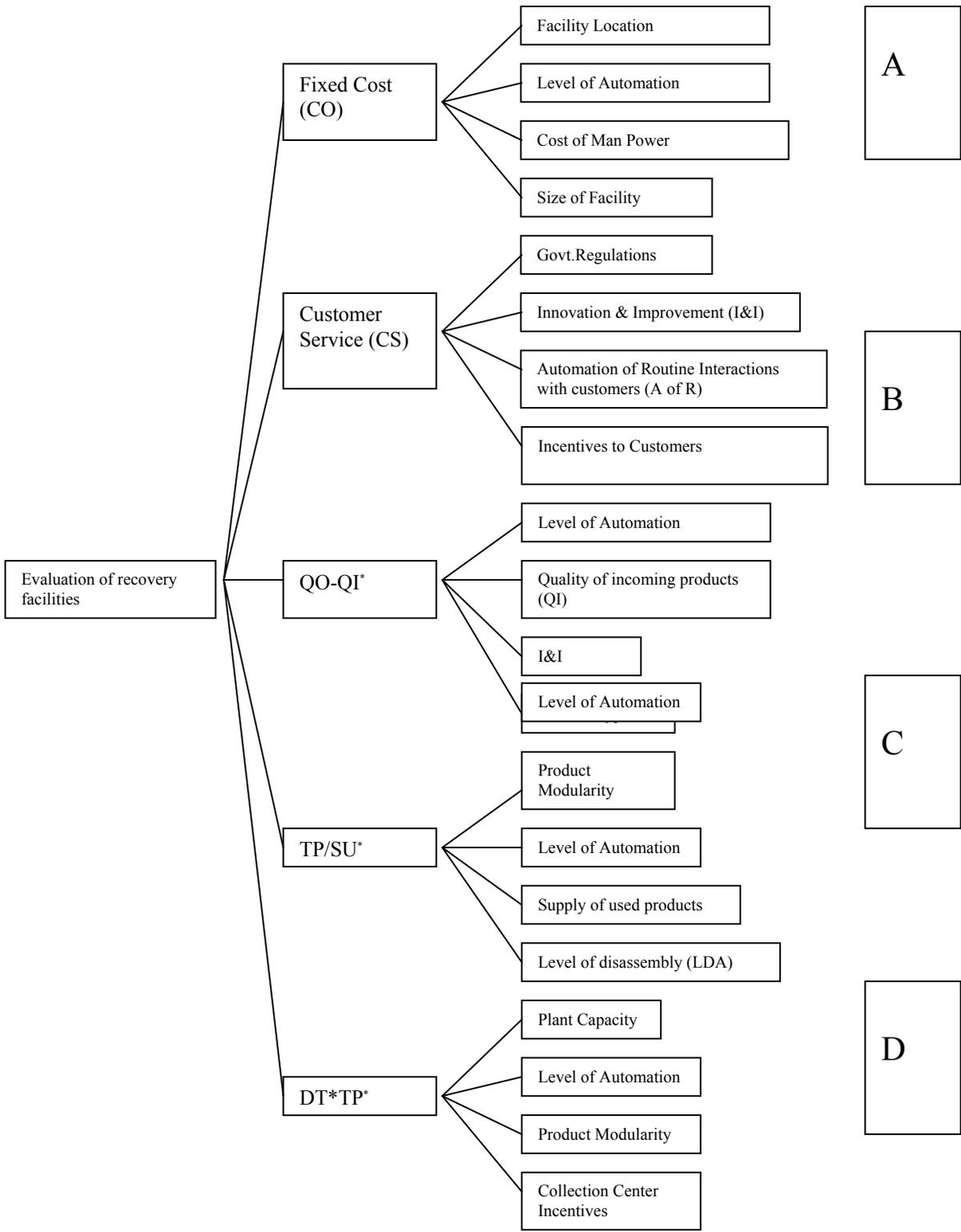


Figure 2

Table 2 shows the fuzzy reciprocal judgment matrix (W).

