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Selection of Collection Centers and Recovery Facilities for Designing a Reverse Supply Chain

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ABSTRACT

The designing of a reverse supply chain must involve selection of collection centers and recovery facilities that have sufficient success potentials. These success potentials depend heavily on the participation of the following three important groups who have multiple, conflicting, and incommensurate criteria for evaluation, and so, the potentials must be evaluated based on the maximized consensus among those groups: (i) Consumers (whose primary concern is convenience), (ii) Local government officials (whose primary concern is environmental consciousness), and (iii) Supply chain company executives (whose primary concern is profit). In this paper, we propose a three-phase multi-criteria group approach to select collection centers as well as recovery facilities, of sufficient success potentials. In the first phase of the approach, we identify important criteria for evaluation of the alternatives (collection centers as well as recovery facilities) by each of the above three groups. In the second phase, we give weights to the criteria of each group using the eigen vector method, and then, employ the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) to find the success potential of each alternative, as evaluated by that group. Then, in the third and final phase, we use Borda's choice rule that, for each alternative, combines individual success potentials into a group success potential.

Keywords: reverse supply chain; strategic planning; group decision-making; Borda's choice rule; TOPSIS.

1. MOTIVATION

A reverse supply chain, which is the series of activities required to retrieve used products discarded by consumers and either recover the products' left-over market values or dispose them of, utilizes at least the following [7]: collection centers (where consumers discard used products), recovery facilities (where re-processing, viz., disassembly, remanufacturing and/or recycling are performed), and demand centers (where re-processed goods are sold). Obviously, for a prospective reverse supply chain to operate efficiently, the strategic planning (designing) of that chain must involve selection of collection centers and recovery facilities that have sufficient success potentials. These success potentials depend heavily on the participation (in the reverse supply chain) of three important groups who have multiple, conflicting, and incommensurate goals. Therefore the potentials must be evaluated based on the maximized consensus among the three groups as follows:

i. Consumers whose primary concern is *convenience*,
ii. Local government officials whose primary concern is *environmental consciousness*, and
iii. Supply chain company executives whose primary concern is *profit*.

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In this paper, we propose a three-phase multi-criteria group approach to select collection centers as well as recovery facilities, of sufficient success potentials. In the first phase of the approach, we identify important criteria for evaluation of the alternatives (collection centers as well as recovery facilities) by each of the above three groups. In the second phase, using the eigen vector method [12], we give weights to the criteria identified for each group, and then, employ the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [5] to find the success potential of each alternative, as evaluated by that group. In the third and final phase, we use Borda's choice rule [4] that, for each alternative, combines individual success potentials into a group success potential or maximized consensus ranking.

In the next section, we review a few important papers in the literature, which propose models to design a reverse supply chain. In Section 3, we briefly introduce the techniques, viz., the eigen vector method, the TOPSIS, and the Borda's choice rule, which are used in our approach to select collection centers and recovery facilities of sufficient success potentials. Section 4 presents the approach to select collection centers, and Section 5 presents the approach to select recovery facilities. Finally, Section 6 gives some conclusions.

2. LITERATURE REVIEW

Many papers in the literature propose how to design a reverse supply chain (for a good review, see [2]). However, every paper assumes that all the recovery facilities that are engaged in the supply chain are profited by re-processing economical used products, and also that these facilities have sufficient potential to efficiently re-process the incoming used products. Motivated by the risk of re-processing uneconomical used products in recovery facilities of insufficient potentiality, Pochampally and Gupta [7], [10] proposed an approach that employs linear programming to select economical used products for re-processing in a reverse supply chain and Analytic Hierarchy Process (AHP) [12] to identify potential recovery facilities operating in a region where that supply chain is to be designed. Furthermore, realizing the increasing enforcement of environmental consciousness by governmental regulations [3], and the developing practice of collection and re-processing of used products being carried out by the same parties that are involved in a forward supply chain (the series of activities required to produce new products from raw material), they developed an integrated approach to design a closed-loop supply chain. To that end, they formulated a fuzzy [14] cost-benefit function that can be used to perform a multi-criteria economic analysis to select economical products to process in the closed-loop supply chain [9], and proposed a fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) approach [1] to identify efficient production facilities in a region where that closed-loop supply chain is to be designed, in terms of both environmental consciousness (mainly associated with the forward supply chain) and potentiality (mainly associated with the reverse supply chain) [8].

