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SUPPLIER SELECTION IN A CLOSED-LOOP SUPPLY CHAIN NETWORK

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INTRODUCTION

The growing interest in reverse logistics has many reasons, of which, consumers and governments concerns for environment being the primary reason. The growing desire of customers to acquire the latest technology, along with the rapid technological development in every industry, has led to a new environmental problem: "waste", consisting of both end-of-life products and used products (products that are discarded prematurely). Increased consumption results in increased use of raw material and energy, thereby depleting the world's finite natural resources. This environmental degradation is not sustainable by the earth's eco-system [1]. This environmental issue, in addition to government regulations is the major driving force for companies to engage in the reverse supply chain activities. Apart from the environmental regulations, reverse supply chains reduce the operating costs by reusing products or components [2].

A reverse supply chain consists of a series of activities required to retrieve a used-product from a consumer and either recover its left over market value or dispose it off. The combination of traditional/forward supply chain and reverse supply chain forms the closed-loop supply chain (CLSC). While this process is mandatory in many European nations, it is still in its infancy in the United States.

PROBLEM ADDRESSED

While many authors address a variety of strategic, tactical and operational planning issues in reverse and closed-loop supply chains (for example see [3], [4], and [5]), the issue of supplier selection has not been addressed thoroughly. Supplier selection is one of the key decisions to be made in the strategic planning of supply chains that has far-reaching implications in the subsequent stages of planning and implementation of the supply chain strategies. In traditional/forward supply chain, the problem of supplier selection is not new. First publications on supplier selection in traditional/forward supply chains date back to the early 1960s [6]. Contrary to a traditional/forward supply chain however, the strategic, tactical and operational planning issues in reverse and closed-loop supply chains involve decision making under uncertainty. A typical supplier selection problem involves selecting the suppliers and assigning the order quantities to those suppliers taking into consideration numerous conflicting constraints. Traditionally, in supply chain literature, the supplier selection problem is treated as an optimization problem that requires formulating a single objective function. However, not all supplier selection criteria can be quantified, because of which, only a few quantitative criteria are included in the problem formulation.

METHODOLOGY

In this paper, we identify the critical criteria that influence the supplier selection problem in a reverse/closed-loop supply chain and develop an integrated multi-criteria decision making methodology using Taguchi loss functions, AHP and Goal programming techniques. While the Taguchi loss functions quantifies the suppliers attributes to quality loss, the AHP transforms these quality losses into a variable for decision making that can be used in formulating the goal programming objective function to determine the order quantities. A numerical example is presented to illustrate the proposed methodology.

Taguchi Loss Functions

According to Taguchi's quality philosophy, any deviation from a characteristic's target value results in a loss that can be measured by a quadratic loss function [7]. Taguchi proposed three types of loss functions: 1) Nominal value is the best, used when there is a finite target point to achieve, 2) Smaller-is-better, used where it is desired to minimize the result, with the ideal target being zero and 3) Higher-is-better, used where it is desired to maximize the result, the ideal target being infinity [8]. The three loss functions are shown in equations (1), (2) and (3) and figures 1, 2, 3 and 4 respectively [9].

$$L(y) = k(y-m)^2 \tag{1}$$

$$L(y) = k(y)^2 \tag{2}$$

$$L(y) = \frac{k}{y^2} \tag{3}$$

where, L(y) is the loss associated with a particular value of quality characteristic y, m is the nominal value and k is the loss coefficient. The quality losses of all the critical criteria for all the suppliers are calculated using the above mentioned loss functions.

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) [10] is a tool, supported by simple mathematics, which enables decision-makers to explicitly weigh tangible and intangible criteria against each other for evaluating different alternatives. The AHP in such cases is conducted in two steps: (1) Weigh independent criteria using pair-wise judgments, (2) Compute the relative ranks of alternatives using pair-wise judgments with respect to each independent criterion.



Ranking the Suppliers

Once the quality losses of all the critical criteria for all the suppliers are calculated using the above mentioned Taguchi loss functions and the weights of all the decision criteria are obtained by the AHP, the total loss of all the criteria to each supplier can be calculated by equation (4):

$$Loss_{j} = \sum_{i=1}^{n} W_{i} X_{ij}$$

$$\tag{4}$$

where, $Loss_j$ is the total loss of supplier *j* for all the critical evaluation criteria, W_i is the weight of criterion *i* calculated by the AHP and X_{ij} is the Taguchi loss of criterion *i* of supplier *j*. Suppliers can be ranked based on the smallest to the largest loss; the best supplier is the one with the smallest loss [9].

