



Design of a Government-Subsidized Collection System for Incentive-Dependent Returns

A. Gönül Tanuğur, Boğaziçi University, İstanbul, Turkey



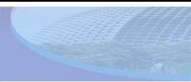
Deniz Aksen, Koç University, İstanbul, Turkey



Necati Aras, Boğaziçi University, İstanbul, Turkey



December 2–3, 2007, SINGAPORE



Content

- ✿ Introduction and Motivation
- ✿ Basic Literature Review
- ✿ Problem Description / Model Formulation
- ✿ Solution Method
- ✿ Experimental Results
- ✿ What next



Introduction and Motivation

- There are two main motives behind an engagement in product recovery
- **Economic:** Reduction in the unit production cost due to the savings in material, energy etc.
- However, accepting all end-of-used products may not be a good strategy → Core acquisition strategies, buy-back campaigns
- The number of collected cores may be limited when the objective is profit maximization



Introduction

- **Environmental legislation:** WEEE 2002 directive in the EU, target collection, reuse and recycling rates
- These regulations may prove product recovery unprofitable
- The profit maximization objective of the companies is not streamlined with the objective of the regulator to reach a desired amount/rate of collected cores
- Offering a subsidy to the company for each collected item may be helpful

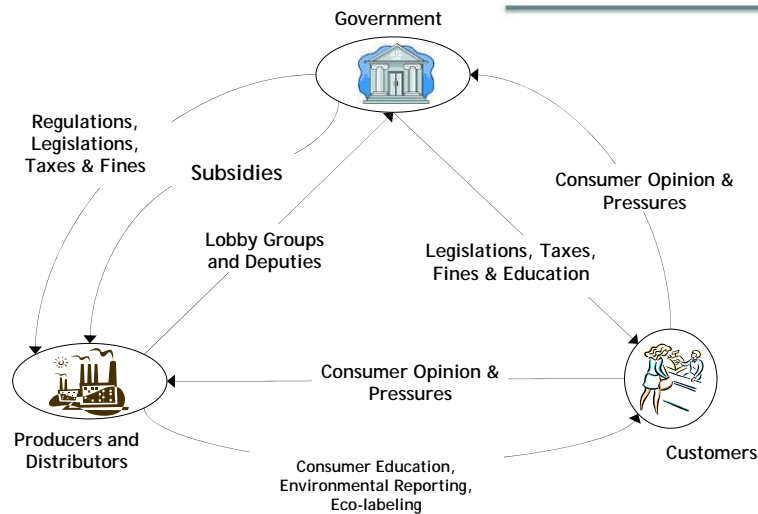


Introduction and Motivation

- ❑ **Collection:** process of rendering used products available and physically moving them to some point for further treatment. It may include activities purchasing, transportation, and storage
- ❑ **Inspection/separation:** the set of operations for determining whether a given product is re-usable and in which way
- ❑ **Reprocessing:** transformation of a used product into a usable product again
- ❑ **Disposal:** getting rid of products that cannot be re-used for technical or economical reasons
- ❑ **Redistribution:** distributing reusable products to a potential market



Introduction and Motivation





Basic Literature Review

- *Papers modeling logistics networks with reverse flows only*
 - Customers drop products to collection points (CP)
 - Products are then transferred to Central Return Centers (CRC)
 - Discrete facility location-allocation models formulated as MILP
 - To determine the number and location of CPs and CRCs so as to minimize total logistics cost (transportation and facility opening)
e.g., Jayaraman et al. (2003); Min et al. (2006).

