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A TAGUCHI LOSS APPROACH TO SELECTION OF COLLECTION CENTERS FOR REVERSE SUPPLY CHAIN DESIGN

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ABSTRACT

Many a supply chain today is involved in reprocessing of used products, which requires a series of activities that are performed by multiple parties, viz., collection centers, recovery facilities, etc. Such a supply chain is called reverse supply chain. In this paper, we propose a three-phase approach for the selection of efficient collection centers in a region where a reverse supply chain is to be designed. The first phase identifies the selection criteria, the second phase uses the eigen vector method to give relative weights to the selection criteria, and the third phase uses the Taguchi loss function to select efficient collection centers.

INTRODUCTION

Traditionally, a supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer desire. But, today, many supply chains are no longer limited to fulfilling a customer desire. The reason being that the growing desire of customers to acquire the latest technology, along with the rapid technological development of new products, has led to a new environmental problem: “waste”, consisting of products that are discarded after their useful lives and the products that are discarded prematurely (hereafter, we refer to the “waste” as used products). Reprocessing of used products is essential for saving natural resources, saving energy, saving clean air and water, saving landfill space, and saving money. Besides these motivators, an important driver for companies to engage in reprocessing is the enforcement of environmental regulations by local governments [4].

Reprocessing of used products requires a series of activities (collection, disassembly, recycling, remanufacturing, disposal, etc.) that are performed by multiple parties, viz., collection centers, recovery facilities, etc., known together as a reverse supply chain. In the past decade, there has been an explosive growth of reverse supply chains, both in scope and scale.

Reverse supply chain design is a relatively new area of research, and a few case studies (with application of quantitative models) have been reported in the literature about the same. See Fleischmann’s book [1] for a detailed survey of those case studies.

This paper addresses the selection of efficient collection centers in a region where a reverse supply chain is to be designed.

SELECTION OF COLLECTION CENTERS

We propose a three-phase approach for selection of efficient collection centers in a region where a reverse supply chain is to be designed. The first phase identifies the selection criteria, the second phase uses the eigen vector method [5] to give relative weights to the selection criteria, and the third phase uses the Taguchi loss function [3] to identify efficient collection centers.

Phase – I (Identification of Selection Criteria)

We identify the following criteria for selection of collection centers:

- Process Sigma value (n) (the higher the better)
- Distance from residential area (DH) (lower distance implies higher collection)
- Distance from roads (DR) (lower distance implies higher collection)
- Simplicity of the collection process (SP) (simpler process implies higher collection)
- Per capita income of the people in the residential area (PI) (the higher the per capita income, the higher the left-over value of used products)
- Space cost (SC) (the lower the better)
- Labor cost (LC) (the lower the better)
- Incentives from local government (IG) (higher incentives from local government imply higher incentives to consumers, and hence higher collection)

The Process Sigma value (n) for a collection center represents the center's quality that could be a function of factors such as functionality of used products, efficiency of collection process, efficiency of delivery (to recovery facilities) process, and effectiveness of customer service.

Phase – II (Relative Weights of Selection Criteria)

The eigen vector method [5] begins with 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
2, 4, 6, 8	Intermediate judgment values

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:

$$CR = \frac{(\lambda_{\max} - f)}{(f - 1)I} \quad (1)$$

where λ_{\max} is the principal eigen value of the matrix of comparative importance values; f is the number of rows (or columns) in the matrix; I is the Random Index for each f value that is greater than or equal to one. Table 2 shows various I values for f values ranging from 1 to 10.

Table 2. Random Index Value for Each f Value

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

We consider a numerical example with the pair-wise comparison matrix shown in Table 3, for our selection criteria. For example (see Table 3), per-capita income of the people in the residential area (PI) is given 5 times more importance than the Process Sigma (n) value and 3 times more importance than the simplicity of the collection process (SP).

