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# Supplier Selection in a Closed-Loop Supply Chain Network: An ANP-Goal Programming Based Methodology

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#### **ABSTRACT**

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, as a result of which, only a few quantitative criteria are included in the problem formulation. To this end, in this paper, we develop an integrated analytic network process (ANP) and preemptive goal programming (PGP) based multi-criteria decision making methodology to address the qualitative and quantitative criteria that influence the supplier selection problem in a closed-loop supply chain network (CLSC). While the ANP methodology aids in determining qualitatively the supply chain strategy by evaluating the suppliers with respect to several criteria, the PGP methodology uses the ANP ratings as inputs and aids in mathematically determining the optimal quantities to be ordered from the suppliers.

Key words: Closed-Loop Supply Chain Network, Analytic Network Process, Goal Programming, Supplier Selection

#### 1. INTRODUCTION

Consumers and governments concerns for environment are driving many original equipment manufacturers (OEM's) to engage in the product take back business. Product take back is a remarkable way of ensuring that products that have reached their end-of-lives are reclaimed for reuse, remanufacturing or recycling [1]. Apart from minimizing environmental degradation and reducing overall resource consumption, product take back offers economic value to manufacturers and consumers [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 of. The combination of traditional/forward supply chain and reverse supply chain forms the closed-loop supply chain (CLSC). Even though this process is still in its infancy in the United States, it is mandatory in many countries in Europe.

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. Supplier selection problem is of paramount importance in the effective management of a CLSC. Many issues downstream that include transportation, facility location are influenced heavily by the proper selection of suppliers. 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. The uncertainty stems from several sources, the quality and timing of availability of the used-products being the major ones. Also, the relative importance of the different selection criteria varies for each supplier. Hence, the issue of supplier selection in reverse/closed-loop supply chains must take into consideration several qualitative and quantitative criteria. 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, as a result of which, only a few quantitative criteria are included in the problem formulation. To this end, in this paper, we develop an integrated analytic network process (ANP) and preemptive goal programming (PGP) based multi-criteria decision making methodology to address the qualitative and quantitative criteria that influence the supplier selection problem in a closed-loop supply chain network. While the ANP methodology aids in determining qualitatively the supply chain strategy by evaluating the suppliers with respect to several criteria, the PGP methodology uses the ANP ratings as inputs and aids in mathematically determining the optimal quantities to be ordered from the suppliers.

#### 2. ANP & GOAL PROGRAMMING

#### **Analytic Network Process**

ANP [7] 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. Analytic Hierarchy Process (AHP) forms the starting point for ANP. AHP assumes independence among the criteria and sub-criteria considered in the decision making, but real life situations warrant against such assumption. ANP provides a more generalized framework for decision making by allowing dependence within a set of criteria (inner-dependence) as well as between sets of criteria (outer-dependence), therefore ANP goes beyond AHP [8]. ANP allows for a more complex relationship among decision levels and attributes as it does not require a strict hierarchical structure while AHP assumes uni-direction hierarchical relationships among the decision levels.

#### Steps Involved in the ANP Methodology

#### **Step 1**. Model development and problem formulation

In this step, the decision problem is structured into its constituent components. The relevant criteria, the sub-criteria, alternatives are chosen and are structured in the form of a control hierarchy as shown in figure 1.

#### Step 2. Pair-wise comparisons

In this step, the decision maker is asked to carry out a series of pair-wise judgments of importance using the scale shown in table 1 where two main criteria are simultaneously compared with respect to the "goal", two sub-criteria are simultaneously compared with respect to their main criteria, pair-wise comparisons to address the interdependencies among the sub-criteria and the pair-wise comparisons for the relative impact of the alternatives on the sub-criteria in influencing the main criteria. The resulting matrix of comparative importance values is used to weigh the criteria, sub-criteria and the alternatives using mathematical techniques like eigen value, mean transformation or row geometric mean. In this paper, we use the eigen value technique.