- *Papers modeling logistics networks with forward and reverse flows*
 - Discrete facility location-allocation models formulated as MILP
 - Fleischmann, 2001; Salema et al., 2006; Lu and Bostel, 2007



Basic Literature Review

- *Papers modeling government regulation on the throughput of collection operations*
 - Rodrigue et al. (2001): "greenness" of production, importance of environmental awareness for companies that anticipate tighter environmental regulations in the future
 - Kulshreshtha and Sarangi (2001): the government gives a subsidy to a firm involved in recycling of product packages.
 - Sheu et al. (2005) :: a linear multi-objective optimization model
 - The difficulty of integrating logistics flows in a green-supply chain.
 - Coordinating the activities of all chain members
 - Externalities such as end-customer behavior and governmental policies (subsidies, return ratio, recycle fees)



Model Formulation

- We address the problem of locating collection centers for a company that aims to collect used products (cores) in order to capture their remaining value by recovery operations.
- A pick-up strategy is in place according to which vehicles are dispatched from collection centers to the locations of product holders to transport their returns.
- Each product holder has an inherent willingness to return a core, and decides on the basis of the quality-dependent financial incentive offered by the company.
- Since the company seeks only economic profitability, the collected amounts may not be aligned with the target collection rate imposed by the government.

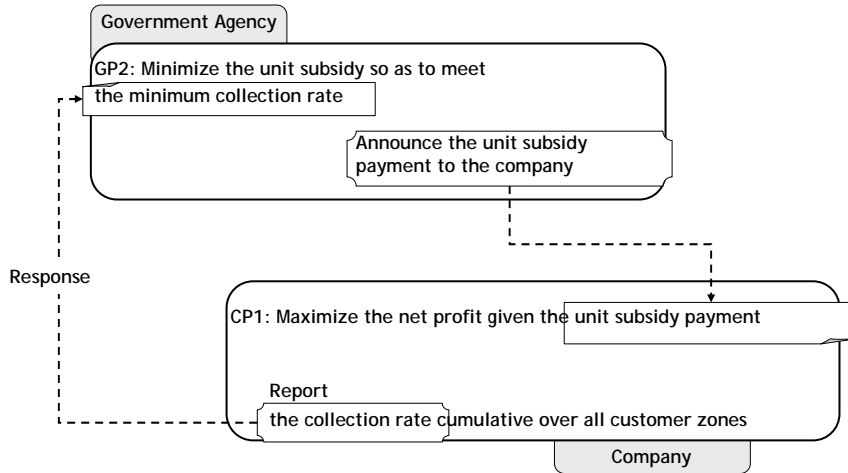


Model Formulation

- In this case, the government may alleviate the under-collection issue through a subsidy paid to the company for each core collected.
- From the government's perspective the problem is to find the minimum subsidy level while meeting the target collection ratio.
- We propose a bilevel programming formulation for this collection system design problem.

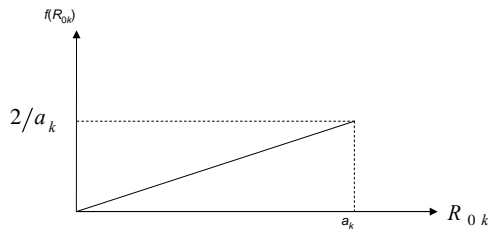


Model Formulation



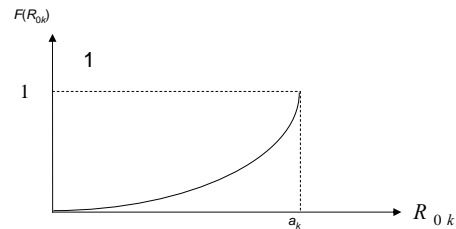
Model Formulation

Reservation incentive $R_{0k} \sim \text{Right Triangular}(0, a_k)$



Probability density function of R_{0k}

$$f(R_{0k}) = \frac{2R_{0k}}{a_k^2}$$



Cumulative distribution function of R_{0k}

$$P_{jk} = \Pr(R_k \geq R_{0k}) = F(R_k) = \frac{R_k^2}{a_k^2}$$

Parameter:

h_j = number of product holders living in zone j

γ_k = proportion of product holders of type k

1-median problem:

→ Candidate sites for CCs are customer zones

$h_{jk} = h_j \gamma_k$

→ The reservation incentive

Variable: x_{ij} = number of vehicles needed for zone j

→ incentives, each customer will react differently

→ Potential returns of type k in zone j : $h_{jk} R_k^2$

→ at least as large as $\frac{h_{jk} R_k^2}{a_k^2}$

Parameter:

→ It may not be profitable to collect all potential returns

$q = \Pr(R_k - R_{0k} > 0) = \frac{R_k^2}{a_k^2}$ (see article by Pappalardo, 2005; Wojanowski et al., 2007; Aras and Aksen, 2007)

→ Proportion of willing product holders

Variable: X_{ij} and v_i

→ number of vehicles needed for zone j turns of type k collected in zone j site i .