Despite all of the papers cited above, there is no paper in the literature, which proposes how to identify collection centers of sufficient success potentials. Moreover, no one has ever looked at the problem of evaluating recovery facilities based upon the consensus among the important groups involved, viz., the consumers, local government officials, and the supply chain company executives. This paper attempts to fill both the voids.

3. TECHNIQUES USED IN THIS PAPER

In this section, we briefly review the techniques that we use in our approach to identify collection centers and recovery facilities of sufficient success potentials.

3.1. Eigen vector method

Eigen vector method was developed by Saaty [12] in the context of the Analytic Hierarchy Process (AHP). This method, supported by simple mathematics, enables decision makers to explicitly weigh tangible and intangible criteria against each other for the purpose of resolving conflict or setting priorities. In a large number of cases (for example, [11]), the tangible and intangible criteria are considered independent of each other, i.e., those criteria do not depend on sub-criteria and so on. The eigen vector method in such cases enables to make pair-wise judgments of importance between independent criteria with respect to the scale shown in Table 1. The normalized eigen vector of the resulting matrix of comparative importance values gives the relative weights assigned to the criteria.

The degrees of consistency of the pair-wise judgments are measured using an index called the Consistency Ratio (*CR*). Perfect consistency implies a value of zero for *CR*. However, perfect consistency cannot be demanded since, as human beings, we are often biased and inconsistent in our subjective judgments. Therefore, it is considered acceptable if *CR* is less than or equal to 0.1. For *CR* values greater than 0.1, the pair-wise judgments must be revised before the weights of criteria are computed. *CR* is computed using the formula:

$$CR = \frac{(\lambda \max - n)}{(n-1)(R)} \tag{1}$$

where λmax is the principal eigen value of the matrix of comparative importance values; *n* is the number of rows (or columns) in the matrix; *R* is the Random Index for each *n* value that is greater than or equal to one. Table 2 shows various *R* values for *n* values ranging from 1 to 10.

Table 1. Scale for pair-wise judgments

Comparative Importance	Definition
1	Equally important
3	Moderately more important
5	Strongly important
7	Very strongly more important
9	Extremely more important
2, 4, 6, 8	Intermediate judgment values

Table 2. Random Index value for each *n* value

n	1	2	3	4	5	6	7	8	9	10
R	0	0	0.58	0.90	1.12	1.24	0.32	1.41	1.45	1.49

3.2. TOPSIS

The basic concept of the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method [5] is that the rank of the alternative selected as the best from a set of different alternatives, should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution in a geometrical (i.e., Euclidean) sense.

The TOPSIS method evaluates the following decision matrix, which refers to *m* alternatives that are evaluated in terms of *n* criteria:

	Criteria				
	C_1	C_2	C_3	…..	C_n
Alternatives	w_1	w_2	w_3	……..	w_n
A_1	z_{11}	z_{12}	z_{13}	……..	z_{1n}
A_2	z_{21}	z_{22}	z_{23}	……..	z_{2n}
A_3	z_{31}	z_{32}	z_{33}	……..	z_{3n}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
A_m	z_{m1}	z_{m2}	z_{m3}	…….	z_{mn}

where A_i is the *i*th alternative, C_j is the *j*th criterion, w_j is the weight assigned to the *j*th criterion, and z_{ij} is the performance measure of the *i*th alternative in terms of the *j*th criterion.