Table 2. Triangular Fuzzy Reciprocal Judgment Matrix (W)

Criteria/Sub-Criteria			
CO Cluster			
Location	0.021107	0.132851	0.63530906
Automation	0.029398	0.144238	0.61605727
Man Power Cost	0.016597	0.080132	0.37953528
Size of Facility	0.003685	0.014641	0.11166038
CS Cluster			
Govt Reg	0.017402	0.090149126	0.450031252
I&I	0.015911	0.074373029	0.362525175
Incentives	0.014518	0.059348175	0.287519967
A of R	0.002285	0.007870162	0.066433185
QO-QI Cluster			
Automation	0.019039	0.083273	0.36718439
QI	0.017597	0.078647	0.32347196
Prod.Type	0.010275	0.047882	0.20399133
I&I	0.002134	0.007567	0.05624332
TP/SU Cluster			
Capacity	0.013694	0.065923282	0.310924837
Automation	0.008217	0.041507251	0.215255656
Modularity	0.004855	0.023230109	0.125964421
CC Incentives	0.001636	0.006022621	0.053529184
DT*TP Cluster			
Modularity	0.003061	0.017256	0.11330329
Automation	0.002186	0.012079	0.08183016
Supply Used Prod(SU)	0.002544	0.011298	0.07175875
Level of DA (LDA)	0.000429	0.001712	0.0205025

Table 3 shows the normalized performance matrix.

Tables 4 and 5 show the positive and negative ideal solutions with respect to each criterion/sub-criterion.

Table 6 shows the overall performance index for each alternative at α level of confidence in the fuzzy assessments and λ degree of optimism towards risk.

Alternative C's overall performance index is the largest; hence, the decision maker would choose facility C.

4. CONCLUSIONS

Selecting potential recovery facilities is a critical step in the strategic planning of a reverse supply chain network. In the past, researchers employed AHP for such multi-criteria decision analysis problems. However, traditional AHP is often criticized for its unbalanced scale of judgments and inability to handle inherent uncertainty in carrying out pair-wise comparisons. In order to address these drawbacks, in this paper, we employed a fuzzy approach to traditional AHP in selecting potential recovery facilities in the strategic planning of a reverse supply chain network. This approach addressed issues such as decision maker's confidence in the fuzzy assessments and his/her attitude towards risk, which, traditional AHP does not address. We illustrated the methodology with a numerical example.

Table 3. Normalized Performance Matrix

Criteria/Sub-Criteria	A	B	C	D
CO Cluster				
Location	0.615573	0.576267	0.475426	0.250909
Automation	0.619471	0.594539	0.442666	0.258508
Man Power Cost	0.637795	0.588866	0.428002	0.251531
Size of Facility	0.583876	0.591948	0.501666	0.238783
CS Cluster				
Govt Reg	0.56034492	0.51760188	0.35683496	0.24091641
I&I	0.55867177	0.50361118	0.37920224	0.25230449
Incentives	0.5623508	0.52020229	0.37358467	0.22646131
A of R	0.56144962	0.48487866	0.34440124	0.23307286
QO-QI Cluster				
Automation	0.653242305	0.564537376	0.437127461	0.251975445
QI	0.640657629	0.557690811	0.474052841	0.231975573
Prod.Type	0.634163796	0.572450988	0.463340336	0.235482225
I&I	0.650158583	0.575515604	0.425101437	0.255664576
TP/SU Cluster				
Capacity	0.619530863	0.594393076	0.442737728	0.258576266
Automation	0.57823569	0.602241829	0.497016362	0.236480448
Modularity	0.625306076	0.571804849	0.47343126	0.240612484
CC Incentives	0.636255413	0.576674599	0.44368119	0.256461414
DT*TP Cluster				
Modularity	0.641705487	0.554466352	0.473204232	0.238451017
Automation	0.636266147	0.576525602	0.443799159	0.256565639
Supply of Used Prod(SU)	0.620864724	0.544754723	0.506487702	0.247466147
Level of DA (LDA)	0.636284896	0.576264259	0.444005975	0.256748376

*QO-QI = Quality of outgoing products – Quality of incoming

*TP/SU = Throughput / Supply of used products

*DT*TP = Disassembly time * Throughput

Table 4. Positive Ideal Solutions

Alternative	Degree of similarity to positive ideal solution
A	0.997465185
B	0.913373162
C	0.717705709
D	0.399118427

Table 5. Negative Ideal Solutions

Alternative	Degree of similarity to negative ideal solution
A	2.48400167
B	2.273606101
C	1.753054565
D	1

Table 6. Overall Performance Indices

Alternative	Overall Performance Index
A	0.286507
B	0.286595
C	0.29048
D	0.285264

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