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An integer linear programming for a comprehensive reverse supply chain

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Abstract: Reverse supply chain is a cycle of recovery for the products and materials used by the customers but can be returned to the chain performing some operations. Due to significance of reverse supply chain in the content of environmental and economical aspects, we formulate a mathematical model of reverse multi-layer multi-product supply chain for minimizing the total costs including returning, disassembly, processing, recycling, remanufacturing, and distribution centers. The presented model is an integer linear programming model being solved using Lingo 9 software. Numerical experiments are conducted to gain insight into the proposed model. The solutions provide a decision aid stream strengthening the concept of reverse supply network design and analysis for profit-making organization.

Keywords: reverse supply chain, mathematical modeling, cost analysis

1. Introduction

Companies focus on setting up a reverse supply chain either because of environmental regulations or to reduce their operating costs by reusing products or components. IBM, for instance, has profited from its programs to receive end-of-use products, promote second hand items internet auctions, and dismantle equipment as a source of spare parts (Fleischmann, Van Nunen, & Gräve, 2003).

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PUBLIC INTEREST STATEMENT

Due to significance of reverse supply chain in the content of environmental and economical aspects, we formulate a mathematical model of reverse multi-layer multi-product supply chain for minimizing the total costs including returning, disassembly, processing, recycling, remanufacturing, and distribution centers.

A reverse logistics system comprises a series of activities, which form a continuous process to treat return-products until they are properly recovered or disposed. These activities include collection, cleaning, disassembly, test and sorting, storage, transport, and recovery operations. The latter can also be represented as one or a combination of several main recovery options, like reuse, repair, refurbishing, remanufacturing, cannibalization, and recycling (Dekker & Van Der Laan, 1999; Guide, Harrison, & Van Wassenhove, 2003; Thierry, Salomon, Van Nunen, & Van Wassenhove, 1993). In reuse, the returned product can be used more than once in the same form after cleaning or reprocessing. Remanufacturing is an industrial process in which worn-out products are restored to like-new condition. Recycling denotes material recovery without conserving any product structure.

Reverse supply chain refers to the movement of goods from customer to vendor. This is the reverse of the traditional supply chain movement of goods from vendor to customer. Reverse logistics is the process of planning, implementing and controlling the efficient and effective inbound flow, and storage of secondary goods and related information for the purpose of recovering value or proper disposal. Typical examples of reverse supply chain include:

- Product returns and management of their deposition.
- Remanufacturing and refurbishing activities.
- Management and sale of surplus, as well as returned equipment and machines from the hardware leasing business.

In these cases, the resource goes at least one step back in the supply chain. For instance, products move from customer to distributor or manufacturer. Other instances of products reversing direction in the supply chain are manufacturing returns, commercial returns (B2B and B2C), product recalls, warranty returns, service returns, end-of-use returns, and end-of-life returns. There are various types of reverse supply chains, and they arise at different stages of the product cycle; however, most return supply chains are organized to carry out five key processes:

- Product acquisition: Obtaining the used product from the user by the reseller or manufacturer.
- Reverse logistics: Transporting products to a facility for inspecting, sorting, and disposition.
- Inspection and disposition: Assessing the condition of the return and making the most profitable decision for reuse.
- Remanufacturing or refurbishing: Returning the product to its original specifications.
- Marketing: Creating secondary markets for the recovered products.

Kim, Hong, and Goyal (2009) developed a fair and equitable mechanism of sharing the profits achieved due to cooperation in a supply chain between a single manufacturer and a single retailer. Damghani and Taghavifard (2012) considered a generic process in which just-in-time practices and changed them into agility indices, and agility indices were converted into performance measurement in supply chain. Fazlollahtabar, Mahdavi, and Mohajeri (2013) proposed a fuzzy mathematical programming model for a supply chain which considered multiple depots, multiple vehicles, multiple products, multiple customers, and different time periods.

Concerning reverse logistics, a lot of researches have been made on various fields and subjects such as reuse, recycling, remanufacturing logistics, etc. In this paper, we propose a framework and a mathematical model for costs in a multi-layer multi-product in reverse supply chain system.

This paper is organized as follows. In next section, we introduce some key literatures relevant to this study. In Section 3, a general framework and problem definition for reverse supply chain are proposed. Section 4 proposes the mathematical model of the reverse supply chain. In Section 5, numerical experiments are presented. Finally, conclusions and further researches are addressed in the last section.

