A closed-loop logistics model for remanufacturing

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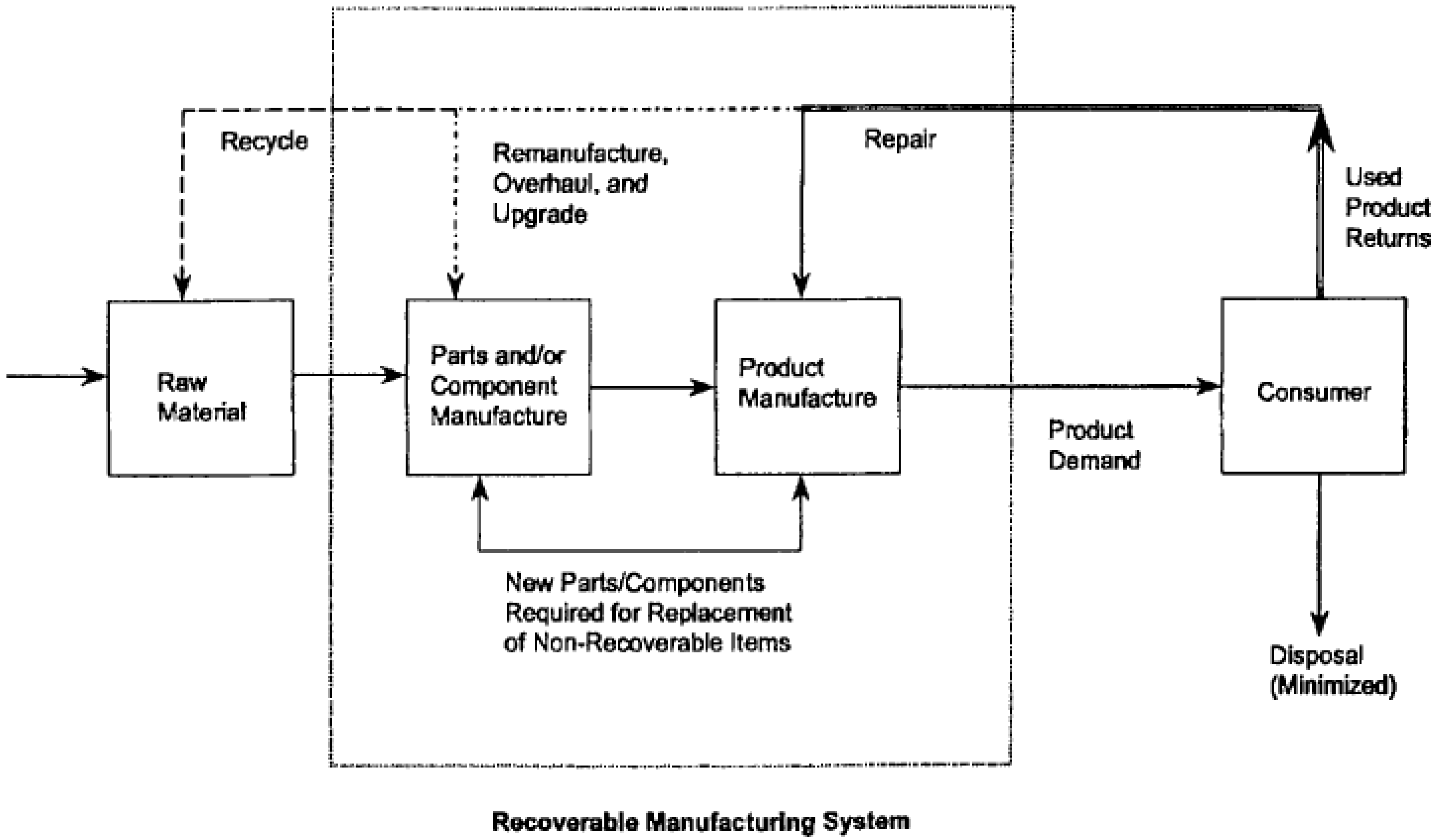
1 Introduction

Introduction

➢ **Recoverable manufacturing system and closed loop logistics**



Literature review

- Vandermerwe and Oliff(1991)
  - the development of manufacturing infrastructures to support recoverable manufacturing system

- Graedel TE and Allenby BR(1995)
  - Remanufacturing offers several advantages as a form of waste reduction since it is profitable and environmentally conscious

- Jahre and Flygansvaer(1996)
  - developed a theoretic framework for logistics systems and proposed a set of managerial propositions based on a series of case studies