The following steps are performed:

Step 1: *Construct the normalized decision matrix*. This step converts the various dimensional measures of performance into non-dimensional attributes. An element r_{ij} of the normalized decision matrix *R* is calculated as follows:

$$r_{ij} = \frac{z_{ij}}{\sqrt{\sum_{i=1}^{m} z_{ij}^2}} \tag{2}$$

Step 2: *Construct the weighted normalized decision matrix*. A set of weights $W = (w_1, w_2, \ldots w_n)$ (such that $\sum w_j = 1$), specified by the decision-maker, is used in conjunction with the normalized decision matrix R to determine the weighted normalized matrix V defined by $V = (v_{ij}) = (r_{ij} w_j)$.

Step 3: *Determine the ideal and the negative-ideal solutions*. The ideal (A*) and the negative-ideal (A-) solutions are defined as follows:

$$A^* = \{\min_i v_{ij} \quad \text{for } i = 1, 2, 3, \ldots\ldots, m\} \tag{3}$$

$$= \{p_1, p_2, p_3, \ldots\ldots, p_n\}$$

$$A- = \{\max_i v_{ij} \quad \text{for } i = 1, 2, 3, \ldots\ldots, m\} \tag{4}$$

$$= \{q_1, q_2, q_3, \ldots\ldots, q_n\}$$

With respect to each criterion, the decision maker desires to choose the alternative with the minimum rank (it is important to note that this choice varies with the way he awards ranks to the alternatives). Obviously, A* indicates the most preferable (ideal) solution. Similarly, A- indicates the least preferable (negative-ideal) solution.

Step 4: *Calculate the separation distances*. In this step, the concept of the n-dimensional Euclidean distance is used to measure the separation distances of the rank of each alternative from the ideal solution and the negative-ideal solution. The corresponding formulae are

$$S_{i*} = \sqrt{\sum (v_{ij} - p_j)^2} \quad \text{for } i = 1, 2, 3, \ldots, m \tag{5}$$

where S_{i*} is the separation (in the Euclidean sense) of the rank of alternative i from the ideal solution, and

$$S_{i-} = \sqrt{\sum (v_{ij} - q_j)^2} \quad \text{for } i = 1, 2, 3, \ldots, m \tag{6}$$

where S_{i-} is the separation (in the Euclidean sense) of the rank of alternative i from the negative-ideal solution.

Step 5: *Calculate the relative closeness coefficient*. The relative closeness coefficient for alternative A_i with respect to the ideal solution A* is defined as follows:

$$C_{i*} = \frac{S_{i-}}{S_{i*} + S_{i-}} \tag{7}$$

Step 6: *Form the preference order*. The best alternative can now be decided according to preference order of C_{i*}. It is the one with the rank that has the shortest distance to the ideal solution. The way the alternatives are processed in the previous steps reveals that if an alternative has the rank with the shortest distance to the ideal solution, then that rank is guaranteed to have the longest distance to the negative-ideal solution. That means, the higher the C_{i*}, the better the alternative.

3.3. Borda's choice rule

In this method, marks of m-1, m-2, ……., 1, 0 are assigned to the best, second-best, ……, worst alternatives, for each decision maker (group, in our case) [4]. That means that a larger mark corresponds to higher preference. Borda score (maximized consensus mark) for each alternative is then determined as the sum of the individual marks for that alternative. Then the alternative with the highest Borda score is declared the winner. That means that the different decision makers unanimously choose the alternative that obtains the largest Borda score as the most preferred one.

4. SELECTION OF COLLECTION CENTERS

In this section, we present our approach to select collection centers of sufficient success potentials, using a numerical example. Three collection centers, C1, C2, and C3 are considered for evaluation.

4.1. Phase I of the approach to select collection centers

We consider the following sets of criteria for the three groups, for evaluating each of the collection centers:

4.1.1. *Consumers*

- Incentives from collection center (IC) (higher incentives imply higher motivation to participate)
- Proximity to the residential area (PH) (higher proximity implies more motivation to participate)
- Proximity to roads (PR) (higher proximity implies more motivation to participate)
- Simplicity of the collection process (SP) (simpler process implies more motivation to participate)
- Employment opportunity (EO) (the more the better)
- Salary (SA) (the higher the better)

