Multi-period reverse logistics network design

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Contents

Introduction

❖ **Reverse logistics network**

Reverse logistics network design problem [1]

- Reverse logistics process involved collection, inspection, recycling, refurbishing, and remanufacturing of used or returned products.

→ Process of planning, implementing and controlling of backward flows

Problem characteristics

- A multi-period and multi-product setting.
- Modular capacities and capacity expansion of the facilities.
- Reverse bill of materials.
- Finite demands in the secondary market
- Minimum throughput at the facilities and variable operational cost.
- A profit-oriented objective function.

Introduction

❖ **Reverse logistics network**

Reverse logistics network design problem [2]

- Consider a multi-period and product reverse logistics network that involved inspection/disassembly and remanufacturing facilities.

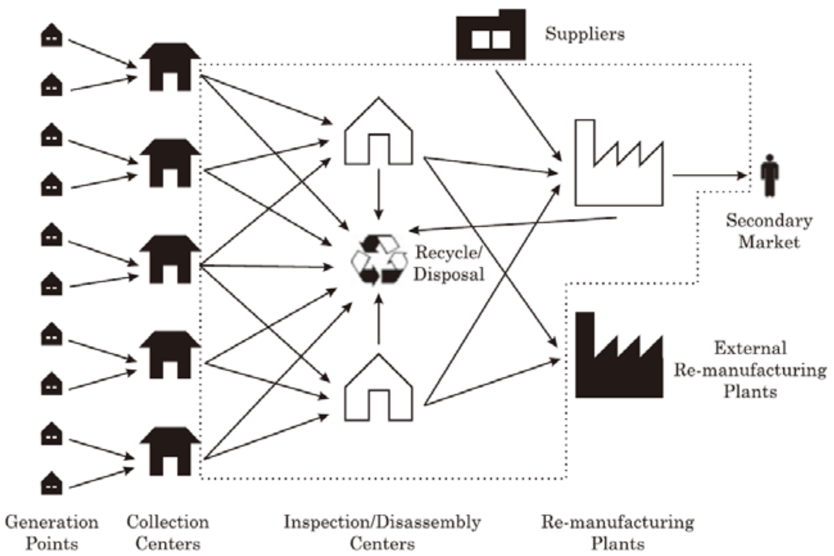

Figure 1. A reverse logistics network.

Literature review

Refer to configurational decisions

Table 1. Reverse logistics features in addition to the location of the reverse facilities.

Article	Location decisions for reverse activities: Inspection disassembly	Location decisions for reverse activities: Recycling	Location decisions for reverse activities: Remanufacturing refurbishing	Multiple products	Reverse BOM	Dynamic returns	Dynamic location	Capacities	Time adjustment capacities	Minimum throughput	Profit oriented	Secondary market
Jayaraman et al. (1999)			√	√				C				
Krikke et al. (1999)			√									
Louwers et al. (1999)		√		√								√
Fleischmann et al. (2001)	√		√									
Schultmann et al. (2003)	√				√			C				
Krikke et al. (2003)	√	√	√	√	√							
Realff et al. (2004)	√	√	√	√	√	√		C			√	√
Listeş and Dekker (2005)	√	√		√				C			√	√
Lieckens and Vandaele (2007)		√	√					ML			√	√
Figueiredo and Mayerle (2008)	√											
Pati et al. (2008)	√	√		√				C				
Salema et al. (2009)	√		√	√		√		C		√	√	
Srivastava (2008)			√	√				C	√		√	
Fonseca et al. (2010)	√	√		√	√			M				
Gomes et al. (2011)	√	√		√	√	√		C				
The new model	√	√	√	√	√	√	√	M	√	√	√	√

'C': Capacitated
'M': Modular capacities
'ML': Multi-level capacities

Problem description

- **Multi-product reverse logistics network design problem (MPRLND)**

Objective function

- Maximizes the profit.

→ Revenue - costs

Revenue

← Sum of the revenues from the recycling centers, from the external remanufacturing plants, from the secondary market, and then subtract the costs.