- **Contribution**
  - the characteristics of the remanufacturing environment

2 Problem description

Problem description

- **Problem**
  - Location of plant for recovery manufacturing
- **Objective**
  - Minimize total cost
- **Decision variables**
  - quantity of core shipped form collection zone to facility location
  - quantity of remanufactured product distributed form facility location to customer zone
  - the number of facilities that can be open
- **Assumptions**
  - the quality of product is not considered
  - no backlogging

Problem description

- **Parameters**
  - I set of products that need to be remanufactured
  - J set of potential distribution locations
  - K set of customer outlets who demand remanufactured products
  - V set of collection zones for the cores
  - F_j fixed cost incurred to operate location j
  - WR_j capacity of facility location j to store remanufactured products
  - WU_j capacity of facility location j to store the cores
  - S_v total amount of space available at collection zone v
  - d_{ik} forecasted demand placed by customer zone k for remanufactured product i
  - CI_{ijv} per unit inbound cost to ship core i from collection zone v to facility location j
  - CO_{ijk} per unit outbound cost to supply customer outlet k demand for remanufactured product i from facility location j
  - CR_{ij} per unit value added cost to remanufacture product i at facility location j
  - CU_{iv} per unit cost of core i as a function of customer zone v
  - h inventory carrying cost
  - R_i per unit storage space occupied by remanufactured product i
  - U_i per unit storage space occupied by core i

Problem description

- **Decision variables**
  - M_{ijv} quantity of core i shipped from collection zone v to facility location j
  - Q_{ijk} quantity of remanufactured product i distributed from facility location j to customer zone k
  - P the maximum number of facilities that can be open
  - Z_i 1 if we open facility at location j
    0 otherwise

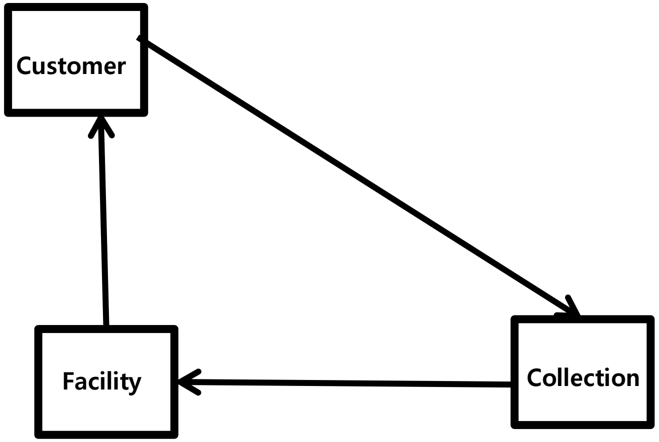
Problem description

- **Mathematical Formulation (Model REVLOG)**
  - Minimize total cost
    1) Transportation cost
    2) Inventory holding cost
    3) Facility cost

$$\min \sum_i \sum_j \sum_v CU_{iv} M_{ijv} + \sum_i \sum_j \sum_v CI_{ijv} M_{ijv} + \sum_i \sum_j \sum_k CR_{ij} Q_{ijk} + \sum_i \sum_j \sum_k CO_{ijk} Q_{ijk} \quad 1)$$

$$+ \sum_i \sum_j \sum_v h\left(\frac{CU_{iv}}{2}\right) M_{ijv} + \sum_i \sum_j \sum_k h\left(\frac{CR_{ij}}{2}\right) Q_{ijk} \quad 2)$$

$$+ \sum_j F_j Z_j \quad 3)$$



Problem description

➢ **Mathematical Formulation**

subject to

$\sum_{j} Q_{ijk} \leqslant d_{ik} \quad \text{for all } i \text{ and } k$	(1)	Total number of remanufactured products does not exceed the demand
$\sum_{k} Q_{ijk} \leqslant \sum_{v} M_{ijv} \quad \text{for all } i \text{ and } j$	(2)	Total number of remanufactured products does not exceed the demand
$\sum_{i} \sum_{k} R_i Q_{ijk} \leqslant WR_j Z_j \quad \text{for all } j$	(3)	Product storage capacity constraint
$\sum_{i} \sum_{v} U_i M_{ijv} \leqslant WU_j Z_j \quad \text{for all } j$	(4)	Core storage capacity constraint
$\sum_{j} Z_j \leqslant P$	(5)	Total number of facilities is less than P
$\sum_{i} \sum_{j} U_i M_{ijv} \leqslant S_v \quad \text{for all } v$	(6)	Total number of facilities is less than P
$M_{ijv} \text{ and } Q_{ijk} \geqslant 0 \quad \text{for all } i, j, k \text{ and } v$	(7)	Binary (yes/no) decision variable Zj
$Z_j \in \{0, 1\} \quad \text{for all } j$	(8)	

