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A Business-Mapping Approach to Multi-Criteria Group Selection of Collection Centers and Recovery Facilities

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Abstract

For a prospective reverse supply chain to operate efficiently, the 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 that have multiple, conflicting, and incommensurate goals. Therefore, the potentials must be evaluated based on the maximized consensus among the three groups, viz., (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) for 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 or maximized consensus ranking. We also employ a GIS-based application, MapLand, to "map" the results obtained in the second and the third phases of our approach.

MOTIVATION

A reverse supply chain (see Figure 1), which is a 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 [4]: collection centers (where consumers discard used products), recovery facilities (where disassembly, remanufacturing and/or recycling operations are performed), and demand centers (where recovered 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 that 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*.

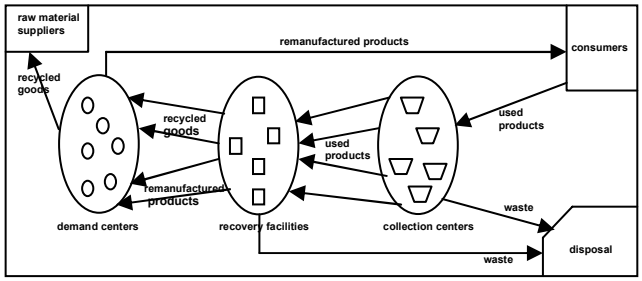

Figure 1. Generic Reverse Supply Chain

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 [7], 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. Then, in the third and final phase, we use Borda's choice rule [2] that, for each alternative, combines individual success potentials into a group success potential or maximized consensus ranking. Furthermore, motivated by a recent paper [3] that addresses the necessity for building the strategic planning process "around a picture", to make the chairman of the concerned supply chain company easily understand the "dense documents filled with numbers" and to convince him that it is important to implement the proposed action (selection of particular collection centers as well as particular recovery facilities, in our case), in this paper, we use a GIS-based business-mapping application, MapLand [8], to "map" the results obtained in the second and the third phases of our approach.

LITERATURE REVIEW

Many papers in the literature propose how to design a reverse supply chain (for a good review, see [1]). Since every paper assumes that all the facilities that are engaged in the reverse supply chain are profited by re-processing (remanufacturing and/or recycling) economical used products, and also that the facilities have sufficient potential to efficiently re-process the incoming used products, the authors of this paper, motivated by the risk of re-processing uneconomical used products in facilities of insufficient potentiality, proposed an approach [4] that employs linear programming to select economical used products for re-processing in a reverse supply chain and Analytic Hierarchy Process (AHP) [7] 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, 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), the authors developed an integrated approach to design a closed-loop supply chain. To that end, they formulated a fuzzy cost-benefit function [6] that is used to perform a multi-criteria economic analysis for selecting economical products to process in a closed-loop supply chain, and proposed a fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) approach [5] 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).

Despite all 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 on the consensus among all the important participators involved, viz., consumers, local government officials, and supply chain company executives, who often have multiple, conflicting and incommensurate goals. This paper attempts to fill both the voids.

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.

Eigen Vector Method

Eigen vector method is [7] is supported by simple mathematics, and 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, the tangible and intangible criteria are considered independent of each other, i.e., those criteria do not depend upon 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.

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

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; see [7]).

Table 2. Random Index Values for Various *n* Values

n	1	2	3	4	5	6	7	8	9	10
R	0	0	0.6	0.9	1.1	1.2	0.3	1.4	1.5	1.5

TOPSIS

The basic concept of the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [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				
Alternatives	C_1 w_1	C_2 w_2	C_3 w_3	…… ……	C_n 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 ith alternative, C_j is the jth criterion, w_j is the weight assigned to the jth criterion, and z_{ij} is the rank (for example, on a scale of 1-10, the lower the rank, the better it is) of the ith alternative in terms of the jth 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:

$$A^* = \left\{\min_i v_{ij} \quad \text{for } i = 1, 2, 3, \ldots, m\right\} \quad \text{for } i = 1, 2, \ldots, m$$
$$= \{p_1, p_2, p_3, \ldots, p_n\} \tag{3}$$

$$A- = \left\{\max_i v_{ij} \quad \text{for } i = 1, 2, 3, \ldots, m\right\} \quad \text{for } i = 1, 2, \ldots, m$$
$$= \{q_1, q_2, q_3, \ldots, q_n\} \tag{4}$$

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.