4.1.2. *Local government officials*

- Proximity to residential area (PH) (higher proximity implies greater collection and hence lower disposal)
- Proximity to roads (PR) (higher proximity implies greater collection and hence lower disposal)

4.1.3. *Supply chain company executives*

- Per capita income of the people in the residential area (PI) (the higher it is, the more the number of "resourceful" discarded products, and the less the people will care about the incentives from the collection center)
- Space cost (SC) (the lower the better)
- Labor cost (LC) (the lower the better)
- Utilization of incentives from local government (UI) (the higher the better)
- Proximity to residential area (PH) (higher proximity implies greater collection and hence greater profit)
- Proximity to roads (PR) (higher proximity implies greater collection and hence greater profit)
- Incentives from local government (IG) (higher incentives from local government imply higher incentives to consumers)

4.2. Phase II of the approach to select collection centers

Tables 3, 4 and 5 show the pair-wise comparison matrices as formed by the consumers, the local government officials, and the supply chain company executives respectively.

Table 3. Pair-wise comparison matrix formed by consumers for collection centers

Criteria	IC	PH	PR	SP	EO	SA
IC	1	1	1	2	1/2	1
PH	1	1	2	1	1	1/2
PR	1	1/2	1	1	1/7	1/2
SP	1/2	1	1	1	1	1
EO	2	1	7	1	1	1
SA	1	2	2	1	1	1

Table 4. Pair-wise comparison matrix formed by local government officials for collection centers

Criterion	PH	PR
PH	1	2
PR	1/2	1

Table 5. Pair-wise comparison matrix formed by supply chain company executives for collection centers

Criteria	PI	SC	LC	UI	PH	PR	IG
PI	1	2	4	6	8	9	4
SC	1/2	1	2	6	8	9	1
LC	1/4	1/2	1	1	1	1	1
UI	1/6	1/6	1	1	1	1	1
PH	1/8	1/8	1	1	1	1	1
PR	1/9	1/9	1	1	1	1	1
IG	1/4	1	1	1	1	1	1

Tables 6, 7 and 8 show the relative weights given by the consumers, the local government officials, and the supply chain company executives respectively to the respective criteria for evaluation. These sets of weights, calculated using the eigen vector method, are the elements of the normalized eigen vectors of pair-wise comparison matrices shown in Tables 3, 4, and 5, respectively. For example, the relative weights of the criteria, PH (proximity to residential area) and PR (proximity to roads) shown in Table 7 are the elements of the normalized eigen vector of the pair-wise comparison matrix in Table 4.

Table 6. Relative weights given by consumers to criteria for evaluation of collection centers

Criteria for evaluation	Relative weights
IC	0.1621
PH	0.1515
PR	0.0960
SP	0.1434
EO	0.2533
SA	0.1938

Table 7. Relative weights given by local government officials to criteria for evaluation of collection centers

Criteria for evaluation	Relative weights
PH	0.6667
PR	0.3333

Table 8. Relative weights given by supply chain company executives to criteria for evaluation of collection centers

Criteria for evaluation	Relative weights
PI	0.3876
SC	0.2599
LC	0.0781
UI	0.0634
PH	0.0598
PR	0.0585
IG	0.0927

The decision matrices formed by the consumers, the local government officials, and the supply chain company executives, for implementation of the TOPSIS for each group, are shown in Tables 9, 10, and 11 respectively. The elements of these matrices are the ranks (ranging from 1 to 10) assigned to the collection centers with respect to each criterion for evaluation. A lower rank implies higher success potential (with respect to that criterion).

