A carbon footprint based reverse logistics network design model

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Contents

Introduction

❖ **Reverse logistics network design with carbon footprint**

Reverse logistics network design [1]

- Multistage reverse logistics network including customers, collection/inspection, recovery, and disposal centers with limited capacities. (based on Pishvaee et al. 2010)

→ Multi-stage reverse logistics network design

Problem characteristics

- All of the returned products from customers must be collected.
- Customer locations are fixed and predefined.
- Numbers, locations, and capacities of recovery and disposal centers are known in advance.

Introduction

❖ **Reverse logistics network design with carbon footprint**

Reverse logistics network design [2]

- Consider a multistage reverse logistics network with collection/inspection, recovery, and disposal facilities.

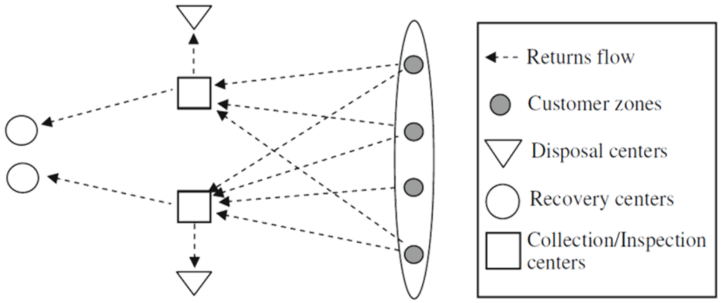

Figure 1. Structure of a reverse logistics network

Structure of reverse logistics network

- Returned products are collected from customer zones into collection/inspection centers.
- After quality inspection, returned products are divided into recoverable products and scrapped products.
- The recoverable products are carried to the recovery centers.
- Scrapped products are sent to the disposal centers.

Introduction

❖ **Reverse logistics network design with carbon footprint**

Carbon footprint

- "The total set of greenhouse gas (GHG) emissions caused by an organization, event, product or person."

◄---- Awareness of climate change, take back end-of-life products, etc.

e.g., produce of goods, transportation, etc.

Introduction

❖ **Literature review**

Concerned with reverse logistics

• Sheu (2007), Pishvaee et al. (2010), Paksoy et al. (2010)

Paksoy et al. (2010) to minimize the cost and emission in the forward logistics and the cost only in reverse logistics.

✓ Feature of literature

Most of the literature considers an objective problem which minimizes the cost (or) maximizes the utilization, minimizes emissions, and minimize waste or risk.

→ Fragmentary extension

✓ In this paper

A carbon footprint based objective model is developed for a reverse logistics network design that considers both cost and emissions.

→ Systematic extension

Problem description

❖ **Carbon footprint based reverse logistics network design problem**

Objective function

- Minimize the costs involved in the reverse logistics network model.

  ← The carbon footprint involved both in transportation and reverse logistics operations (collection) costs.

  e.g., collection, disposal, transportation, fixed opening, and emissions costs in a multistage reverse logistics.

Decision variables

- Choose the location and to determine the number of collection/inspection centers.
- Determine the quantity of flow between the network facilities.

  → Finding the location choices for collecting the used product and for implementing recovery options such as recycling and disposal options.

Problem description

❖ **Carbon footprint based reverse logistics network design problem**

Main constraints

- Capacity constraints

  ◄---- Collection/inspection, recovery, disposal centers.

Assumptions

- Single product and single period is considered.
- All the related costs, emissions, and capacity parameters are known.
- All the recycled material can be sold in the market.

Problem description

❖ Mathematical formulation of the model

Notations

I – set of the candidate points for collection/inspection centers, $\forall i \in I$
J – fixed set of points for recovery centers, $\forall j \in J$.
K – fixed set of points for disposal centers, $\forall k \in K$.
L – fixed set of points for customer centers, $\forall l \in L$.

d – average fraction of disposed products (percent).
r_l – amount of returned products from customer centers l.
G – maximum number of collection/inspection centers i.
f_i – fixed cost to set up collection/inspection centers i.
cc_i – collection cost of returned products at collection centers i.
cf_{li} – transportation cost for a unit of returned product from customer centers l to collection/inspection centers i.
cs_{ij} – transportation cost for a unit of recoverable product from collection/inspection centers i to recovery centers j.
ct_{ik} – transportation cost for a unit of scrapped product from collection/inspection centers i to disposal centers k.
d_{li} – distance between customer centers l and collection/inspection centers i.
d_{ij} – distance between collection/inspection centers i and recovery centers j.
d_{ik} – distance between collection/inspection centers i and disposal centers k.