Table 3. Pair-wise Comparison Matrix

Criteria	n	DH	DR	SP	PI	SC	LC	IG
n	1	1	1	3	1/5	1	1	1
DH	1	1	1	1	1	1	1	1
DR	1	1	1	1	1	1	1	1
SP	1/3	1	1	1	1/3	0.2	1	1
PI	5	1	1	3	1	1	1	1
SC	1	1	1	5	1	1	1	0.2
LC	1	1	1	1	1	1	1	1
IG	1	1	1	1	1	5	1	1

Table 4 shows the relative weights of the respective criteria for selection. These weights are the elements of the normalized eigen vector of pair-wise comparison matrix shown in Table 3.

Table 4. Relative Weights of Selection Criteria

Criteria for selection	Relative weights
n	0.11
DH	0.11
DR	0.11
SP	0.07
PI	0.18
SC	0.15
LC	0.11
IG	0.16

Phase – III (Selection of Efficient Collection Centers)

In traditional systems, the product is accepted if the product measurement falls within the specification limits. Otherwise, the product is rejected. The quality losses occur only when the product deviates beyond the specification limits, thereby becoming unacceptable. These costs tend to be constant and relate to the costs of bringing the product back into the specification range. Taguchi suggests a more narrow view of characteristic acceptability by indicating that any deviation from a characteristic’s target value results in a loss. If a characteristic measurement is the same as the target value, the loss is zero.

Otherwise, the loss can be measured using a quadratic function, after which actions are taken to reduce systematically the variation from the target value. There are three types of Taguchi loss functions: “target is best”, “smaller is better”, and “larger is better”.

If $L(y)$ is the loss associated with a particular value of characteristic y , m is the target value of the specification, and k is the loss coefficient whose value is constant depending on the cost at the specification limits and width of the specification, for the “target is best” type,

$$L(y) = k(y - m)^2 \quad (2)$$

For the “smaller is better” type,

$$L(y) = k(y)^2 \quad (3)$$

For the “larger is better” type,

$$L(y) = k/(y)^2 \quad (4)$$

We now calculate the k value for each of our criteria for selection of collection centers.

Process Sigma (n) value

The loss function that applies to this criterion is “larger is better” (Equation 4). If the decision-maker considers 100% loss for n value less than or equal to 4, then the value of k is 1600%. Then, for a candidate collection center, if $n = 5$, $L(y) = 1600/(5)^2 = 64\%$. That means, with respect to quality (i.e., n value), the collection center is 36% short of the worst performance level (which in this case is “ $n \leq 4$ ”).

Distance from residential area (DH)

We consider DH as the distance of the collection center from the center of gravity [2] of all the residential areas around the center. The loss function that applies to this criterion is “smaller is better” (Equation 3). If the decision-maker considers 100% loss for DH value more than or equal to 4 miles, then the value of k is 6.25%. Then, for a candidate collection center, if $DH = 3$, $L(y) = 6.25 * (3)^2 = 56.25\%$. That means, with respect to the distance from the residential area, the collection center is 43.75% short of the worst case scenario (which in this case is “ $DH \geq 4$ miles”).

Distance from roads (DR)

We consider DR as the average distance of all the roads in the region, from the collection center of interest. The loss function that applies to this criterion is “smaller is better” (Equation 3). If the decision-maker considers 100% loss for DR value more than or equal to 5 miles, then the value of k is 4%. Then, for a candidate collection center, if $DR = 4$, $L(y) = 4 * (4)^2 = 64\%$. That means, with respect to the distance from the roads, the collection center is 36% short of the worst case scenario (which in this case is “ $DR \geq 5$ miles”).

Simplicity of collection process (SP)

Since this is a subjective criterion, the decision-maker can obtain ratings (for example, on a 1 – 10 scale, where 1 is the worst and 10 is the best) of the candidate collection centers, from experts in the field of reverse supply chain. The loss function that applies to this criterion is “larger is better” (Equation 4). If the decision-maker considers 100% loss for SP value less than or equal to 5, then the value of k is 2500%. Then, for a candidate collection center, if $SP = 7$, $L(y) = 2500/(7)^2 = 51.02\%$. That means, with respect to the simplicity of the collection process, the collection center is about 49% short of the worst case scenario (which in this case is “ $SP \leq 5$ ”).