Costs

← The costs are the fixed costs of establishing facilities and capacity modules, operational costs, transportation costs, inventory holding costs, and component purchasing costs.

Problem description

❖ **Multi-product reverse logistics network design problem (MPRLND)**

Decision variables

- Location of the inspection centers and remanufacturing facilities.
- Capacity of the new facilities.
- Capacity expansion of the existing facilities.
- Flow routing through the network.
- Amount of inventory to hold and the amount of components to purchase from the suppliers in the remanufacturing plants

⟶ Location, capacities, flow routing, inventory holding and components purchase.

Problem description

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

Main constraints

• Flow balance constraints

◄---- Collection center, inspection center, remanufacturing center, external remanufacturing center and secondary market

• Capacity (capacity expansion) constraints

◄---- New (existing) facilities

• Minimum throughput constraints

◄---- Inspection center or remanufacturing center

Assumption

• All the components are assumed to be suitable for remanufacturing.

Problem description

Mathematical formulation

Notation [1]

Sets

P	set of products (disposals)
C	set of components
C_p	set of components for product $p \in P (C_p \subset C)$
T	set of periods in the planning horizon
I^G	set of generation points or collection centers
I^I	set of potential locations for inspection centers
I^R	set of potential locations for remanufacturing plants
R^G	recycling node for collection centers
R^I	recycling node for inspection centers
R^R	recycling node for remanufacturing plants
ER	external remanufacturing plants
SM	secondary market
Q^I	set of capacities of the modules available for inspection centers
Q^R	set of capacities of the modules available for remanufacturing plants

Revenues

PRG_p^t	unit revenue from product $p \in P$ recycled from a collection center in period $t \in T$
PRI_c^t	unit revenue from component $c \in C$ recycled from an inspection center in period $t \in T$
PRR_c^t	unit revenue from component $c \in C$ recycled from a remanufacturing plant in period $t \in T$
PER_{ip}^t	unit revenue from product $p \in P$ sold to an external remanufacturing plant at $i \in ER$ in period $t \in T$
PSM_p^t	unit revenue from product $p \in P$ sold to the secondary market in period $t \in T$

General parameters

S_{ip}^t	supply of product or disposal $p \in P$ from collection center $i \in I^G$ in period $t \in T$
D_p^t	demand of the secondary market for product $p \in P$ in period $t \in T$
α_{pc}	amount of component $c \in C_p$ in one unit of product $p \in P$
γI_p	unit capacity consumption factor for product $p \in P$ for inspection
γR_p	unit capacity consumption factor for product $p \in P$ for remanufacturing
γ_c	unit inventory capacity consumption factor for component $c \in C$
MI_i^t	minimum throughput required for an inspection center located at $i \in I^I$ in period $t \in T$
MR_i^t	minimum throughput required for a remanufacturing plant located at $i \in I^R$ in period $t \in T$
KER_i^t	capacity of the external remanufacturing plant located at $i \in ER$ in period $t \in T$
KI_q	capacity of inspection of a module of type $q \in Q^I$
KP_q	production capacity of a module of type $q \in Q^R$
KH_q	inbound handling capacity of a module of type $q \in Q^R$
KIN_q	inventory holding capacity of a module of type $q \in Q^R$

Mathematical formulation

Notation [2]