Borda's Choice Rule

Borda [2] proposed a method in which 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). That means that higher marks correspond to higher preference. Borda score (maximized consensus marks) 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.

Besides the above techniques, in this paper, a GIS-based business mapping application, MapLand [8] is used to "map" the results obtained in the second and the third phases of our approach.

SELECTION OF COLLECTION CENTERS

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

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:

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)

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)

Supply Chain Company Executives

- Per capital income of the people in the residential area (PI) (the higher it is, the more the number of "resourceful" used 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)

Phase-II of the Approach to Select Collection Centers

Table 3 shows the pair-wise comparison matrix as formed by the consumers. Pair-wise comparison matrices for the local government officials and the supply chain company executives are not shown due to the space constraint.

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 shows the relative weights given by the consumers to their criteria for evaluation. These weights are calculated using the Eigen vector method. Relative weights given by the local government officials and the supply chain company executives are not shown.

Table 4. Relative Weights Given by Consumers to the 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

The decision matrix formed by the consumers is shown in Table 5. 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). The decision matrices for the local government officials and the supply chain company executives are not shown. Using Equations 2 through 7, the relative closeness coefficients of the collection centers are calculated for the consumers, the local government officials, and the supply chain company executives, and are shown in Table 6.

Table 5. Decision Matrix Formed by Consumers for Collection Centers

Collection Center	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 6. Relative Closeness Coefficients of Collection Centers

Group	Consumers	Local govt.	Supply chain
C1	0.3926	1.000	0.902
C2	0.5435	1.000	0.851
C3	0.6308	0.739	0.091

Figure 2 shows the mapping classification, as created using MapLand, for relative closeness coefficients. Figures 3, 4, and 5 show the mapping of the relative closeness coefficients of each collection center, as calculated for the consumers, the local government officials, and the supply chain company executives, respectively. While creating Figures 3 through 5, it is assumed that each collection center is in one of the three regions, and the three regions are mapped with respect to the relative closeness coefficients of the corresponding collection centers. The darker the region is, the higher success potential the corresponding collection center has.

Phase-III of the Approach to Select Collection Centers

Table 7 shows the ranks of the collection centers as ranked by Borda's choice rule. Borda score for C1, C2, and C3 are 3, 5, and 3 respectively. Figure 6 shows the mapping classification, as created using MapLand, for Borda score. Also, Figure 7 shows the mapping of the Borda score of each collection center. It is obvious that C2 is the one with the highest success potential.