Table 9. Decision matrix formed by the consumers for collection centers

	IC	PH	PR	SP	EO	SA
C1	8	1	6	2	2	3
C2	2	1	7	3	2	3
C3	3	2	4	1	1	5

Table 10. Decision matrix formed by the local government officials for collection centers

	PH	PR
C1	2	1
C2	2	1
C3	3	2

Table 11. Decision matrix formed by the supply chain company executives for collection centers

	PI	SC	LC	UI	PH	PR	IG
C1	1	3	2	1	3	4	3
C2	2	4	7	1	2	2	2
C3	10	9	8	7	5	1	6

Now, we are ready to perform the six steps in TOPSIS for each group. The following steps show the implementation of TOPSIS for the consumers, to evaluate C1, C2, and C3:

Step 1: *Construct the normalized decision matrix*. Table 12 shows the normalized decision matrix formed by applying Equation 2 on each element of Table 9 (decision matrix formed by the consumers). For example, the normalized rank of collection center, C2, with respect to criterion, PH (see Tables 9 and 12), is calculated using Equation 2 as follows:

$$r_{22} = \frac{1}{\sqrt{1^2 + 1^2 + 2^2}} = 0.4082.$$

Table 12. Normalized decision matrix formed by consumers for collection centers

	IC	PH	PR	SP	EO	SA
C1	0.9117	0.4082	0.5970	0.5345	0.6667	0.4575
C2	0.2279	0.4082	0.6965	0.8018	0.6667	0.4575
C3	0.3419	0.8165	0.3980	0.2673	0.3333	0.7625

Step 2: *Construct the weighted normalized decision matrix*. Table 13 shows the weighted normalized decision matrix for the consumers. This is constructed using the relative weights of the criteria listed in Table 6 and the normalized decision matrix in Table 12. For example, the weighted normalized rank of collection center, C2, with respect to criterion, PH, i.e., 0.0619 (see Table 13), is calculated by multiplying the relative weight of PH, i.e., 0.1515 (see Table 6) with the normalized rank of C2 with respect to PH, i.e., 0.4082 (see Table 12).

Table 13. Weighted normalized decision matrix formed by consumers for collection centers

	IC	PH	PR	SP	EO	SA
C1	0.1478	0.0619	0.0573	0.0767	0.1689	0.0887
C2	0.0370	0.0619	0.0669	0.1150	0.1689	0.0887
C3	0.0554	0.1237	0.0382	0.0383	0.0844	0.1478

Step 3: *Determine the ideal and the negative-deal solutions.* Each column in the weighted normalized decision matrix shown in Table 13 has a minimum rank (found using Equation 3) and a maximum rank (found using Equation 4). They are the ideal and the negative-ideal solutions respectively, for the corresponding criterion. For example (see Table 13), with respect to criterion, PH, the ideal solution (minimum rank) is 0.0619, and the negative-ideal solution (maximum rank) is 0.1237.

Step 4: *Calculate the separation distances.* The separation distances (see Table 14) for each collection center, are calculated using Equations 5 and 6. For example, the positive separation distance for collection center, C2 (see Table 14), is calculated using Equation 5 that contains the weighted normalized ranks of C2 (see Table 13) and the ideal solutions (obtained in step 3) for the criteria.

Table 14. Separation distances calculated by consumers for collection centers

	S*	**S-**
C1	0.1458	0.0942
C2	0.1176	0.1400
C3	0.0875	0.1495

Step 5: *Calculate the relative closeness coefficient.* Using Equation 7, we calculate the relative closeness coefficient for each collection center (see Table 15). For example, relative closeness coefficient (i.e., 0.5435) for collection center C2 (see Table 15) is the ratio of C2's negative separation distance (i.e., 0.1400) to the sum (i.e., 0.1400 + 0.1176 = 0.2576) of its negative and positive separation distances (see Table 14).

Table 15. Relative closeness coefficients calculated by consumers for collection centers

	C*
C1	0.3926
C2	0.5435
C3	0.6308

Step 6: *Form the preference order*. Since the best alternative is the one with the highest relative closeness coefficient, the preference order for the collection centers is C3, C2, and C1 (that means, C3 is the best collection center, as evaluated by the consumers).

The TOPSIS is implemented for the local government officials and the supply chain company executives as well. The relative closeness coefficients of the collection centers, as calculated by those two groups, are shown in Table 16.