Costs

FI_i^t	set-up cost for installing an inspection center at $i \in I^I$ in the beginning of period $t \in T$
FR_i^t	set-up cost for installing a remanufacturing plant at $i \in I^R$ in the beginning of period $t \in T$
FKI_{iq}^t	set-up cost for a module of type $q \in Q^I$ to be added to an inspection center located at $i \in I^I$ in period $t \in T$
FKR_{iq}^t	set-up cost for a module of type $q \in Q^R$ to be added to a remanufacturing plant located at $i \in I^R$ in period $t \in T$
OI_{ip}^t	cost for operating one unit of product $p \in P$ in an inspection center $i \in I^I$ in period $t \in T$
OR_{ip}^t	cost for producing one unit of product $p \in P$ in a remanufacturing plant $i \in I^R$ in period $t \in T$
T_{ijp}^t	unit transportation cost of product $p \in P$ (component $p \in C$) from $i \in I^G$ to $j \in I^I$, or $i \in I^I$ to $j \in I^R$ in period $t \in T$
IC_{ic}^t	unit inventory holding cost for component $c \in C$ in a remenufacturing plant $i \in I^R$ in period $t \in T$
BC_{ic}^t	cost of purchasing one unit of component $c \in C$ for remanufacturing plant $i \in I^R$ in period $t \in T$

Decision variables

x_{ijp}^t	amount of product $p \in P$ (component $p \in C$) shipped from site i to site j, $(i,j) \in A$, in period $t \in T$
I_{ic}^t	amount of component $c \in C$ hold in inventory in remanufacturing plant $i \in I^R$ in the end of period $t \in T$
b_{ic}^t	amount of component $c \in C$ purchased for remanufacturing plant $i \in I^R$ in the beginning of period $t \in T$

$$y_i^t = \begin{cases} 1 & \text{If an inspection center } i \in I^I \text{ is operating in period } t \in T, \\ 0 & \text{otherwise,} \end{cases}$$

$$z_i^t = \begin{cases} 1 & \text{If a remanufacturing plant } i \in I^R \text{ is operating in period } t \in T, \\ 0 & \text{otherwise.} \end{cases}$$

$$u_{iq}^t = \begin{cases} 1 & \text{If a module of type } q \in Q^I \text{ is added to an inspection center} \\ & i \in I^I, \text{ in the beginning of period } t \in T, \\ 0 & \text{otherwise,} \end{cases}$$

$$v_{iq}^t = \begin{cases} 1 & \text{If a module of type } q \in Q^R \text{ is added to a remanufacturing center} \\ & i \in I^R, \text{ in the beginning of period } t \in T, \\ 0 & \text{otherwise.} \end{cases}$$

Problem description

- **Mathematical formulation of the model**

MPRLND [1]

$$
\begin{aligned}
Max \quad & \sum_{t\in T}\Bigg[\sum_{p\in P}\sum_{i\in I^G} PRG^t_p x^t_{iR^Gp} + \sum_{c\in C}\sum_{i\in I^I} PRI^t_c x^t_{iR^Ic} + \sum_{c\in C}\sum_{i\in I^R} PRR^t_c x^t_{iR^Rc} \\
& + \sum_{p\in P}\sum_{i\in I^I}\sum_{j\in ER} PER^t_{jp} x^t_{ijp} + \sum_{p\in P}\sum_{i\in I^R} PSM^t_p x^t_{iSMp}\Bigg] \\
& - \sum_{t\in T}\Bigg[\sum_{i\in I^I} FI^t_i\left(y^t_i - y^{t-1}_i\right) + \sum_{i\in I^R} FR^t_i\left(z^t_i - z^{t-1}_i\right)\Bigg] \\
& - \sum_{t\in T}\Bigg[\sum_{i\in I^I}\sum_{q\in Q^I} FKI^t_{iq} u^t_{iq} + \sum_{i\in I^R}\sum_{q\in Q^R} FKR^t_{iq} v^t_{iq}\Bigg] \\
& - \sum_{t\in T}\sum_{p\in P}\Bigg[\sum_{i\in I^G}\sum_{j\in I^I} OI^t_{jp} x^t_{ijp} + \sum_{i\in I^R} OR^t_{ip} x^t_{iSMp}\Bigg] \\
& - \sum_{t\in T}\Bigg[\sum_{p\in P}\sum_{i\in I^G}\sum_{j\in I^I} T^t_{ijp} x^t_{ijp} + \sum_{c\in C}\sum_{i\in I^I}\sum_{j\in I^R} T^t_{ijc} x^t_{ijc}\Bigg] \\
& - \sum_{t\in T}\sum_{c\in C}\sum_{i\in I^R} IC^t_{ic} I^t_{ic} \\
& - \sum_{t\in T}\sum_{c\in C}\sum_{i\in I^R} BC^t_{ic} b^t_{ic}, \qquad (1)
\end{aligned}
$$

s.t.