Goal Programming

Goal programming (GP), generally applied to linear problems, deals with the achievement of specific targets/goals. This technique was first reported by Chanrnes and Cooper [11], [12] later extended in the 1960s and 1970s by Ijiri [13], Lee [14] and Ignizio [15]. The basic purpose of GP is to simultaneously satisfy several goals relevant to the decision-making situation. To this end, several criteria are to be considered in the problem situation on hand. For each criterion, a target value is determined. Next, the

deviation variables are introduced which may be positive or negative (represented by ρ_k and η_k respectively). The negative deviation variable, η_k , represents the under-achievement of the *k*th goal. Similarly, the positive deviation variable, ρ_k , represents the over-achievement of the *k*th goal. Finally for each criterion, the desire to over-achieve (minimize η_k) or under-achieve (minimize ρ_k), or satisfy the target value exactly (minimize $\rho_k + \eta_k$) is articulated [16].

Procedure to solve the GP model

The following steps are used to solve the GP model:

Step 1: Read in all the relevant data, set the first goal as the current goal.

Step 2: Obtain a linear programming (LP) solution with the current goal as the objective function.

Step 3: If the current goal is the last goal, set it equal to the LP objective function value found in Step 2, STOP. Else, go to Step 4.

Step **4**: If the current goal is just achieved or over-achieved, set it equal to its aspiration level and add this equation to the constraint set, go to Step 5. Else, if the value of the current goal is under-achieved, set the aspiration level of the current goal to the LP objective function value found in Step 2, go to Step 5.

Step 5: Set the next goal as the current goal, go to Step 2.

NUMERICAL EXAMPLE

We consider three suppliers for evaluation. For the qualitative evaluation using Taguchi loss functions and AHP, we consider four criteria: 1) Quality of the products delivered (smaller defective rate is better) 2) On-Time delivery (lesser the delays or early deliveries the better) 3) Proximity (closer the better) and 4) Cultural and Strategic Issues, that include level of cooperation and information exchange, supplier's financial stability/economic performance, supplier's green image, flexibility etc. Table 3 shows the relative weights of the criteria obtained after carrying out steps involved in AHP detailed in the above sections.

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Criteria	Relative Weight
Quality	0.384899
On-Time Delivery	0.137363
Proximity	0.052674
Cultural & Strategic Issues	0.425064

Table 2 shows the decision variables for calculating the Taguchi losses for the suppliers.

Tuble 2. Devision variables for selecting suppliers					
Criteria	Target Value	Range	Specification Limit		
Quality	0%	0-30%	30%		
On-Time Delivery	0	10-0-5	10 days earlier, 5 days delay		
Proximity	Closest	0-40%	40% higher		
Cultural & Strategic Issues	100%	100%-50%	50%		

Table 2. Decision variables for selecting suppliers

To illustrate the calculation of Taguchi losses, consider for example the criteria, Quality. The target defect rate/breakage probability is zero at which there is no loss to the manufacturer and the upper specification limit for the defect rate/breakage probability is 30% at which there is a 100% loss to the manufacturer. Cultural and Strategic issues are hard to quantify. Monczka and Trecha [17] proposed a service factor rating (SFR) that includes performance factors difficult to quantify but are decisive in the supplier selection process. In practice, experts rate these performance factors. The ratings are given on a scale of 1-10, the level of importance being directly proportional to the rating. For a given

supplier, these ratings on all factors are summed and averaged to obtain a total service rating. The supplier's service factor percentage is obtained by dividing the total service rating by the total number of points possible. Column 8 in table 4 shows the service factor percentages of the sub-criteria considered under the Cultural and Strategic issues. We assume a specification limit of 50% for the service factor percentage, at which, the loss will be 100%, while there will be no loss incurred at a service factor percentage of 100%. Computing the value of loss coefficient, k, using appropriate equations (1), (2) or (3) gives a value of 1111.11, 625 and 25 for Quality, Proximity and Cultural and Strategic Issues. For On-Time delivery, $k_1 = 4$ and $k_2 = 1$. Table 3 shows the characteristic value and relative value of each criterion for the three suppliers. For supplier 1, the quality value is 15% defect rate, which translates to 15% deviation from target value. The relative values together with the value of loss coefficient, k, are entered into equations (1), (2) or (3) to compute the Taguchi losses for each supplier. Table 4 shows the Taguchi losses for each criterion calculated from the appropriate loss functions for the individual suppliers.