2. Related literature

Supply chain redesign involves complex competencies such as integration with suppliers and customers to create value as well as the acquisition of external information and its transformation into practices capable of producing marketable outputs (Dobrzykowski, Tran, & Hong, 2011). Supply chain management (SCM) is regarded as a means to maximize the overall value generated. SCM includes all functions involved in receiving and filling a customer request by forging close relationships with customers and suppliers. Strong relationships and mutual trust between buyer and suppliers are essential for the successful implementation of SCM (Kumar, Singh, & Singh, 2011). In a supply chain, selection of right suppliers is a strategic consideration. Supplier selection is the process of finding suitable suppliers from the set of alternative suppliers who can be strategic partners to the organization and provide the right quality of product or services at the right price at the right time. Such a problem is highly complex one because it involves a number of qualitative and quantitative factors having interdependencies among themselves (Sreekumar & Mahapatra, 2011).

Increasing inclination of firms towards supply chain collaboration as a means of developing or enhancing core competency has gained noticeable research attention. Successfully implementing collaboration is a major concern for both industries and academia. Building from the literature base, the study investigates effect of collaborative culture on all collaborative activities, and effect of preparedness that moderates the relationship of collaborative activities to supply chain performance (Kumar & Banerjee, 2012). The rapid advancement in communication technology, coupled with spiraling customer expectations, are increasingly forcing business enterprises to seek inter-organizational coordination for smooth material and informational flow across the total supply chain justifiably. Therefore, given the inherent uncertainties pervading the operational environment within real-world supply chains, it becomes imperative for each partnering echelon to focus on individual information requirements from a viewpoint of global optimization of overall supply chain performance (Dev & Shankar, 2012). Currently, a number of factors encountered in global competition force companies to pursue the more rapid development and introduction of new and innovative products and product generations. Comparatively, little academic research has been conducted on product change projects in the context of SCM (Slamanig & Winkler, 2012).

For the last decade, increasing concerns over environmental degradation and increased opportunities for cost savings or revenues from returned products prompted some researchers to formulate more effective reverse logistics strategies. Kroon and Vrijens (1995) reported a case study concerning the design of a logistics system for reusable transportation packages. The authors proposed a mixed integer programming (MIP), closely related to a classical un-capacitated warehouse location model. Jayaraman, Patterson, and Rolland (2003) proposed a general MIP model and solution procedure for a reverse distribution problem focused on the strategic level. The model decided whether each remanufacturing facility is open considering the product return flow.

Jayaraman, Guide, and Srivastava (1999) presented a MIP to determine the optimal number and locations of remanufacturing facilities for the electronic equipment. They developed heuristic concentration procedures combined with heuristic expansion components to handle relatively large problems. Kim, Song, and Jeong (2006) discussed a notion of remanufacturing system in reverse logistics environment. They proposed a general framework in view of supply planning and developed a mathematical model to optimize the supply planning function. The model determined the quantity of products parts processed in the remanufacturing facilities subcontractors and the amount of parts purchased from the external suppliers while maximizing the total remanufacturing cost saving.

Barros, Dekker, and Scholten (1998) proposed a MIP model considered two-echelon location problems with capacity constraints based on a multi-level capacitated warehouse location problem. Pati, Vrat, and Kumar (2008) developed an approach based on a mixed integer goal programming model to solve the problem recycling in supply chain. The model studied the inter-relationship between multiple objectives of a recycled paper distribution network. The objectives considered were reduction in reverse logistics cost.

Listes and Dekker (2005) suggested a scenario-based stochastic mixed integer programming model to maximize the total profit in a sand recycling network. Lee and Dong (2008) developed an mixed integer linear programming (MILP) model for integrated logistics network design for end-of-lease computer products. They considered a simple network with a single production center and a given number of hybrid distribution-collection facilities to be opened which have been solved using tabu search.

Du and Evans (2008) minimized tardiness and total costs for location and capacity decisions in a closed-loop logistics network operated by third party logistics (3PL) providers. To solve the bi-objective MILP model, a hybrid scatter search method was developed. Salema, Barbosa-Povoa, and Novais (2007) studied the design of a reverse distribution network and found that most of the proposed models on the subject are case based and, for that reason, they lack generality. The model contemplates the design of a generic reverse logistics network where capacity limits, multi-product management, and uncertainty on product demands and returns are considered. A mixed integer formulation was developed. This formulation allowed for any number of products, establishing a network for each product while guaranteeing total capacities for each facility at a minimum cost. But the inventory was not taken into consideration.

Lee, Rhee, and Gen (2007) proposed the reverse logistics network problem minimizing total reverse logistics various shipping costs. However, several researchers studied and analyzed cost problem in reverse logistics, our study focuses on a general framework and state total cost in reverse supply chain.