$$S^t_{ip} = x^t_{iR^Gp} + \sum_{j\in I^I} x^t_{ijp}, \quad i\in I^G,\ p\in P,\ t\in T, \qquad (2)$$

$$\sum_{j\in I^G} x^t_{jip} = \sum_{j\in ER} x^t_{ijp} + \frac{1}{\alpha_{pc}} x^t_{iR^Ic} + \sum_{j\in I^R}\frac{1}{\alpha_{pc}} x^t_{ijc},$$
$$i\in I^I, p\in P, c\in C_p, t\in T, \qquad (3)$$

$$\sum_{j\in I^I} x^t_{jic} + I^{t-1}_{ic} + b^t_{ic} = x^t_{iR^Rc} + \alpha_{pc} x^t_{iSMp} + I^t_{ic},$$
$$i\in I^R,\ p\in P,\ c\in C_p,\ t\in T, \qquad (4)$$

Flow balance

$$\sum_{i\in I^R} x^t_{iSMp} \leqslant D^t_p, \quad p\in P,\ t\in T, \qquad (5)$$

Amount of products sold to the secondary market

Problem description

- **Mathematical formulation of the model**

MPRLND [2]

$$\sum_{i\in I^I}\sum_{p\in P} x_{ijp}^t \leqslant KER_j^t, \quad j\in ER,\ t\in T, \tag{6}$$

$$\sum_{j\in I^G}\sum_{p\in P} \gamma l_p x_{jip}^t \leqslant \sum_{\tau=1}^{t}\sum_{q\in Q^I} KI_q u_{iq}^\tau, \quad i\in I^I,\ t\in T, \tag{7}$$

$$\sum_{p\in P} \gamma R_p x_{iSMp}^t \leqslant \sum_{\tau=1}^{t}\sum_{q\in Q^R} KP_q v_{iq}^\tau, \quad i\in I^R,\ t\in T, \tag{8}$$

$$\sum_{j\in I^I}\sum_{c\in C} x_{jic}^t \leqslant \sum_{\tau=1}^{t}\sum_{q\in Q^R} KH_q v_{iq}^\tau, \quad i\in I^R,\ t\in T, \tag{9}$$

$$\sum_{c\in C} \gamma_c I_{ic}^t \leqslant \sum_{\tau=1}^{t}\sum_{q\in Q^R} KIN_q v_{iq}^\tau, \quad i\in I^R,\ t\in T, \tag{10}$$

Capacity constraints

$$\sum_{q\in Q^I} u_{iq}^t \leqslant y_i^t, \quad i\in I^I,\ t\in T, \tag{11}$$

$$\sum_{q\in Q^R} v_{iq}^t \leqslant z_i^t, \quad i\in I^R,\ t\in T, \tag{12}$$

Capacity expansion constraints

$$\sum_{j\in I^G}\sum_{p\in P} x_{jip}^t \geqslant MI_i^t y_i^t, \quad i\in I^I,\ t\in T, \tag{13}$$

$$\sum_{p\in P} x_{iSMp}^t \geqslant MR_i^t z_i^t, \quad i\in I^R,\ t\in T, \tag{14}$$