→ Total amount collected from zone j :

$$\sum_k \frac{X_{ijk} h_{jk} R_k^2}{a_k^2}$$

Objective: maximize the TOTAL NET PROFIT by determining

- Locations of collection centers
- Financial incentives offered for products with differing qualities
- The number and the load composition of vehicles



Model Formulation

Objective Function

$$\max \Pi = \sum_{i=1}^m \sum_{j=1}^n \sum_{k=1}^K \frac{X_{ijk} h_{jk} R_k^2 (g_k + S - R_k)}{a_k^2} - \sum_{i=1}^m \sum_{j=1}^n (c_1 + 2c_2 d_{ij}) V_{ij} - \sum_{i=1}^m f_i Y_i$$

Constraints:

Fraction of products to be collected: $X_{ijk} \leq Y_i$ $i = 1, \dots, m; j = 1, \dots, n; k = 1, \dots, K$

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

$$\sum_{i=1}^m X_{ijk} h_{jk} \left(\frac{R_k^2}{a_k^2} \right)$$

Number of vehicles: $V_{ij} \geq \frac{\sum_{k=1}^K X_{ijk} h_{jk} \left(\frac{R_k^2}{a_k^2} \right)}{q}$ $i = 1, \dots, m; j = 1, \dots, n$

Restrictions on the financial incentive:

$$R_k \leq a_k \quad k = 1, \dots, K \quad R_k \leq g_k + S \quad k = 1, \dots, K$$

Non-negativity and binary constraints: $V_{ij} \geq 0$ and integer $Y_i \in \{0, 1\}$ $X_{ijk} \geq 0$
 $R_k \geq 0 \quad k = 1, \dots, K$



Model Formulation

Leader's (Government's) Problem:

objective \rightarrow minimize subsidy

subject to \rightarrow target collection ratio is achieved

minimize S

$$S \geq 0$$

$$\text{Subject to } \sum_{i \in \mathbf{I}} \sum_{j \in \mathbf{J}} \sum_{k \in \mathbf{K}} X_{ijk} h_{jk} \frac{R_k^2}{a_k^2} \geq t \sum_{j \in \mathbf{J}} h_j$$

where $\{X_{ijk}, R_k\}$ solves the company's problem



Model Formulation

Bilevel programs are shown to be \mathcal{NP} -hard.

The inner problem (CP) has to be solved using the subsidy value S determined by the outer problem (GP).

Once the value of S is set, the inner problem CP becomes a MINLP problem which itself is difficult to solve.

An efficient heuristic solution method for this problem is described in Aras et al. (2007).

It capitalizes on the following characteristic: given the locations of CCs, the problem reduces to a nonlinear problem in variables R_k and V_{ij} only.