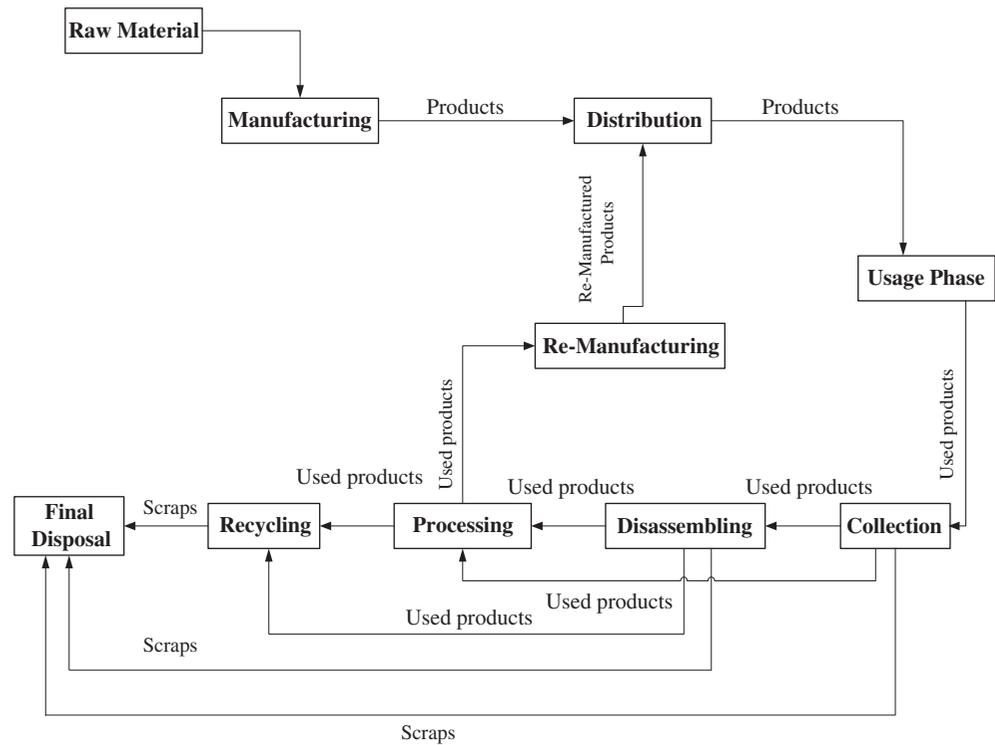
This paper propose a multi-layer, multi-product reverse supply chain problem which consist of returning center, disassembly center, processing center, manufacturing center, recycling center, material center, and distribution center costs while minimizing of total costs in reverse supply chain for returned products.

3. Problem definition

The reverse supply chain under study is a multi-layer and multi-product one, where the chain includes several products in a same category (e.g. electronic devices in media category, TV, and Radio). Also, several layers are considered in the proposed supply chain namely, supplier, manufacturer, distributor, and consumer. In general, the current reverse logistic systems aim at determining the economic value of reusable items. Recent models focused on the vehicle routing problem and second hand product sale and services. In the proposed model, the returned products after collecting and inspecting divides into two groups of disassemblable and not disassemblable products. The products which can be taken parted to the parts will be sent to the disassembling centers and there, they will be converted to the parts. There they are divided into reusable and not reusable parts. The not reusable parts will rebut safely and the reusable parts will be sent to the processing center. Some of the products that don't need to be disassembling; according to their variety, will be transmitted to the processing center right after collecting centers, then considering to the variety of product and the request of manufacturing centers, they will be sent to them accordingly. In the remanufacturing process, according to the production center's demand, the parts which can be used again, after processing center will be sent to the remanufacturing center and after compounding with the other parts will be changed into new products and can return to the distribution layer in the proposed supply chain. In the recycling process according to the recycling center's demand, the disassembled parts (which can recover again) right after disassembling centers will be sent to the recycling centers. The configuration is shown in Figure 1.

Several tasks in the process of reverse supply chain motivated us to focus on cost analysis over the elements required for the reverse process. In the previous studies, researches considered some of the cost elements and formulated a mathematical model for decision-making. But, a more comprehensive study considering most of the cost elements exist in a reverse supply chain is developed here.

Figure 1. Framework for the proposed reverse supply chain.



3.1. Purpose

In this paper, the reverse supply chain model has been considered for returned products with the purpose of minimizing the reverse supply chain costs.