Table 1. Scale for pair wise judgments

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

#### **Step 3**. Super Matrix Formulation

The super matrix allows for a resolution of interdependencies that exist among the sub-criteria. It is a partitioned matrix where each sub-matrix is composed of a set of relationships between and within the levels as represented by the decision maker's model. The super matrix  $\mathbf{M}$  is made to converge to obtain a long-term stable set of weights. For convergence,  $\mathbf{M}$  must be made 'column stochastic' which is done by rising  $\mathbf{M}$  to the power of  $2^{k+1}$ , where k is an arbitrarily large number.

#### **Step 4**. Selection of the best alternative

The selection of the best alternative depends on the "desirability index". The desirability index,  $D_i$  for alternative i is defined as:

$$D_{i} = \sum_{j=1}^{J} \sum_{k=1}^{K_{j}} P_{j} A_{kj}^{D} A_{kj}^{I} S_{ikj}$$
(1)

where

 $P_i$  is the relative importance weight of main criteria j,

- $A^{D}_{kj}$  is the relative importance weight for sub-criteria k of main criteria j for the dependency (D) relationships between among sub-criteria (pair wise comparisons among sub-criteria),
- $A^{I}_{kj}$  is the stabilized relative importance weight (determined by the super matrix) for sub-criteria k of main criteria j for interdependency (I) relationships among sub-criteria,

 $S_{iki}$  is the relative impact of alternative i on sub-criteria k of main criteria j.

#### **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 [9], [10] later extended in the 1960s and 1970s by Ijiri [11], Lee [12] and Ignizio [13]. 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  $\rho_k$  and  $\eta_k$  respectively). The negative deviation variable,  $\eta_k$ , represents the under-achievement of the kth goal. Similarly, the positive deviation variable,  $\rho_k$ , represents the over-achievement of the kth goal. Finally for each criterion, the desire to over-achieve (minimize  $\eta_k$ ) or under-achieve (minimize  $\rho_k$ ), or satisfy the target value exactly (minimize  $\rho_k$ +  $\eta_k$ ) is articulated [14].

#### 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.

#### 3. SUPPLIER SELECTION METHODOLODY

As stated earlier, we develop an integrated analytic network process (ANP) and preemptive goal programming (PGP) based multi-criteria decision making methodology to address the qualitative and quantitative criteria that influence the supplier selection problem in a closed-loop supply chain network. While the ANP methodology aids in determining qualitatively the supply chain strategy by evaluating the suppliers with respect to several criteria, the PGP methodology uses the ANP ratings as inputs and aids in mathematically determining the optimal quantities to be ordered from the suppliers.

#### Qualitative evaluation of suppliers

We frame the problem of evaluating qualitatively the suppliers as a four level hierarchy (figure 1), the first level contains the objective of evaluation of each available supplier, the second level consists of the main criteria for evaluating the suppliers, the third level contains the sub-criteria under each main criteria and the fourth level contains the different suppliers available. The main and sub-criteria considered in our methodology are self explanatory, see [15], [16], [17], [18], [19], [20] for a detailed explanation.

The first part of our methodology consists of evaluating the suppliers qualitatively for which the steps involved in ANP are carried out for the hierarchical structure proposed and the desirability indices for each supplier are obtained. The supplier with the highest performance index is the best choice. If there are no capacity constraints, the highest ranked supplier is chosen to satisfy all the demand, else, other suppliers need to be considered and the decision process proceeds to the second stage.

#### Quantitative evaluation of suppliers

The second stage of the decision process uses goal programming technique that uses the suppliers performance indices obtained in the first stage as coefficients of the objective function in addition to any capacity and other constraints present.

Nomenclature used in the methodology

 $c_i$  = unit purchasing cost of product from supplier i

 $d_i$  = demand for product j

g = goal index

i = supplier index, i = 1, 2, ..., s

 $k_i$  = capacity of supplier i

 $p_i$  = probability of breakage of products purchased from supplier i

 $p_{\text{max}}$  = maximum allowable probability of breakage

 $Q_i$  = decision variable representing the purchasing quantity from supplier i

s = number of alternate suppliers available

 $w_i$  = performance index of supplier *i* obtained by carrying out ANP

We consider two goals in our GP model:

- 1. Maximize the total value of purchase (TVP)
- 2. Minimize the total cost of purchase (TCP)

While the first goal involves minimizing the under-achievement of the target, the second goal involves minimizing the over-achievement of the target. 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.