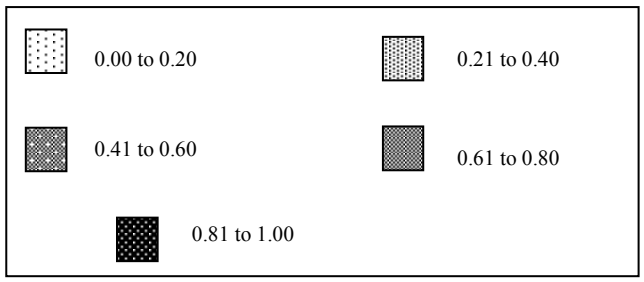

Figure 2. Relative Closeness Mapping Classification

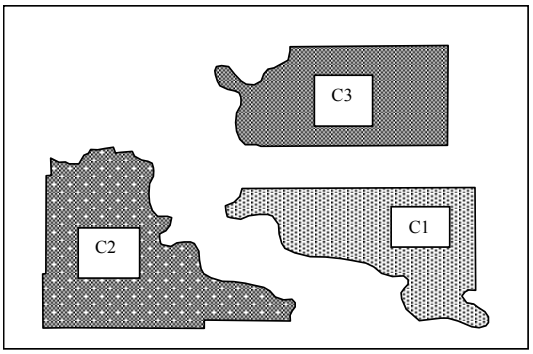

Figure 3. Mapping of Collection Centers with Respect to Consumers

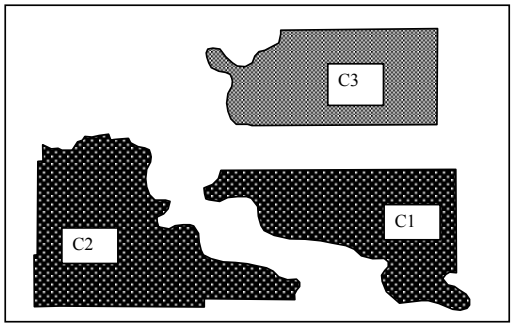

Figure 4. Mapping of Collection Centers with Respect to Local Govt. Officials

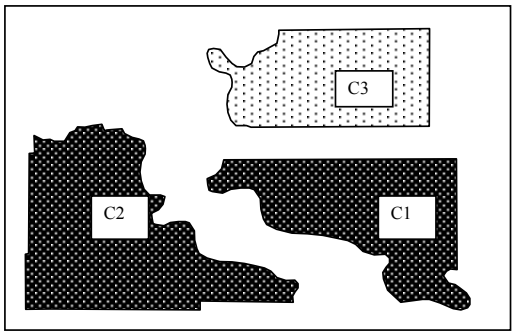

Figure 5. Mapping of Collection Centers with Respect to Supply Chain Company Executives

Table 7. Ranks Given to Collection Centers by Borda's Choice Rule

Group	Consumers	Local govt.	Supply chain
C1	0	2	1
C2	1	2	2
C3	2	1	0

SELECTION OF RECOVERY FACILITIES

In this section, due to the space constraint, we only present phase-I of the approach to select recovery facilities. Phases II and III are similar to the ones for selection of collection centers.

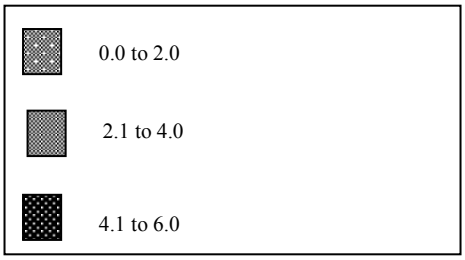

Figure 6. Borda Score Mapping Classification

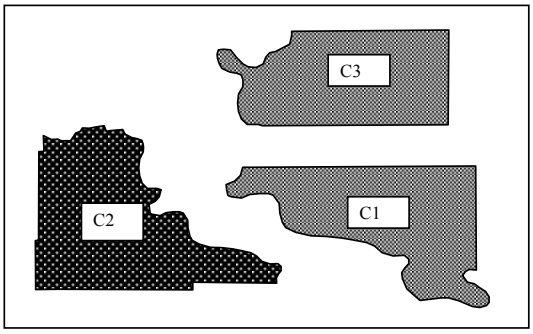

Figure 7. Mapping of Collection Centers with Respect to Borda Score

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 of interest:

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)

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)

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.

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.

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.

CONCLUSIONS

In this paper, we proposed a three-phase approach to select collection centers as well as recovery facilities, of sufficient success potentials. In the first phase of the approach, we identified criteria for evaluation of the alternatives (collection centers and recovery facilities), for each group participating in the reverse supply chain. In the second phase, we gave weights to the criteria of each group using the Eigen vector method, and then, employed the TOPSIS 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 to combine individual success potentials of each alternative into a maximized consensus ranking.

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