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SELECTION OF COLLECTION CENTERS FOR REVERSE LOGISTIC NETWORKS

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ABSTRACT

In this paper, we address the problem of locating collection centers for a company that collects used products from product holders. Each product holder has an inherent willingness to return the product, and makes the decision on the basis of financial incentive offered by the company. We present a mixed-integer nonlinear facility location-allocation model to find the optimal locations, the optimal incentive values for different product types and the optimal vehicle type. Because the problem is NP-complete, a heuristic method is proposed to solve medium and large-size instances. We experiment with location dependent transportation costs which reflect the road conditions and other geographical factors. We conclude that the location dependent transportation cost approach is inferior to fixed transportation cost approach resulting in a higher loss of profit when the variation of the cost with respect to location is relatively high.

INTRODUCTION

The alarming increase in the use of virgin resources to produce new products has threatened the environment. The governments and consumers are quite aware of this phenomenon which has led to several legislations and given birth to the concept of environment consciousness. The goal of environmentally conscious manufacturing is to produce goods with minimal (or zero) harm to the environment. The concept of environment consciousness, however, now extends beyond manufacturing and includes the responsibility to manage the end-of-life products by the manufacturer [3]. The process involved in collecting, transporting and managing the EOL products is known as reverse logistics.

Reverse logistics and remanufacturing operations are more complex than forward logistics and traditional manufacturing operations. A lot of complexity stems from high degrees of uncertainties in the quality and quantity of products [2]. In reverse flow, the type of the recovery process is determined by the condition (quality) of returned products [1]. Just as the quality of returned products is unpredictable so is the quantity of returns as it may be dependent on the incentive offered to the last customer.

The type of the product recovery is dependent on the condition of a returned product. The possibilities include repairing, refurbishing, remanufacturing, cannibalizing, and recycling [4].

Used product acquisition or collection is the first step of product recovery that triggers other activities of the recovery system. As was mentioned before, there are considerable uncertainties in quantity, timing, and quality of returned products. Manufacturers can influence the quantity of returns by using buy-back campaigns and incentives to product holders. Clearly, the amount of incentive offered by the company (also called unit acquisition price) influences the quality level of used product returns. Accepting all end-of-use products in the waste stream is not a viable

strategy for most companies since a high percentage of these will have a poor quality, and hence will not be recoverable. As a result, a used product acquisition strategy, by offering an appropriate incentive, is crucial for a company engaged in product recovery [1].

In this paper, we present a model to find the optimal locations of a predetermined number of collection centers and the optimal incentive that should be offered by the company to product holders based on the quality condition of their used items. In this model we consider a pick-up scenario in which the company collects used products from the premises of the product holders and takes responsibility of all the collection-related costs. It is assumed that the willingness of the product holders to return is effected by the amount of the financial incentive offered. Thus, a higher incentive reduces the unit cost savings from a return, yet increases the product holders' willingness to return their used products.

MODEL

Assumptions

We assume that a pick-up strategy is in place according to which vehicles with limited capacity are dispatched from the collection centers to the locations of product holders to transport the returns. There are three vehicle alternatives (small, medium and large size) to be considered. There are no capacity constraints on collection centers. The cost per unit distance traveled between a customer zone and a candidate site is not fixed for all zone-site pairs. We also assume that the financial incentive offered by the company determines the willingness of product holders to return their used products.

Nomenclature

Parameters:

m	number of candidate sites,
n	number of customer zones,
d_{ij}	travel distance between customer zone j and, candidate site i ,
L	number of vehicle alternatives,
c_{1l}	operating cost of a vehicle of type l ,
c_{2ij}	cost per unit distance traveled between site i and zone j ,
q_l	capacity of a vehicle of type l ,
h_j	number of product holders living in zone j ,
K	number product types,
γ_{jk}	proportion of product holders of type k in zone j ,
h_{jk}	number of product holders of type k living in zone j ($h_{jk} = \gamma_{jk}h_j$),
s_k	unit cost savings from a used product of type k ,
a_k	the maximum incentive level of product holder of type k ,
m_l	travel cost coefficient for vehicles of type l ,
p	number of collection centers to be opened.

Variables:

Π	total profit,
X_{ijk}	fraction of potential returns of type k collected in zone j and transported to the CC at site i ,

V_{ij} number of vehicles required to transport returns from zone j to the CC at site i ,
 R_k unit incentive offered (unit acquisition price) for a used product of type k ,

$$Y_i = \begin{cases} 1, & \text{if a collection center (CC) is located at site } i \\ 0, & \text{otherwise} \end{cases},$$

$$t_l = \begin{cases} 1, & \text{if a vehicle of type } l \text{ is selected} \\ 0, & \text{otherwise} \end{cases}.$$

Formulation

$$\max \Pi = \sum_i^m \sum_j^n \sum_k^K \frac{X_{ijk} h_{jk} R_k (s_k - R_k)}{a_k} - \sum_i^m \sum_j^n \sum_l^L (c_{1l} t_l + 2c_{2l} m_l d_{ij}) V_{ij} \quad (1)$$

s.t.