3.2. Assumptions

- The quantity of return, disassembly, processing, manufacturing, recycling, material, and distribution centers are determined.
- Some products will be transported straightly from return centers to the processing centers.
- Some parts will be transported straightly from disassembly centers to the recycling centers.

3.3. Indices, parameters, and decision variables

3.3.1. Indices

- i : index of returning centers
- j : index of disassembly centers
- k : index of processing center
- f : index of manufacturing center
- r : index of recycling center
- p : index of products
- m : index of parts
- l : index of distribution centers
- c : index of customers

3.3.2. Parameters

- a_{ip} : the capacity of returning center i for product p
- b_{jm} : the capacity of disassembly center j for parts m
- u_{km} : the capacity of processing center k for part m
- h_{fm} : the capacity of production center f for parts m
- E_{lm} : the capacity of distribution center l for part m
- DM_{fm} : the manufacturing center's demand f for part m
- $DRCP_r$: the recycling center's demand r for product p
- $DRCM_{rm}$: the recycling center's demand r for part m
- DD_{lm} : the distribution center's demand l for part m
- DC_{cm} : the client's demand c for part m
- n_{mp} : The produced part's amount m from disassembling one product p
- CSR_{jp} : unit cost of transportation from returning center i to disassembly center j for product p
- CSR_{ikp} : unit cost of transportation from returning center i into the processing center k for product p
- $CSDP_{jkm}$: unit cost of transportation from disassembly center j into processing center k for part m
- $CSDRC_{jrm}$: unit cost of transportation from disassembly center j into the recycling center r for part m
- $CSPM_{kfm}$: unit cost of transportation from processing center k into the manufacturing center f for part m
- $CSPRC_{krm}$: unit cost of transportation from processing center k into the recycling center r for part m
- $CSPDC_{flm}$: unit cost of transportation from manufacturing center f into the distribution center l for part m
- $CSDC_{lcm}$: unit cost of transportation from distribution center l into the clients c for part m
- $FOCD_{jm}$: the fixed opening cost for disassembly center j for part m
- $FOCP_{km}$: the fixed opening cost for processing centers k for part m
- $FOCR_{ip}$: the fixed opening cost for returning centers i for product p
- $FOCRC_{rm}$: the fixed opening cost for recycling centers r for part m
- RMC_{fm} : unit cost of remanufacturing in manufacturing center f for part m
- IC_{ip} : unit cost of maintaining in returning center i for product p
- OCD_{jm} : unit cost of operations in disassembly center j for part m
- OCP_{km} : unit cost of operations in processing center k part m
- $OCRC_{rm}$: unit cost of operations in recycling center r part m
- NRS_{min} : the minimum amount of returning center for opening and operations
- NRS_{max} : the maximum amount of returning centers for operations and opening
- NDS_{min} : the minimum amount of disassembling centers for opening and operations
- NDS_{max} : the maximum quantity of disassembling centers for opening and operations
- NPS_{min} : the minimum amount of processing centers for opening and operations

- NPS_{max} : the maximum amount of processing centers for opening and operations
- $NRCS_{min}$: the minimum amount of recycling centers for opening and operations
- $NRCS_{max}$: the maximum amount of recycling centers for opening and operations

3.3.3. Decision variables

- Φ_{ijp} : amount shipped from returning center i to disassembling center j for product p
- δ_{ikp} : amount shipped from returning center i into the processing center k for product p
- G_{jkm} : amount shipped from disassembly center j into the processing center k for part m
- O_{jrm} : amount shipped from disassembly center j into the recycling center r for part m
- Q_{kfm} : amount shipped from processing center k into the manufacturing center f for part m
- S_{krm} : amount shipped from processing center k into the recycling center r for part m
- T_{flm} : amount shipped from manufacturing center f into the distribution center l for part m
- V_{lcm} : amount shipped from distribution center l into the clients c for part m
- α_{jm} : if the disassembly center j is open for part m , 1 or otherwise 0
- β_{km} : if processing center k is open for part m , 1 or otherwise 0
- γ_{ip} : if the returning center i is open for product p , 1 or otherwise 0
- λ_{rm} : if recycling center r is open for part m , 1 or otherwise 0
- μ_{fm} : the part's flow amount m in manufacturing center f
- X_{ip} : the product's flow amount p in returning center i
- Y_{jm} : the part's flow amount m in disassembly center j
- θ_{km} : the part's flow amount m in processing center k
- τ_{rm} : the part's flow amount m in recycling center r