3 Example and results

Example and results

- **numerical example environment**
  - **Potential facility location : 10**
  - **Customer zones to supply used product : 5**
  - **Customer zones that demand remanufactured product : 10**
  - Demand for multiple products

    $$d_{ik} \sim \text{uniform } (10\,000,\ 20\,000) \text{ units}$$
  - Fixed cost to open and operate

    $$\text{facilities: } F_j \sim \text{ uniform } (50\,000,\ 100\,000)$$
  - Inbound cost to facilities:

    $$CI_{ijv} = CON(i) \times \text{distance between supply zones and facilities}/100$$
  - Outbound cost to distribute remanufactured products from facilities to customer outlets:

    $$CO_{ijk} = CON(i) \times \text{distance between facility and customer outlets}/100$$

    $$CON(i) \text{ - Characteristic of product } i \sim \text{uniform } (10, 25)$$
  - Per unit remanufacturing cost for products at facilities

    $$CR_{ij} \sim \text{uniform } (5, 20)$$
  - Per unit cost of core i as a function of supply zone

    $$CU_{iv} \sim \text{uniform } (20, 50)$$
  - Capacity of facilities to handle remanufactured products

    $$W_{rj} \sim \text{uniform } (175\,000,\ 250\,000)$$
  - Capacity of facilities to handle used products

    $$W_{uj} \sim \text{uniform } (150\,000,\ 225\,000)$$
  - Space occupied by remanufactured product

    $$R_i \sim \text{uniform } (0, 1)$$
  - Space occupied by used product

    $$U_i \sim \text{uniform } (0, 1)$$

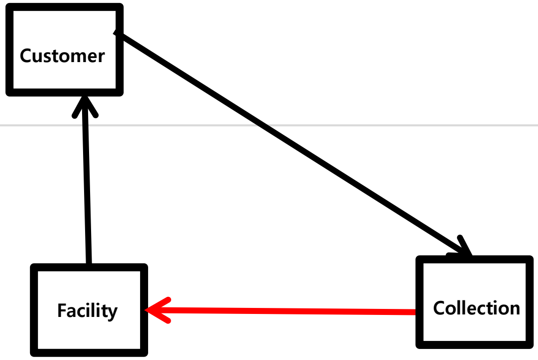
Example and results

➢ **Numerical example**

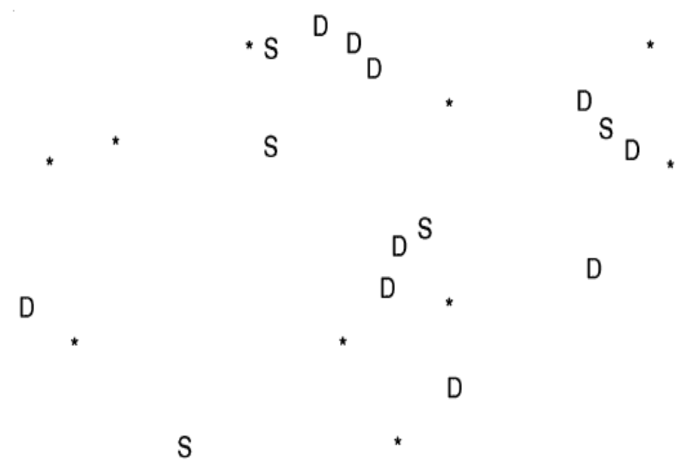
Table 2 Location of facilities and allocation of core

Number of open facilities	*Node no. of open facility*	*Number of units of used products received by open facilities*					*Facility storage load ratio (remanufactured products) (%) Product no. (load)*	*CPU (sec)*
		P1	*P2*	*P3*	*P4*	*P5*		
2	3	153 744	—	—	111 520	148 660	P1(34.7); P4(27.5); P5(29.9)	1.96
	8	—	149 440	152 271	38 211	—	P2(47.3); P3(43.0); P4(9.7)	
3	1	—	149 440	—	134 142	—	P2(58.2); P4(41.8)	2.08
	2	—	—	152 271	155 89	148 660	P3(46.8); P4(4.3); P5(33.4)	
	3	153 774	—	—	—	—	P1(34.7)	
4	1	—	149 440	120 127	—	—	P2(58.2); P3(41.8)	2.33
	2	—	—	32 144	—	148 660	P3(9.9); P5(33.4)	
	3	153 774	—	—	—	—	P1(34.7)	
	6	—	—	—	149 731	—	P4(45.9)	
5	1	—	149 440	120 127	—	—	P2(58.2); P3(41.8)	
	2	—	—	32 144	—	148 660	P3(9.9); P5(33.4)	2.19
	3	153 774	—	—	—	—	P1(34.7)	
	6	—	—	—	149 731	—	P4(45.9)	
	7	—	—	—	—	—	—	