Minimum throughput constraints

$$y_i^t \leqslant y_i^{t+1}, \quad i\in I^I,\ t\in T\setminus\{|T|\}, \tag{15}$$

$$z_i^t \leqslant z_i^{t+1}, \quad i\in I^R,\ t\in T\setminus\{|T|\}, \tag{16}$$

$$x_{ijp}^t \geqslant 0, \quad (i,j)\in A,\ p\in P, C,\ t\in T, \tag{17}$$

$$I_{ic}^t \geqslant 0, \quad i\in I^R,\ c\in C,\ t\in T, \tag{18}$$

$$b_{ic}^t \geqslant 0, \quad i\in I^R,\ c\in C,\ t\in T, \tag{19}$$

$$y_i^t \in \{0,1\}, \quad i\in I^I,\ t\in T, \tag{20}$$

$$z_i^t \in \{0,1\}, \quad i\in I^R,\ t\in T, \tag{21}$$

$$u_{iq}^t \in \{0,1\}, \quad i\in I^I,\ q\in Q^I,\ t\in T, \tag{22}$$

$$v_{iq}^t \in \{0,1\}, \quad i\in I^R,\ q\in Q^R,\ t\in T. \tag{23}$$

A case study

- **Experiment design with results**

Case data

A real life problem in Germany in the context of reverse logistics network design for washing machines and tumble dryers.

→ 40 collection centers, 5-years planning horizon, etc.

✓ Solution method

CPLEX 11.2.

- **Experiment design with results**

Test results

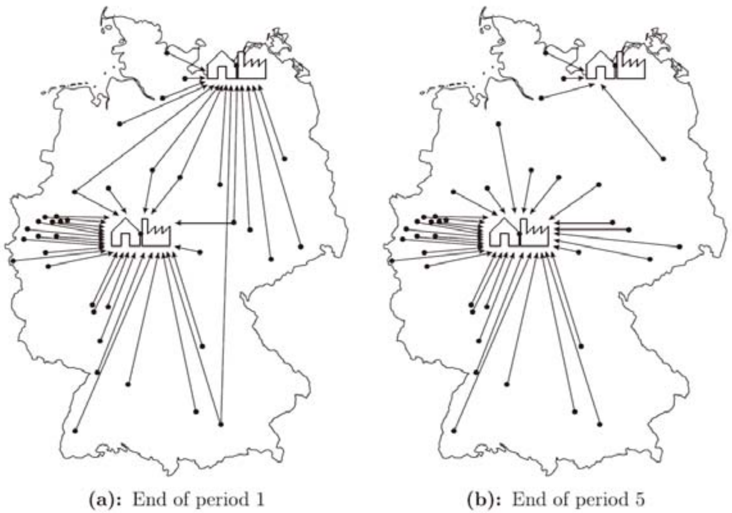

Figure 2. A solution of the problem.

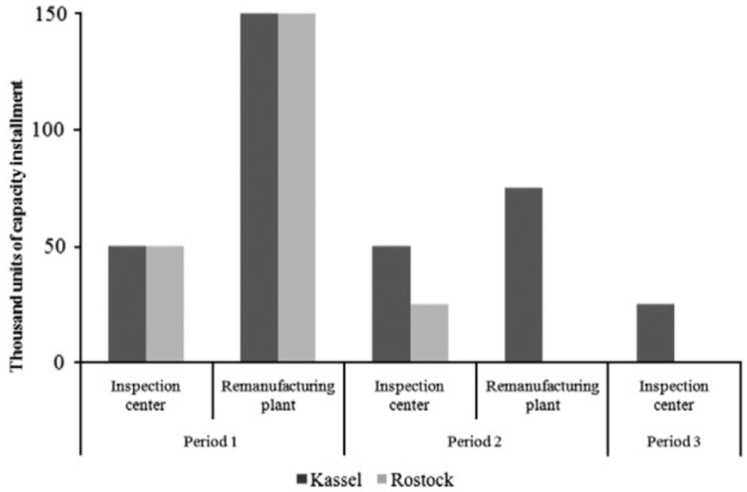

Figure 3. Capacity installment decisions in the solution.

Conclusion

❖ Summary

- Proposed a mathematical programming framework for multi-period reverse logistics network design problems.
- The proposed model accommodates several features of practical relevance.
- There can be gains in the profit by using a multi-period model compared to using a static one.
- The study also gave some essential insights such as inspection centers and remanufacturing plants can be co-located due to potential savings in the transportation costs between facilities.

Thank You !

Q and A