4. Mathematical formulation

Considering the purpose and the accompanying assumptions, we formulate the problem in an integer linear mathematical program. The advantages of such a program are: obtaining exact solutions, no essence for linearization causing more computational efforts, capability of the program in large-sized problems and simplicity of implementation in optimization software. The formulation of the mathematical model is given below:

$$\begin{aligned}
 \text{Min } Z = & \sum_{i=1}^I \sum_{j=1}^J \sum_{p=1}^P \text{CSR}_{D_{ijp}} \Phi_{ijp} + \sum_{i=1}^I \sum_{k=1}^K \sum_{p=1}^P \text{CSR}_{P_{ikp}} \delta_{ikp} + \sum_{j=1}^J \sum_{k=1}^K \sum_{m=1}^M \text{CSD}_{P_{jkm}} G_{jkm} \\
 & + \sum_{j=1}^J \sum_{r=1}^R \sum_{m=1}^M \text{CSD}_{R_{jrm}} O_{jrm} + \sum_{k=1}^K \sum_{f=1}^F \sum_{m=1}^M \text{CSR}_{M_{kfm}} Q_{kfm} + \sum_{k=1}^K \sum_{r=1}^R \sum_{m=1}^M \text{CSP}_{R_{krm}} S_{krm} \\
 & + \sum_{f=1}^F \sum_{l=1}^L \sum_{m=1}^M \text{CSP}_{D_{flm}} T_{flm} + \sum_{l=1}^L \sum_{c=1}^C \sum_{m=1}^M \text{CSD}_{C_{lcm}} V_{lcm} + \sum_{j=1}^J \sum_{m=1}^M \text{FOCD}_{jm} \alpha_{jm} \\
 & + \sum_{k=1}^K \sum_{m=1}^M \text{FOCP}_{km} \beta_{km} + \sum_{i=1}^I \sum_{p=1}^P \text{FOCR}_{ip} \gamma_{ip} + \sum_{r=1}^R \sum_{m=1}^M \text{FOCRC}_{rm} \lambda_{rm} + \sum_{f=1}^F \sum_{m=1}^M \text{RCM}_{fm} \mu_{fm} \\
 & + \sum_{i=1}^I \sum_{p=1}^P \text{IC}_{ip} X_{ip} + \sum_{j=1}^J \sum_{m=1}^M \text{OCD}_{jm} Y_{jm} + \sum_{k=1}^K \sum_{m=1}^M \text{OCP}_{km} \theta_{km} + \sum_{r=1}^R \sum_{m=1}^M \text{OCRC}_{rm} \tau_{rm} \tag{1}
 \end{aligned}$$

s.t.

$$\sum_{j=1}^J \Phi_{ijp} \leq a_{ip} \gamma_{ip} \quad \forall i, p \quad (2)$$

$$\sum_{k=1}^K \delta_{ikp} \leq a_{ip} \gamma_{ip} \quad \forall i, p \quad (3)$$

$$X_{ip} \leq a_{ip} \gamma_{ip} \quad \forall i, p \quad (4)$$

$$\sum_{k=1}^K G_{jkm} \leq b_{jm} \alpha_{jm} \quad \forall j, m \quad (5)$$

$$\sum_{r=1}^R O_{jrm} \leq b_{jm} \alpha_{jm} \quad \forall j, m \quad (6)$$

$$Y_{jm} \leq b_{jm} \alpha_{jm} \quad \forall j, m \quad (7)$$

$$\sum_{f=1}^F Q_{kfm} \leq u_{km} \beta_{km} \quad \forall k, m \quad (8)$$

$$\sum_{r=1}^R S_{krm} \leq u_{km} \beta_{km} \quad \forall k, m \quad (9)$$

$$\theta_{km} \leq u_{km} \beta_{km} \quad \forall k, m \quad (10)$$

$$\sum_{l=1}^L T_{flm} \leq h_{fm} \quad \forall f, m \quad (11)$$

$$\mu_{fm} \leq h_{fm} \quad \forall f, m \quad (12)$$

$$\sum_{c=1}^C V_{lcm} \leq e_{lm} \quad \forall l, m \quad (13)$$

$$\sum_{k=1}^K Q_{kfm} \geq DM_{fm} \quad \forall f, m \quad (14)$$

$$\mu_{fm} \geq DM_{fm} \quad \forall f, m \quad (15)$$

$$\sum_{f=1}^F T_{flm} \geq DD_{lm} \quad \forall l, m \quad (16)$$

$$\sum_{l=1}^L V_{lcm} \geq DC_{cm} \quad \forall c, m \quad (17)$$

$$\sum_{j=1}^J O_{jrm} + \sum_{k=1}^K S_{krm} \geq DRCM_{rm} \quad \forall r, m \quad (18)$$