	Quality		On-Time Delivery		Proximity		Cultural	& Strategic Issues
Supplier	Value	Relative Value	Value	Relative Value	Value	Relative Value	Value	Relative Value
1	15%	15%	+3	+3	8	33.33%	57.5%	57.5%
2	20%	20%	+1	+1	6	0	62.5%	62.5%
3	10%	10&	-8	-8	9	50%	67.5%	67.5%

 Table 3. Characteristic and Relative values of criteria

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Supplier	Quality	On-time Delivery	Proximity	Cultural & Strategic Issues	
1	24.99	36	69.43	75.61	
2	44.44	4	0	64	
3	11.11	64	156.25	54.86	

Table 4. Supplier characteristic Taguchi losses

The weighted Taguchi loss is then calculated using the AHP weights from table 1 and equation (4). Table 5 shows the weighted Taguchi loss and the normalized losses for the individual suppliers.

Table 5. Weighted Taguchi Losses				
Supplier	Weighted Taguchi Loss	Normalized Loss		
1	50.36567	0.360148		
2	44.86013	0.32078		
3	44.62138	0.319072		

Determining the Order Quantities

The second stage of the decision process uses goal-programming technique detailed above. The supplier's normalized losses calculated using the Taguchi loss functions and AHP as detailed above are used in formulating the goal programming objective function in addition to any system constraints present.

We consider two goals in our GP model:

- 1. Minimize the total loss of purchase (TLP)
- 2. Minimize the total cost of purchase (TCP)

It is at the discretion of the decision maker to add any other goals that are considered relevant to the situation to this proposed model.

Nomenclature used in the methodology

 c_j = unit purchasing cost of product from supplier *j*, d_k = demand for product *k*, *g* = goal index, *j* = supplier index, *j* = 1, 2, ..., s, *Loss*_j = total loss of supplier *j* for all the critical evaluation criteria, r_j =

capacity of supplier j, p_j = probability of breakage of products purchased from supplier j, p_{max} = maximum allowable probability of breakage, Q_j = decision variable representing the purchasing quantity from supplier j, s = number of alternate suppliers available, w_i = weight of criterion i calculated by the AHP, X_{ij} = Taguchi loss of criterion i of supplier j.

Goal 1: Minimize TLP:
$$\sum_{j=1}^{s} Loss_j * Q_j$$
 (5)

Goal 2: Minimize TCP:

$$\sum_{j=1}^{s} c_j * Q_j \tag{6}$$

Subject to:

$$Q_i \le r_i; \sum_j Q_j = d_j; d_k * p_{\max} \ge \sum_{j=1}^s Q_j * p_j; \text{ and } Q_j \ge 0$$
 (7)

Table 6 shows the data considered in the numerical example for the second stage of the decisionmaking process.

Table 6. Data for Goal Programming Model

Supplier	1	2	3	
Capacity	300	650	750	
Unit Purchasing Cost	1.2	0.9	1.0	
Breakage Probability	0.03	0.015	0.01	
Net demand for the product $=1000$				
Maximum acceptable breakage probability $= 0.025$				

The goal programming is solved using LINGO-8 and the above data; table 7 shows the results from our methodology.

Table 7. Results			
Supplier	Normalized Taguchi loss	Quantity Ordered	
1	0.360148	0	
2	0.32078	543	
3	0.319072	457	
Total loss of purchase $(TLP) = 320$			
Total cost of purchase $(TCP) = 945.7$			

Supplier 3 is ranked first in terms of minimal Taguchi losses, if there are no other system constraints in place; all 750 units (supplier 3's capacity) may be ordered from supplier 3 before assigning order quantities to other suppliers. However, supplier 3's unit procurement cost is higher compared to supplier 2, whose normalized Taguchi loss is not much different from that of supplier 3. This, in addition to other system constraints in place leads to the results detailed in table 7.

CONCLUSIONS

Traditional supplier selection problems involve formulating a single objective function with the inherent risk of neglecting several critical criteria influencing the supplier evaluation and selection issue that cannot be quantified. To this end, in this paper, we proposed an integrated multi-criteria decision making methodology that used Taguchi loss functions, AHP and goal programming techniques. While the Taguchi loss functions quantifies the suppliers attributes to quality loss, the AHP transforms these quality losses into a variable for decision making that can be used in formulating the goal programming objective function to determine the order quantities. A numerical example was considered to illustrate the proposed methodology.

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