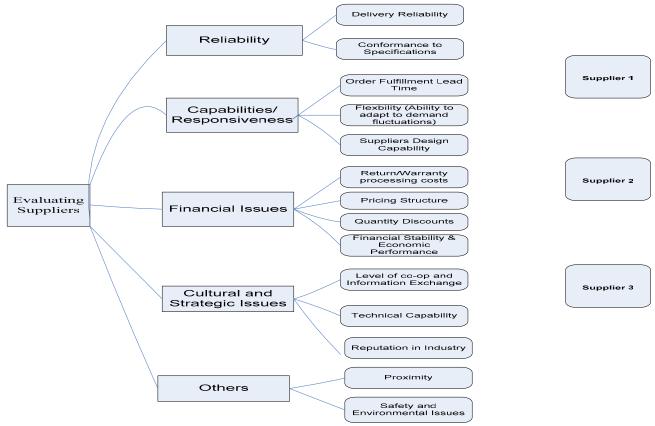


Figure 1. Main and sub-criteria for evaluating suppliers

Goal 1: Maximize TVP

$$\sum_{i=1}^{s} w_i * Q_i = TVP \tag{2}$$

Goal 2: Minimize TCP

$$\sum c_i * Q_i = TCP \tag{3}$$

**Capacity Constraint:** 

$$Q_i \le k_i \tag{4}$$

**Demand Constraint:** 

$$\sum_{i} Q_i = d_j \tag{5}$$

**Quality Constraint:** 

$$d_j * p_{\text{max}} \ge \sum_{i=1}^{s} Q_i * p_i \tag{6}$$

$$Q_i \ge 0 \tag{7}$$

#### 4. ILLUSTRATIVE EXAMPLE

We consider a CLSC where a remanufacturer has three suppliers available to supply the used-product. In the first stage, ANP is carried out to assess the suppliers in terms of the qualitative criteria. As illustrated in section 3, for the main and sub-criteria considered in our methodology (figure 1) the steps involved in ANP are carried out.

Table 2 shows the comparative importance values and the normalized Eigen vectors of the main criteria (second level in the hierarchy) in this example. The eigen vectors are the relative weights  $(P_j)$  given by the decision maker to the main criteria with respect to the goal.

Table 2. Comparative importance values of main criteria  $(P_i)$ 

Criteria	Reliability	Responsiveness	Financial Issues	Cultural & Strategic	Others	Relative Weight
				Issues		
Reliability	1	5	2	4	3	0.36570216
Responsiveness	1/5	1	0.2	6	7	0.18517144
Financial Issues	1/2	5	1	6	7	0.32777589
Cultural &	1/4	1/6	1/6	1	2	0.06577171
Strategic Issues						
Others	1/3	1/7	1/7	1/2	1	0.05557879

Table 3 shows the relative weights of the sub-criteria with respect to the main criteria. These weights are obtained after carrying out pair wise comparisons between sub-criteria with respect to their main criteria and calculating their normalized eigen vectors. For pair wise comparison, the question asked to the decision maker is 'what is the relative impact of sub-criteria a on main criteria X compared to sub-criteria b in evaluating each available supplier?'

Table 4 shows the relative weights of the alternate suppliers with respect to the sub-criteria. These weights are obtained after carrying out pair wise comparisons between the alternate suppliers with respect to the sub-criteria and calculating their normalized Eigen vectors.

Table 3. Relative weights of sub-criteria (  $A_{\it kj}^{\it D}$  )

Sub-Criteria	Relative Weight
Delivery Reliability	0.25
Conformance to Specs	0.75
Order Fulfillment LT	0.593968582
Flexibility	0.296754959
Design Capability	0.109276459
Returns/Warranty	0.099346706
Pricing	0.439188443
Qty Discounts	0.179462643
Stability & Eco.Perf	0.282002208
Co-Op & Info Exchange	0.686580087
Tech.Capability	0.222164502
Reputation	0.091255411
Proximity	0.25
Safety & Env	0.75

Table 4. Relative weights of alternate suppliers with respect to the sub-criteria ( $S_{ikj}$ )