$$\tau_{rm} \geq DRCM_{rm} \quad \forall r, m \quad (19)$$

$$\sum_{i=1}^I \sum_{k=1}^K \delta_{ikp} \geq \sum_{r=1}^R DRCP_{rp} \quad \forall p \quad (20)$$

$$\sum_{j=1}^J \sum_{k=1}^K G_{jkm} \geq \sum_{f=1}^F DM_{fm} \quad \forall m \quad (21)$$

$$\sum_{j=1}^J \sum_{k=1}^K G_{jkm} \leq n_{mp} \left(\sum_{i=1}^I \sum_{j=1}^J \Phi_{ijp} \right) \quad \forall m, p \quad (22)$$

$$\sum_{j=1}^J \sum_{r=1}^R O_{jrm} \leq n_{mp} \left(\sum_{i=1}^I \sum_{j=1}^J \Phi_{ijp} \right) \quad \forall m, p \quad (23)$$

$$NRS_{\min} \leq \sum_{i=1}^I \gamma_{ip} \leq NRS_{\max} \quad \forall p \quad (24)$$

$$NDS_{\min} \leq \sum_{j=1}^J \alpha_{jm} \leq NDS_{\max} \quad \forall m \quad (25)$$

$$NPS_{\min} \leq \sum_{k=1}^K \beta_{km} \leq NPS_{\max} \quad \forall m \quad (26)$$

$$NRCS_{\min} \leq \sum_{r=1}^R \lambda_{rm} \leq NRCS_{\max} \quad \forall m \quad (27)$$

$$\sum_{f=1}^F T_{flm} = \sum_{c=1}^C V_{lcm} \quad \forall l, m \quad (28)$$

$$\sum_{k=1}^K G_{jkm} + \sum_{r=1}^R O_{jrm} \leq Y_{jm} \quad \forall j, m \quad (29)$$

$$\sum_{j=1}^J \Phi_{ijp} + \sum_{k=1}^K \delta_{ikp} \leq X_{ip} \quad \forall i, p \quad (30)$$

$$\sum_{f=1}^F Q_{kfm} + \sum_{r=1}^R S_{krm} \leq \theta_{km} \quad \forall k, m \quad (31)$$

$$\sum_{l=1}^L T_{flm} \leq \mu_{fm} \quad \forall f, m \quad (32)$$

$$\Phi_{ijp}, \delta_{ikp}, G_{jkm}, O_{jrm}, Q_{kfm}, S_{krm}, T_{flm}, V_{lcm}, \mu_{fm}, X_{ip}, Y_{jm}, \theta_{km}, \tau_{rm} \geq 0 \quad \forall i, j, k, f, r, p, m, l, c \quad (33)$$

$$\alpha_{jm}, \beta_{km}, \gamma_{ip}, \lambda_{rm} = \{0, 1\} \quad \forall i, j, k, p, m \quad (34)$$

4.1. Objective function

We want to demonstrate a model in reverse supply chain in a way to minimize the chain costs. We should introduce a model which minimizes the transportation cost of products and parts between centers and at the same time minimizes the fixed opening cost of sites and operation's cost on parts and supply maintenance costs and remanufacturing costs. By attention to the definition of indices, parameters, and decision variables; the objective function consists of: minimizing the costs of transportation of products and parts, the fixed opening cost of centers and operations costs on parts and the supply maintenance costs, remanufacturing costs in reverse supply chain (Equation 1).