Decision variables

X_{li} – amount of returned products transferred from customer centers l to collection/inspection centers i.
Z_{ij} – amount of recoverable products transferred from collection/inspection centers i to recovery centers j.
W_{ik} – amount of scrapped products transferred from collection/inspection centers i to disposal centers k.

$$Y_i - \begin{cases} 1 \ \textit{if a collection/inspection center is open at location } i; \\ 0 \ \textit{otherwise} \end{cases}$$

CO_2 – amount of carbon dioxide (CO_2) emitted currently in tons

ca_{fi} – capacity of the collection/inspection centers i.
cas_j – capacity of the recovery centers j.
cat_k – capacity of the disposal centers k.
dc_k – disposal cost at the disposal centers k.
E – CO_2 transportation emissions factor per unit of returned product in g/km
LE – CO_2 equiv. per collection center location opened
Ω – cost of carbon credits in \$ per ton CO_2

Problem description

- **Mathematical formulation of the model**

Model

$$\text{Min } Z = \sum_{l\in L}\sum_{i\in I} \mathrm{cc}_i X_{li} + \sum_{i\in I} f_i Y_i + \sum_{l\in L}\sum_{i\in I} \mathrm{cf}_{li} X_{li} + \sum_{i\in I}\sum_{j\in J} \mathrm{cs}_{ij} Z_{ij}$$
$$+ \sum_{i\in I}\sum_{k\in K} \mathrm{ct}_{ik} w_{ik} + \sum_{i\in I}\sum_{k\in K} \mathrm{dc}_k w_{ik} + \Omega(\mathrm{CO_2} - \mathrm{CO_2^{cap}}) \quad (1)$$

subject to,

$$\sum_{i\in I} Y_i \le G \quad (2)$$

$$\sum_{i\in I} X_{li} = rl, \quad \forall l \in L \quad (3)$$

$$\sum_{j\in J} Z_{ij} = (1-d)\sum_{l\in L} X_{li}, \quad \forall i \in I \quad (4)$$

$$\sum_{k\in K} W_{ik} = d\sum_{l\in L} X_{li}, \quad \forall i \in I \quad (5)$$

$$\sum_{l\in L} X_{li} \le Y_i\, \mathrm{caf}_{li}, \quad \forall i \in I \quad (6)$$

$$\sum_{i\in I} Z_{ij} \le \mathrm{cas}_j, \quad \forall j \in J \quad (7)$$

$$\sum_{i\in I} W_{ik} \le \mathrm{cat}_k, \quad \forall k \in K \quad (8)$$

$$\sum_{l\in L}\sum_{i\in I} E_t D_{li} X_{li} + \sum_{i\in I}\sum_{j\in J} E_t D_{ij} Z_{ij} + \sum_{i\in I}\sum_{k\in K} E_t D_{ik} W_{ik} + \sum_{i\in I} \mathrm{LE},$$
$$Y_i = \mathrm{CO_2} \quad (9)$$

$$Y_i \in \{0,1\}, \quad \forall i \in I \quad (10)$$

$$X_{li}, Z_{ij}, W_{ik} \ge 0, \quad \forall i \in I, \quad \forall j \in J, \quad \forall k \in K, \quad \forall l \in L \quad (11)$$

Computational experiments

❖ Experiment design with results

Test instances and experiment design

Ten different test problems of various sizes for the carbon footprint based (CFP) reverse logistics network design are considered.

→ In order to validate the proposed mixed integer linear program (MILP) model.

✓ Solution method

Lingo 8 software.

Table1. Test instances (adopted from Pishvaee et al., 2010)

Problem number	No. of collection/ inspection centers	No. of recovery centers	No. of disposal centers	No. of customer zones
1	5	2	2	5
2	10	2	2	5
3	10	2	4	8
4	14	3	5	10
5	20	3	5	15
6	25	3	5	20
7	30	4	6	25
8	35	4	6	30
9	55	4	6	45
10	80	4	6	60

Computational experiments

- **Experiment design with results**

Test results

For the small sized problems, Lingo takes fewer than 5 s to find the optimum solution. Medium sized problems require 10-1500 s to find the optimum solution, and the large sized problems take 5000-20,000 s.

Table2. Computational results

Problem number	Total cost (Z)	CPU time (s)
1	5020	2
2	6031	3
3	8323	2
4	9931	3
5	10,568	7
6	13,843	56
7	14,833	101
8	16,856	1496
9	21,598	5100
10	30,593	17,688

Conclusion

- **Summary**

  - Introduced a carbon footprint-based reverse logistics network design model.

  - Minimize the total cost involved in the reverse logistics network model and the emissions resulting from the logistics and facilities.

  - Supply chain managers can make decisions by incorporating environmental emissions into their costs.

Thank You !

Q and A