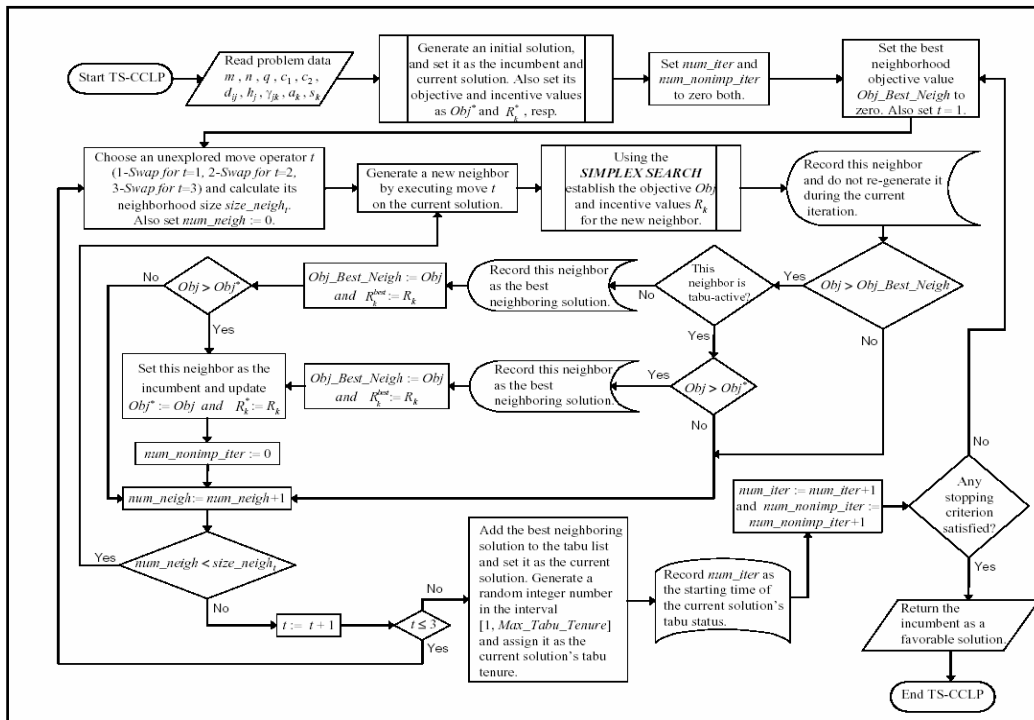



Solution Method

OUTER SHELL → TABU SEARCH

- Explores the search space of all possible collection center locations.
- SWAP move operators generate a neighborhood of the current solution
- Search terminates if
 - ✓ max_iter iterations have been executed
 - ✓ the best solution found does not improve


remaining vertices by reflection, expansion or contraction operations.





IEEM2007

THE IEEE INTERNATIONAL CONFERENCE ON INDUSTRIAL ENGINEERING AND ENGINEERING MANAGEMENT




Solution Method

Since the inner problem CP is solvable for a given value of S, we may adopt the following approach:

We can start with the smallest possible value of S, which is zero, and solve the CP.

If this solution satisfies the minimum collection constraint of the outer problem GP, then we are done. Otherwise, we slightly increase S and solve the CP again.

This iterative procedure is continued until the constraint is satisfied.



Singapore, 2-5 Dec 2007

20



Experimental Results

By assigning four distinct values to n ($n=10, 20, 50, 100$), three different values to t ($t=0.2, 0.4, 0.6$), and two distinct values to K ($K=2,3$), we obtain $4 \times 2 \times 3 = 24$ test instances

In all instances, the candidate sites for collection centers coincide with the customer zones, i.e., $m = n$. The x - and y -coordinates of customer zones (collection centers) are sampled independently from a discrete uniform distribution in the interval $[0,100]$.

The number of product holders in each zone is also generated from the same distribution supported on $[1,100]$.



Experimental Results

TABLE I
PARAMETER VALUES FOR THE PROBLEMS

	$K=2$		$K=3$		
k	1	2	1	2	3
g_k	25	15	25	20	15
α_k	15	5	15	10	5
γ_k	0.5	0.5	1/3	1/3	1/3