4.2. Constraints

Equations 2 and 3 state that the amount of shipping products from any returning center (if it is opened) into the disassembly, and processing centers for each product should be equal or smaller than the capacity of that returning center. Equation 4 states that the amount of products which will be collected in the returning center should be equal or smaller than the capacity of that returning center. Equations 5 and 6 state that the amount of sent parts from any disassembly centers and recycling centers should be equal or smaller than the capacity of the same disassembly center for each part. Equation 7 is stating that the amount of a part which is in the disassembly center should be equal or smaller than the capacity of the same disassembly center. Equations 8 and 9 state that the amount of shipping parts from any processing centers (if it is opened) into the manufacturing centers and recycling centers should be equal or smaller than the capacity of the same processing centers for each part. Equation 10 states that the amount of a part which is in the processing center should be equal or smaller than the capacity of the same processing center. Equation 11 states that the amount of sent parts from any manufacturing center into the distribution centers should be equal or smaller than the capacity of the same manufacturing center for each part. Equation 12 states that the amount of part in each manufacturing center should be equal or smaller than the capacity of the same manufacturing center. Equation 13 states that the amount of sent parts from any distribution center to the client should be equal or smaller than the capacity of the same distribution center for clients. Equations 14 and 15 state the demand amount of manufacturing center for parts. Equation 16 states the part demand amount of distribution centers. Equation 17 indicates the client's part demand amount. Equations 18 and 19 state the part demand amount of recycling centers. Equations 20 and 21 state that the manufacturing and recycling center's demand, is for products and parts which are transported from the returning and disassembly centers into the processing center. Equations 22 and 23 are related to the balance of parts flow from the disassembly of products. Equations 24–27 are stating the min and max indices amount of returning, disassembling, processing, and recycling centers. Equation 28 states that the amount of sent parts from manufacturing centers to the distribution center is equal to the sent parts from distribution centers in to the client.

Equations 29 states that the amount of sent parts from each disassembly center into the processing and recycling centers should be equal or smaller than the parts amount in that disassembly center. Equation 30 states that the amount of sent products from each returning center into the disassembly, processing centers, should be equal or smaller than the product's amount in that returning center. Equation 31 states that the amount of sent parts from each of the processing centers into the manufacturing and recycling centers should be equal or smaller than the flow amount of parts in that processing center. Equation 32 states that the sent parts amount from any manufacturing center into the distribution centers should be equal or smaller than the parts flow amount in that manufacturing center. Equations 33 and 34 enforce the binary and non-negativity restrictions on the corresponding decision variables.

Table 1. Numerical results using Lingo 9 software

$\varphi(2,1,4)$	1.2	$T(2,3,3)$	16	$\theta(2,2)$	16
$\varphi(2,3,2)$.9	$T(3,2,1)$	8	$\theta(2,3)$	63
$\varphi(3,3,1)$.9	$T(3,2,2)$	8	$\theta(3,1)$	8
$\varphi(3,3,3)$	1.1	$T(4,1,1)$	13	$\theta(4,2)$	20
$\delta(2,1,2)$	34	$T(4,2,1)$	3	$\theta(4,3)$	7
$\delta(2,4,4)$	28	$T(4,2,2)$	5	$\gamma(2,1)$	1
$\delta(3,1,1)$	41	$T(5,1,1)$	8	$\gamma(2,2)$	1
$\delta(3,4,3)$	8	$T(5,1,2)$	16	$\gamma(2,3)$	1
$G(1,3,2)$	62	$T(5,3,3)$	17	$\gamma(2,4)$	1
$G(1,4,3)$	50	$V(1,1,2)$	6	$\gamma(3,1)$	1
$G(2,1,3)$	16	$V(1,1,3)$	6	$\gamma(3,2)$	1
$G(3,2,1)$	59	$V(1,2,2)$	17	$\gamma(3,3)$	1
$O(1,1,3)$	8	$V(1,3,1)$	1	$\gamma(3,4)$	1
$O(1,3,2)$	18	$V(1,4,1)$	20	$X(2,2)$	34.87
$O(1,3,3)$	4	$V(2,1,2)$	4	$X(2,4)$	29.2
$O(2,2,3)$	4	$V(2,2,3)$	16	$X(3,1)$	41.94
$O(2,3,1)$	18	$V(2,3,1)$	19	$X(3,3)$	9.09
$Q(1,1,1)$	9	$V(2,4,2)$	9	$\lambda(1,3)$	1
$Q(1,1,2)$	17	$V(2,4,3)$	14	$\lambda(2,1)$	1
$Q(1,2,1)$	18	$V(3,1,1)$	20	$\lambda(3,2)$	1
$Q(1,2,2)$	16	$V(3,1,3)$	13	$\tau(1,1)$	16
$Q(1,3,2)$	8	$V(3,2,1)$	4	$\tau(1,2)$	20
$Q(1,4,1)$	16	$V(3,3,2)$	3	$\tau(1,3)$	12
$Q(1,4,2)$	5	$V(3,3,3)$	20	$\tau(2,1)$	4
$Q(1,5,1)$	8	$\alpha(1,2)$	1	$\tau(2,2)$	11
$Q(2,1,3)$	19	$\alpha(1,3)$	1	$\tau(2,3)$	4
$Q(2,3,3)$	14	$\alpha(2,1)$	1	$\tau(3,1)$	18
$Q(2,4,3)$	9	$\alpha(2,2)$	1	$\tau(3,2)$	18
$Q(2,5,2)$	16	$\alpha(2,3)$	1	$\tau(3,3)$	4
$Q(2,5,3)$	17	$\alpha(3,1)$	1	$\mu(1,1)$	9
$Q(3,3,1)$	8	$Y(1,2)$	80	$\mu(1,2)$	17
$Q(4,2,3)$	7	$Y(1,3)$	62	$\mu(1,3)$	19
$S(1,1,1)$	16	$Y(2,1)$	18	$\mu(2,1)$	24
$S(1,2,1)$	4	$Y(2,3)$	20	$\mu(2,2)$	16
$S(1,2,2)$	11	$Y(3,1)$	59	$\mu(2,3)$	33
$S(2,1,3)$	4	$\beta(1,1)$	1	$\mu(3,1)$	8
$S(4,1,2)$	20	$\beta(1,2)$	1	$\mu(3,2)$	8
$T(1,1,3)$	6	$\beta(2,2)$	1	$\mu(3,3)$	14
$T(1,2,1)$	8	$\beta(2,3)$	1	$\mu(4,1)$	16
$T(1,2,3)$	13	$\beta(3,1)$	1	$\mu(4,2)$	5
$T(1,3,2)$	3	$\beta(4,2)$	1	$\mu(4,3)$	9
$T(2,1,2)$	7	$\beta(4,3)$	1	$\mu(5,1)$	8
$T(2,2,3)$	17	$\theta(1,1)$	71	$\mu(5,2)$	16
$T(2,3,1)$	24	$\theta(1,2)$	57	$\mu(5,3)$	17