Table 16. Relative closeness coefficients calculated by local govt. and supply chain company for collection centers

	Local govt.	**Supply chain company**
C1	1.000	0.902
C2	1.000	0.851
C3	0.739	0.091

4.3. Phase III of the approach to select collection centers

Table 17 shows the marks of the collection centers as given using Borda's choice rule for the consumers, the local government officials, and the supply chain company executives. Borda scores (group success potentials) calculated for C1, C2, and C3 (viz., 3, 5, and 3, respectively) are also shown. For example, Borda score for C2 (i.e., 5) is calculated by summing the marks of C2 for the consumers, the local government officials, and the supply chain company executives (i.e., 1 + 2 + 2). Since C2 has the highest Borda score, it is the best of the lot.

Table 17. Marks and Borda scores of collection centers

	Consumers	Local govt.	Supply chain company	Borda score
C1	0	2	1	**3**
C2	1	2	2	**5**
C3	2	1	0	**3**

5. SELECTION OF RECOVERY FACILITIES

In this section, we present only the first phase of our approach to select recovery facilities of sufficient success potentials because the remaining two phases are similar to the ones (viz., implementation of the TOPSIS and the Borda's choice rule) presented for collection centers.

5.1. Phase I of the approach to select recovery facilities

We consider the following sets of criteria for the three groups, for evaluating each of the recovery facilities:

5.1.1. *Criteria of consumers*

- Proximity to surface water (PS) (lower proximity implies more suitability, i.e., less hazardous)
- Proximity to residential area (PH) (lower proximity implies more suitability, i.e., less hazardous)
- Employment opportunity (EO) (the more the better)
- Salary (the higher the better) (SA)

5.1.2. *Criteria of local government officials*

- Proximity to surface water (PS) (lower proximity implies more suitability, i.e., less hazardous)
- Proximity to residential area (PH) (lower proximity implies more suitability, i.e., less hazardous)

5.1.3. *Criteria of supply chain company executives*

- Space cost (SC) (the lower the better)
- Labor cost (LC) (the lower the better)
- Proximity to roads (PR) (higher proximity implies easier transportation)
- Quality of re-processed products (QO) – Quality of used-products (QI) (the higher the better)
- Throughput (TP) /Supply (SU) (the higher the better)
- Throughput (TP) * Disassembly time (DT) (the higher the better)
- Utilization of incentives from local government (UI) (the higher the better)
- Pollution control (PC) (the higher the better)

Unlike in a forward supply chain, components of incoming goods (used-products) of even the same type in a recovery facility are likely to be of varied quality (worn-out, low-performing, etc). Though the average quality of re-processed goods (QO) is a criterion that can evaluate a recovery facility, it is not justified to use QO as an independent criterion for evaluation because QO depends on average quality of incoming products (QI). However, QI must not be taken as an independent criterion too because it cannot evaluate the recovery facility. So, the idea is to take the difference between QO and QI as a criterion for evaluation [7].

The only driver to design a forward supply chain is the demand for new products and so if there is low demand for new products, there is practically no forward supply chain. However, this is not the case in some reverse supply chains where even if there is low supply of used-products (SU), reverse supply chain must be administered due to the possible drivers like environmental regulations and asset recovery. In supply-driven cases like these, it is unfair to judge a recovery

facility without considering SU for evaluation. Though throughput (TP) is a criterion that can evaluate a recovery facility, it is not justified to use TP as an independent criterion because TP depends on SU. However, SU must not be taken as an independent criterion too because it cannot evaluate the recovery facility. Furthermore, a low SU might lead to a low TP and a high SU might lead to a high TP. So, the idea is to take (TP)/(SU) as a criterion for evaluation. Thus, we compensate for the effect of a low TP by dividing TP with a possibly low SU, in order not to underestimate the facility under consideration. Similarly, we dampen the effect of a high TP by dividing TP with a possibly high SU, in order not to overestimate the facility under consideration [10].