Experimental Results

TABLE II
RESULTS FOR TWO CORE TYPES

Instance (n, t, K)	Number of CCs opened	Subsidy S	Total Profit Π_{net}	Realized Collection Ratio T
(10, 0.2, 2)	1	1.968	0.01	0.38
(10, 0.4, 2)	1	2.784	187.67	0.41
(10, 0.6, 2)	1	6.135	1195.88	0.64
(20, 0.2, 2)	1	1.773	0.01	0.26
(20, 0.4, 2)	2	4.105	755.68	0.57
(20, 0.6, 2)	2	4.443	944.69	0.61
(50, 0.2, 2)	2	1.126	687.92	0.31
(50, 0.4, 2)	2	1.724	1195.46	0.40
(50, 0.6, 2)	4	3.629	3760.17	0.70
(100, 0.2, 2)	3	0	2389.526	0.31
(100, 0.4, 2)	4	0.442	3213.902	0.42
(100, 0.6, 2)	5	1.461	6012.459	0.62

TABLE III
RESULTS FOR THREE CORE TYPES

Instance (n, t, K)	Number of CCs opened	Subsidy S	Total Profit Π_{net}	Realized Collection Ratio T
(10, 0.2, 3)	1	2.051	0.003	0.38
(10, 0.4, 3)	1	2.917	200.36	0.41
(10, 0.6, 3)	1	6.135	1157.24	0.62
(20, 0.2, 3)	1	1.88	0.001	0.27
(20, 0.4, 3)	2	4.153	718.74	0.58
(20, 0.6, 3)	2	4.443	883.654	0.61
(50, 0.2, 3)	2	1.133	683.42	0.30
(50, 0.4, 3)	3	2.246	1654.96	0.54
(50, 0.6, 3)	3	3.873	4047.09	0.60
(100, 0.2, 3)	4	0	2352.37	0.35
(100, 0.4, 3)	5	0.505	3294.38	0.49
(100, 0.6, 3)	5	1.508	5966.03	0.60



Experimental Results

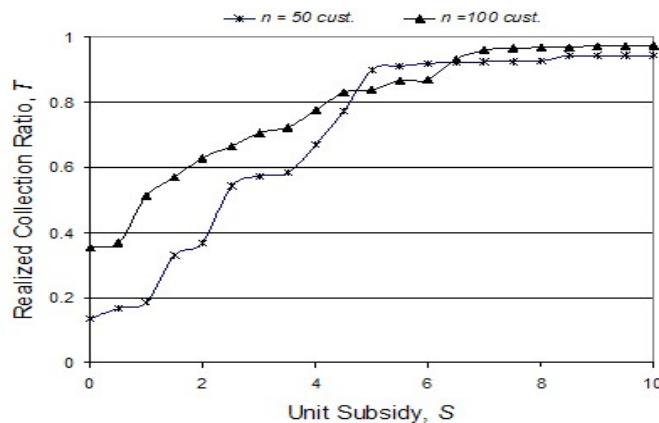
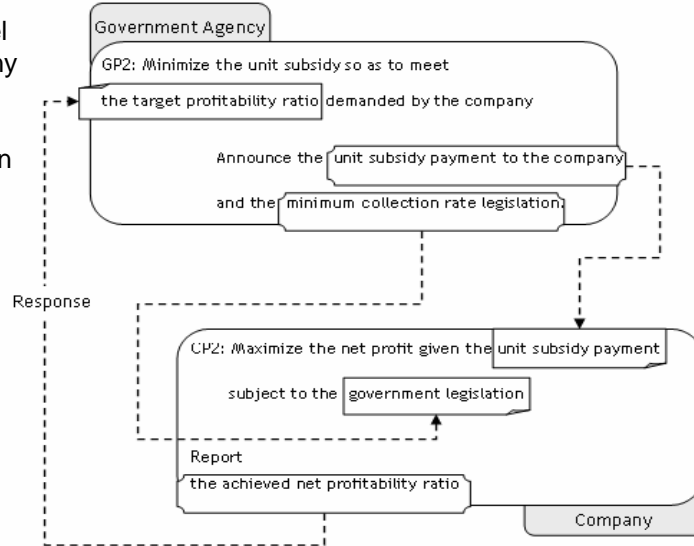


Fig. 2. Frontier curves for $n=50$ and $n=100$ with $K=3$



Current Research

A legislative model where the company must abide by the government's minimum collection rate legislation



Questions and Answers