Sub-Criteria/Alternatives	S1	S2	S3
Delivery Reliability	0.365597	0.354189	0.280214
Conformance to Specs	0.38960114	0.300035613	0.310363248
Order Fulfillment LT	0.338573189	0.3004235	0.361003311
Flexibility	0.102199944	0.211361738	0.686438318
Design Capability	0.090151515	0.187121212	0.722727273
Returns/Warranty	0.621470408	0.120435936	0.258093656
Pricing	0.249680715	0.623084291	0.127234994
Qty Discounts	0.376719577	0.151322751	0.471957672
Stability & Eco.Perf	0.159169	0.259866	0.580965
Co-Op & Info Exchange	0.343055556	0.081944444	0.575
Tech.Capability	0.158992	0.557983	0.283025
Reputation	0.67222222	0.18240741	0.14537037
Proximity	0.302141	0.382556	0.315303
Safety & Env	0.1589916	0.55798319	0.28302521

Pair wise comparisons are done to consider interdependencies among the sub-criteria to obtain the super matrix "M". The question asked to the decision maker for evaluating interdependencies is "when considering pricing with regards to evaluating the suppliers, what is the relative impact of quantity discounts when compared to stability and economic performance?" Table 5 shows the converged super matrix "M" (step 3 in the ANP process).

Table 5. Converged Super Matrix (  $A_{ki}^{I}$  )

Sub-Criteria	Stabilized relative importance weight
Delivery Reliability	1
Conformance to Specs	1
Order Fulfillment LT	0.439306358
Flexibility	0.375722543
Design Capability	0.184971098
Returns/Warranty	0.201909431
Pricing	0.368389318
Qty Discounts	0.136934118
Stability & Eco.Perf	0.292761586
Co-Op & Info Exchange	0.437262357
Tech.Capability	0.380228137
Reputation	0.182509506
Proximity	1
Safety & Env	1

Table 6 shows the desirability indices obtained from equation (1).

Table 6. Desirability Indices (Di)

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Criteria/Suppliers	S1	S2	S3
Reliability	0.383600142	0.313573946	0.302825912
Responsiveness	0.101562588	0.105739348	0.185342753
Financial Issues	0.075261167	0.128399	0.085325032
Cultural & Strategic Issues	0.127617015	0.074774	0.19895317
Others	0.19477894	0.514126514	0.291094546

The overall performance index for each of the three suppliers is calculated by multiplying the desirability index of each supplier for each criterion by the weight of the criteria and summing up over all the criteria. Table 7 shows the overall weighted indices for the three suppliers.

**Table 7. Overall Performance Indices for Alternate Suppliers** 

Supplier	Performance index
S1	0.329987862
S2	0.341132891
S3	0.328879247

The second stage of the decision making process utilizes the qualitative assessment ratings of the alternate suppliers obtained from the first stage by carrying out the ANP in formulating the goal programming objective function. Table 8 shows the data considered in the numerical example for the second stage of the decision making process.

Table 8. Data for Goal Programming Model

Supplier	S1	S2	S3
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 model illustrated in section 3 is solved using LINGO-8 and the above data; the steps involved in solving the goal programming model are given in section 2. Table 9 shows the results from our methodology.

Table 9. Results

Supplier	ANP Rating	<b>Quantity Ordered</b>	
S1	0.329987862	0	
S2	0.341132891 650		
S3	0.328879247	350	
Total value of purchase $(TVP) = 337$			
Total cost of purchase (TCP) = 935			

Since supplier S2, the highest ranked supplier in the first stage of decision process, only has a capacity of 650 units, which does not satisfy the demand of 1000 units, the decision process proceeds to the second stage. Considering the constraints binding the second stage of the decision process, 350 units are ordered from supplier S3.