Example and results



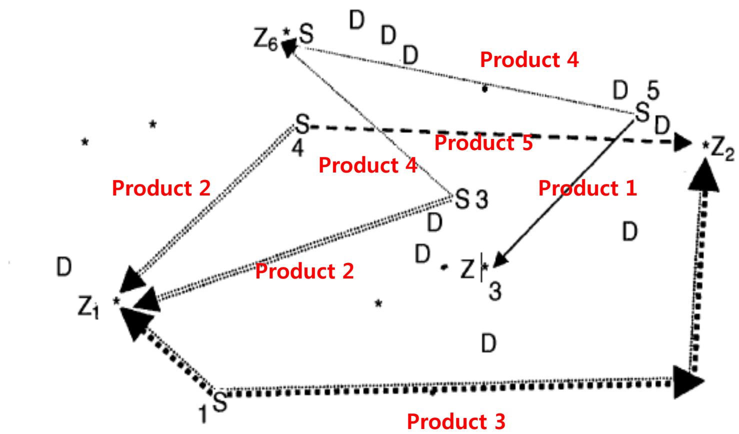
- **Results**



Legend:

* Potential facility locations
D Customer locations
S Collection zone locations

Figure 2a Potential facility locations.

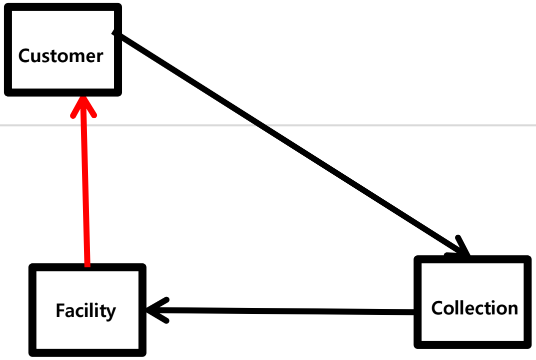


Optimal Transportation of cores to 4 open facilities

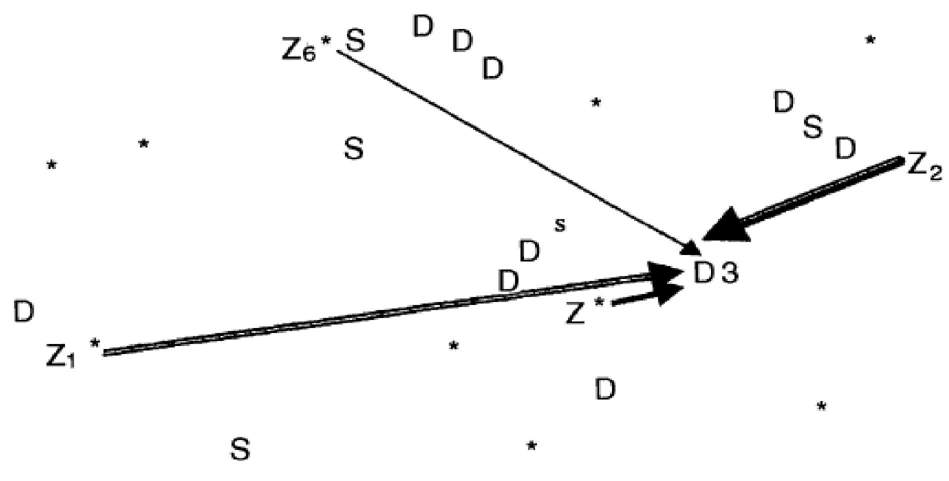
Open facilities at locations 1,2,3, and 6 (Denoted by Z_1, Z_2, Z_3, and Z_6)
Collection zone 1 transports core for product 3 to facilities 1 and 2
Collection zone 3 transports core for product 2 to facility 1 and product 4 to facility 6
Collection zone 4 transports core for product 2 to facility 1 and product 5 to facility 2
Collection zone 5 transports core for product 1 to facility 3 and product 4 to facility 6

Figure 2b Optimal transportation of cores.

Example and results



- **Results**



Optimal Distribution of remanufactured products to customer zone 3
Customer 3 receives:
Product 1 from Z_3
Product 2 from Z_1
Product 3 from Z_1 and Z_2
Product 4 from Z_6
Product 5 from Z_2

Figure 2c Optimal distribution.

4 Conclusion

Contents

- **Conclusion**
  - REVLOG model provides an important set in the design of such systems

- **Future research**
  - the potential benefits of management actions to reduce uncertainty in return flows of products
  - practicality of such programs