Per capita income (PI)

The loss function that applies to this criterion is “larger is better” (Equation 4). If the decision-maker considers 100% loss for PI value less than or equal to \$30,000 per year, then the value of k is 90,000,000,000%. Then, for a candidate collection center, if $PI = \$50,000$ per year, $L(y) = 90,000,000,000 / (50,000)^2 = 36\%$. That means, with respect to the per-capita income of the people in the residential area, the collection center is 64% short of the worst case scenario (which in this case is “ $PI \leq \$30,000$ per year”).

Space cost (SC)

The loss function that applies to this criterion is “smaller is better” (Equation 3). If the decision-maker considers 100% loss for SC value more than or equal to \$1000 per day, then the value of k is 0.0001%. Then, for a candidate collection center, if $SC = \$800$ per day, $L(y) = 0.0001 * (800)^2 = 64\%$. That means, with respect to the space cost, the collection center is 36% short of the worst case scenario (which in this case is “ $SC \geq \$1000$ per day”).

Labor cost (LC)

The loss function that applies to this criterion is “smaller is better” (Equation 3). If the decision-maker considers 100% loss for LC value more than or equal to \$15 per hour, then the value of k is 0.44%. Then, for a candidate collection center, if $LC = \$10$ per hour, $L(y) = 0.44 * (10)^2 = 44\%$. That means, with respect to the labor cost, the collection center is 56% short of the worst case scenario (which in this case is “ $LC \geq \$15$ per hour”).

Incentives from local government (IG)

Since this is a subjective criterion, the decision-maker can obtain ratings (for example, on a 1 – 10 scale, where 1 is the worst and 10 is the best) of the candidate collection centers, from experts in the field of reverse supply chain. The loss function that applies to this criterion is “larger is better” (Equation 4). If the decision-maker considers 100% loss for IG value less than or equal to 7, then the value of k is 4900%. Then, for a candidate collection center, if $IG = 9$, $L(y) = 4900 / (9)^2 = 60.49\%$. That means, with respect to the incentives from the local government, the collection center is about 39.5% short of the worst case scenario (which in this case is “ $IG \leq 7$ ”).

We consider four candidate collection centers in our numerical example: C1, C2, C3, and C4. Table 5 presents the $L(y)$ for our criteria for each of the collection centers. For example, the Taguchi loss of collection center C2 with respect to the per-capita income of the people in the residential area is 52% (i.e., 48% short of the worst case scenario).

Table 5. $L(y)$ Values (%) of Collection Centers

Criteria	C1	C2	C3	C4
n (0.11)	35	54	40	63
DH (0.11)	25	15	37	55
DR (0.11)	32	10	9	90
SP (0.07)	100	75	64	50
PI (0.18)	65	52	40	50
SC (0.15)	20	10	5	100
LC (0.11)	15	18	20	67
IG (0.16)	78	64	36	41

The weighted-loss of each collection center j is calculated by using the following equation, and is presented in Table 6.

$$\text{Weighted-loss of collection center } j = \sum_i W_i L_{ij} \quad (5)$$

where W_i is the weight of criterion i (see Table 4), and L_{ij} is the Taguchi loss (see Table 5) of collection center j for with respect to criterion i . For example, the weighted-loss of C4 (see Tables 4, 5, and 6) is $0.11*63 + 0.11*55 + \dots + 0.11*67 + 0.16*41 = 64.31$.

Table 6. Weighted-Losses of Collection Centers

Collection Center	Weighted Loss
C1	45.95
C2	37.02
C3	29.85
C4	64.31

The decision-maker will select C3 because it has the lowest weighted-loss.

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