Average disassembly time (DT) is not exactly the inverse of TP because TP takes into account the whole re-processing (disassembly plus recovery) time. Unlike in a forward supply chain, components of incoming goods (used-products) in a recovery facility are likely to be deformed and/or broken and/or different in number even for the same type of products. Hence, incoming products of the same type might have different re-processing times, unlike in a forward supply chain where manufacturing time and assembly time are pre-determined and equal for products of the same type. Since TP of a recovery facility depends upon the DT, it is unfair to not consider DT for evaluation. However, DT must not be taken as an independent criterion because it cannot evaluate the recovery facility. Furthermore, a high DT might lead to a low TP and a low DT might lead to a high TP. So, the idea is to take (TP)*(DT) as a criterion for evaluation. Thus, we compensate for the effect of a low TP by multiplying TP with a possibly high DT, in order not to underestimate the facility under consideration. Similarly, we dampen the effect of a high TP by multiplying TP with a possibly low DT, in order not to overestimate the facility under consideration [7].

6. CONCLUSIONS

In this paper, we proposed a three-phase multi-criteria group approach to selecting collection centers as well as recovery facilities, of sufficient success potentials. In the first phase of the approach, we identified important criteria for evaluation of the alternatives (collection centers or recovery facilities) by three groups, viz., consumers, local government officials, and supply chain company executives, who have multiple, conflicting, and incommensurate criteria for evaluation. In the second phase, we gave weights to the criteria of each group using the eigen vector method, and then, employed the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) to find the success potential of each alternative, as evaluated by that group. Then, in the third and final phase, we used Borda's choice rule that, for each alternative, combined individual success potentials into a group success potential.

REFERENCES

1. Chu, T. C., "Selecting plant location via a fuzzy TOPSIS approach," *The International Journal of Advanced Manufacturing Technology*, Vol. 20, 859-864, 2002.
2. Fleischmann, M., *Quantititative Models for Reverse Logistics: Lecture Notes in Economics and Mathematical Systems*, Springer-Verlag, Germany, 2001.
3. Gungor, A. and Gupta, S. M., "Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey," *Computers and Industrial Engineering*, Vol. 36, No. 4, 811-853, 1999.
4. Hwang, C. L., *Group Decision Making Under Multi-criteria: Methods and Applications*, Springer-Verlag, New York, 1987.
5. Hwang, C. L. and Yoon, K., *Multiple attribute decision making methods and application*, Springer-Verlag, 1981.
6. Kim, C. W. and Mauborgne, R., "Charting your company's future," *Harvard Business Review*, June, 77-82, 2002.
7. Pochampally, K. K. and Gupta, S. M., "A multi-phase mathematical programming approach to strategic planning of an efficient reverse supply chain network," *Proceedings of the IEEE International Symposium on the Electronics and the Environment*, 72-78, 2003.
8. Pochampally, K. K., Gupta, S. M. and Kamarthi, S. V., "Evaluation of production facilities in a closed-loop supply chain: A fuzzy TOPSIS approach," *Proceedings of the SPIE International Conference on Environmentally Conscious Manufacturing (CD-ROM)*, 2003.
9. Pochampally, K. K., Gupta, S. M. and Cullinane, T. P., "A fuzzy cost-benefit function to select economical used products for re-processing," *Proceedings of the SPIE International Conference on Environmentally Conscious Manufacturing (CD-ROM)*, 2003.

10. Pochampally, K. K., Gupta, S. M. and Kamarthi, S. V., "Identification of potential recovery facilities for effective strategic planning of an efficient reverse distribution network," *Proceedings of the 2003 Northeast Decision Sciences Institute Conference*, 160-162, 2003.
11. Prakash, G. P., Ganesh, L. S. and Rajendran, C., "Criticality analysis of spare parts using the analytic hierarchy process," *International Journal of Production Economics*, Vol. 35, No. 1 – 3, 293-297, 1994.
12. Saaty, T. L., *The Analytic Hierarchy Process*, McGraw-Hill, New York, 1980.
13. Triantaphyllou, E. and Lin, C., "Development and evaluation of five fuzzy multi-attribute decision-making methods," *International Journal of Approximate Reasoning*, Vol. 14, 281-310, 1996.
14. Zadeh, L. A., "Fuzzy Sets," *Information and Control*, Vol. 8, 338-353, 1965.