$$\sum_{i=1}^m X_{ijk} \leq 1, \quad j = 1, \dots, n; \quad k = 1, \dots, K, \quad (2)$$

$$X_{ijk} \leq Y_i, \quad i = 1, \dots, m; \quad j = 1, \dots, n; \quad k = 1, \dots, K, \quad (3)$$

$$\sum_{i=1}^m Y_i = p \quad (4)$$

$$V_{ij} \geq \frac{\sum_k X_{ijk} h_{jk} R_k (s_k - R_k)}{\sum_l t_l a_l}, \quad i = 1, \dots, m; \quad j = 1, \dots, n, \quad (5)$$

$$\sum_{l=1}^L t_l = 1 \quad (6)$$

$$R_k \leq a_k, \quad k = 1, \dots, K, \quad (7)$$

$$R_k \leq s_k, \quad k = 1, \dots, K, \quad (8)$$

$$R_k \geq 0, \quad k = 1, \dots, K, \quad (9)$$

$$X_{ijk} \geq 0, \quad i = 1, \dots, m; \quad j = 1, \dots, n; \quad k = 1, \dots, K, \quad (10)$$

$$V_{ij} \geq 0 \text{ and integer}, \quad i = 1, \dots, m; \quad j = 1, \dots, n, \quad (11)$$

$$Y_i \in \{0,1\}, \quad i = 1, \dots, m, \quad (12)$$

$$t_l \in \{0,1\}, \quad l = 1, \dots, L. \quad (13)$$

SOLUTION METHODOLOGY

The problem formulated as a mixed-integer nonlinear programming model is very difficult to solve even for small problem sizes. For this reason we developed a solution method which reduces the complexity of the problem.

The main loop of the method is based on a tabu search method performed in the space of collection center locations. For each location set prescribed by tabu search, simplex search (Nelder-Mead Simplex) is called to obtain the best incentives and the corresponding net profit (Figure 1). This main loop is run for each vehicle alternatives.

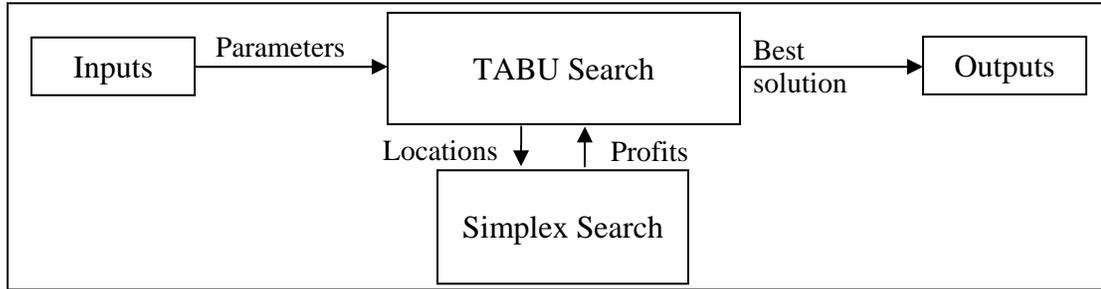


FIGURE 1. Basic flow chart of the proposed solution method.

COMPUTATIONAL RESULTS

For two distinct values of n ($n=10, 20$) and three distinct values to p ($p=2, 3, 4$), we obtain 6 instances and solve them using commercial solvers BARON (in GAMS 22.5) and LINGO 7.0, and using the algorithm described above. Proposed algorithm has been coded in MATLAB 6.1 and all experiments have been conducted on a laptop computer with 1.60 GHz Intel Celeron M processor and 512 MB ram.

Since the worst computation time of the proposed heuristic algorithm is 481.781, we set a time limit of 600 sec. in GAMS and LINGO. GAMS could find a local optimum for the smallest instance whereas LINGO could not find any feasible solution. Comparative results are shown in Table 1. For instances (20x2x2) and (20x3x2), large size vehicles, and for the rest of the instances, medium size vehicles turn out to be the optimal vehicle selection.

TABLE 1. Computational results comparisons

Instance	BARON (GAMS)			Proposed Heuristic			
	R1	R2	Objective	R1	R2	Objective	CPU time (s)
10x2x2	9.841	5.000	1,762.426	10.7621	5.7586	1,890.7	36.125
10x3x2	-	-	-	9.2174	4.4546	2,479.4	91.281
10x4x2	-	-	-	10.6520	5.8922	2,298.9	96.61
20x2x2*	-	-	-	9.2294	4.6540	4,707.1	205.671
20x3x2*	-	-	-	9.0970	4.5468	4,908.3	454.89
20x4x2	-	-	-	9.5697	4.8706	4,432.8	481.781

CONCLUSIONS

In this paper, we presented a mixed integer non-linear programming model to find the optimal locations of a predetermined number of collection centers, the optimal vehicle type and the optimal incentive that should be offered by the company to product holders based on the quality condition of their used items. In order to solve this NP-complete problem, a tabu search based algorithm was developed in MATLAB.

Experiments for 6 instances have shown that the vehicle type has a significant effect on the collection policy. We also conclude that the location dependent transportation cost approach is inferior to fixed transportation cost approach resulting in a higher loss of profit when the variation of the cost with respect to location is relatively high.

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