#### 5. CONCLUSIONS

The issue of supplier selection in a closed-loop supply chain has not received much attention from researchers till date. Not all supplier selection criteria can be quantified, as a result of which, only a few quantitative criteria were considered in the problem formulation in the literature. To this end, in this paper, we identified the important criteria that influence the supplier selection process in a closed-loop supply chain and developed an integrated ANP and preemptive goal programming based multi-criteria decision making methodology to address the qualitative and quantitative criteria that influence the supplier selection problem in a closed-loop supply chain network. While the ANP methodology aids in determining qualitatively the supply chain strategy by evaluating the suppliers with respect to several criteria, the goal programming methodology uses the ANP ratings as inputs and aids in mathematically determining the optimal quantities to be ordered from the suppliers. A numerical example was considered to illustrate the methodology.

#### **REFERENCES**

- [1] Boyer, J. R. and Elter, J. F., "The dynamic behavior of a zero-to-landfill strategy for consumer products", *Proceedings of the 23<sup>rd</sup> International Conference of the Systems Dynamic Society*, 2005.
- [2] Gungor, A. and Gupta, S. M., "Issues in environmentally conscious manufacturing and product recovery: A survey", *Computers and Industrial Engineering*, **36** (4) 811-853, 1999.
- [3] Fleischmann, M., Quantitative Models for Reverse Logistics: Lecture Notes in Economics and Mathematical Systems, Springler-Verlag, Germany, 2001.
- [4] Pochampally, K. K. and Gupta, S. M., "Strategic Planning of a Reverse Supply Chain network", *International Journal of Integrated Supply Management*, **1** (4), 421-441, 2005.
- [5] Nukala, S. and Gupta, S. M., "A Single Phase Unified Approach for Designing a Closed-Loop Supply Chain Network", *Proceedings of the Seventeenth Annual Conference of Production and Operations Management Society*, 2006.
- [6] Wang, G., Huang, S. H. and Dismukes, J. P., "Product-driven supply chain selection using integrated multi-criteria decision-making methodology", *International Journal of Production Economics*, **91**, 1-15, 2004.
- [7] Saaty, T. L., Decision Making with Dependence and Feedback: The Analytic Network Process, Pittsburgh, PA: RWS Publications, 1996.
- [8] Ravi, V., Ravi Shankar. And Tiwari, M. K., "Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach", Computers and Industrial Engineering, 48 (2), 327-356, 2005.
- [9] Charnes, A., Cooper, W. W. and Ferguson, R. O., "Optimal Estimation of Executive Compensation by Linear Programming", *Management Science*, **1** (2), 138-151, 1955.
- [10] Charnes, A. and Cooper, W. W., Management Models and Industrial Applications of Linear Programming (Vol. 1), John Wiley and Sons, New York, 1961.
- [11] Ijiri, Y., Management Goals and Accounting for Control, Rand McNally, Chicago, IL, 1965.
- [12] Lee, S. M., Goal Programming for Decision Analysis, Auerbach Publishers, Philadelphia PA, 1972.
- [13] Ignizio, J. P., *Goal Programming and Extensions*, Lexington Books, D. C. Heath and Company, MA, USA, 1976.

- [14] Ignizio, J. P., Linear Programming in Single and Multi Objective Systems, Prentice Hall, Englewood, Cliffs, NJ, 1982.
- [15] Pearson, J. N. and Ellram, L. M., "Supplier selection and evaluation in small versus large electronics firms", *Journal of Small Business Management*, **33** (4), 53-65, 1995.
- [16] Choi, T. Y. and Hartley, J. L., "An exploration of supplier selection practices across the supply chain", *Journal of Operations Management*, **14**, 333-343, 1996.
- [17] Kannan, V. R. and Tan, K. C., "Supplier selection and assessment: Their impact on business performance", *The Journal of Supply Chain Management*, **38** (4), 11-21, Fall 2002.
- [18] Muralidharan, C., Anantharaman, N. and Deshmukh, S. G., "A multi-criteria group decision making model for supplier rating", *The Journal of Supply Chain Management*, **38** (4), 22-33, Fall 2002.
- [19] Weber, C. A., Current, J. R. and Benton, W. C., "Vendor selection criteria and methods", *European Journal of Operational Research*, **50**, 2-18, 1991.
- [20] Lee, E. K., Ha, S. and Kim, S. K., "Supplier selection and management system considering relationships in SCM", *IEEE Transactions on Engineering Management*, **48** (3), 307-318, 2001