It should be noted that one should decide whether to invest in reverse logistic system. Then, the proposed mathematical with the objective of cost minimization helps to point out the cost aspects of the reverse system and make an economic decision with more reliability.

5. Numerical experiment

We solved the presented mathematical model by using Lingo 9 software. In this multi-layers and multi-product model, we are attempting to minimize the costs of fixed opening facilities, transportation and shipping of products, and parts between centers and also the operations, supply, maintenance and remanufacturing costs as well as the product amount and sending parts into the centers and the amount of it would be calculated. To analyze the suggested model, we create a numerical example and solve the created example by Lingo software.

In this problem, we consider the index values between 3 and 5. We replace the inputs of problem in the model and by using the Lingo, we will solve the problem and finally the outputs are in hand with the corresponding objective function value in a negligible time.

The obtained objective function value is equal to 26121.20 unit of money. All the variables which were not zero (0) quantities are shown in Table 1.

After solving the model, we will find out that the decision variable $\alpha(2,2)$ gained one. This means that the disassembly center 2 should be opened for part 2. The decision variable $\lambda(1,3)$ obtained one, means that the recycling center 1 would be opened for part 3. Generally, when the decision variables α_{jm} , β_{km} , γ_{ip} , and λ_{rm} gained one, it indicates that the considered center to that decision variable will be opened for that part or product.

The decision variable $Q(4,2,3)$ is 7. This means that the amount of part 3 from processing center 4 into the manufacturing center 2 is 7. The decision variable $\tau(3,2)$ got 18, it means that the amount of part 2 in recycling center 3 is 15. $T(3,2,2)=8$ means that the amount of part 2 from manufacturing center 3 into distribution center 2 is 8.

It should be noted that the computational time is negligible since the model is linear. The proposed model is helpful in economic decision-making for investing in reverse supply chain. The activities within the backward flow are configured to make added value on the returned items. The results are effective in a macro decision-making for a reverse supply chain from economic view. Policy-makers can make use of the results to present a policy in the context of environment or economy with respect to lack of first materials and the essence of recycling. Some other factors are also perceived from the results namely the analysis on the effect of boycott in achieving some required materials and parts to produce a product. This issue forces the supply chain managers to conduct a comprehensive reverse chain to increase the productivity and at the same time by analyzing cost elements increase the profitability.

6. Conclusions

In this paper, a reverse supply chain was considered minimizing the total cost of transport, inspection, remanufacture, and maintenance. The presented model was an integer linear programming model for multi-layer, multi-product reverse supply chain. We solved the proposed model using Lingo 9 software. The advantages of the model were: obtaining exact solutions, no essence for linearization causing more computational efforts, capability of the program in large-sized problems, and simplicity of implementation in optimization software. Also, from the managerial aspect, the model was capable to help the policy-makers in the environmental and economical concepts streaming to green supply chain. The limitation of the model was its application in different industries which requires adapting the model with the specifications of a certain industry. As future research, including and integration pricing models is suggested.

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