Original Research

Reused raw materials of returned products in closed-loop supply chain-(CLSC) considering green technology and quality level

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Abstract

In recent years, reverse logistics has been given more research attention. Reverse logistics has backward and forward flow of products which customers are not end of the flow. Reverse logistics has environmental and economic benefits such as recovering the value of returning products, and contenting the environmental requirements. In this lecture, a new multi-objective mixed-integer non-linear program is suggested in order to minimize total cost and air pollution. Decreasing carbon emissions is considered related to environmental aspects or the second aim (minimizing air pollution). The new closed-loop supply chain (CLSC) model is an inventory-location multi-period problem. The demand in this model is depended on green technology and quality level. The returned products are disassembled and sorted, the good raw materials are sent to the manufacturers and other materials disposed. The LP-metric and utility function or total weighted methods /are applied to gain Pareto optimal solutions. Finally, a numerical example is applied for validating the new model.

Keywords- Closed-loop supply chain; Retuned products; Quality; green technology; Bi-objective

INTRODUCTION

Closed-loop supply chain (CLSC) has recently garnered more attention because of enhanced awareness of environmental sustainability. Forward and backward flows are integrated in CLSC. Raw materials are produced to new outputs and sent to the customers in the forward current, provided in the backward current, returned products cumulated and recycle (Jauhary et al. 2020). Returned products are very important in the reveres supply chain (RSC) for having a diversity of external and internal characteristics such as size, functionality, shape and quality (Samuel et al. 2020). Based on the related literature, competition in CLSC is typically formulated using game theory, especially Stackelberg game. The competition occurs mostly between two retailers. Some of previous studies have explored dual-channel management because of the importance of the collection rate of used products. Government subsidy, bullwhip effect, and pricing are the other issues considered in CLSC. Govindone et al. (2019) constructed a bi-objective inventory-location-routing problem to minimize cost and shortage. Atabaki et al. (2020) developed a robust optimization CLSC model considering location allocation, supplier selection, recovery level decisions and transportation mode. However, a gap in the CLSC literature is the little attention to inventory models. The present study addresses this gap by proposing a new inventory-location problem for CLSC plan taking into account multi-period, multi-echelon and multiple products to minimize cost and carbon emissions.

Jauhary et al. (2020) assumed that the demand depends on the green technology level, selling value, the quality related to each product and the; however, they formulated the model by Stackelberg game under five scenarios. Asghari et al. (2022) studied pricing by focusing on advertising and pricing decisions. It is very novel thing that the demand in our new problem depended on product's quality and the green technology level too but in the inventory-location problem. The other contribution of the present research is disassembling the returned products to raw materials and sending these raw materials with good quality to the manufacturers to reuse them. So the contributions of this paper are attention to inventory control in which the demand is depended on the product's quality, selling value and the level of green technology. The two latter issues have been dealt with thoroughly in the past papers of CLSC. The great contribution of the present lecture is reused returned products in which, first, the returned products are disassembled to raw materials; then they are sorted, those materials with good quality are sent to the firm and the low-quality raw materials are disposed of. Simultaneous consideration of these three issues together with reducing air pollution in CLSC is a novel topic too.

The reminder of this lecture is pursued: Review of literature is explained in Section 2. The new MINLP model for the concerned bi-objective CLSC is explained in Section 3. The results of testing and validating the new problem are discussed in part 4. Finally, chapter 5 mentions conclusions and directions for futures studies.

LITERATURE REVIEW

In this article, a new bi-objective CLSC model is developed. Based on the review of the related literature, government subsidy, inventory-location-routing, bullwhip effect, uncertainty, pricing, collection rate, etc. are the main issues considered in CLSC studies. Some researchers modeled the CLSC by game theory (e.g. Zhang et al., 2020). The leading original equipment manufacturers and two third-party manufacturers were considered in their game model. They found outsourcing the subsidy scheme as a dominant answer (Zhang et al. 2020). Zhao et al. (2020) compared the CLSC with different subsidy objects and without financial subsidies. They investigated the proportion of CLSC profit distribution in five models. Li et al. (2019) proposed a CLSC model by two-stage no-cooperative game in which advertising issue was investigated. Wang et al. (2019) studied the behavior of retailers (collusion and competition) in CLSC. They applied Stackelberg game model to consider one manufacturer and two retailers whose compete in reveres and forward channels. In another study, they considered one manufacturer and two retailers too, but the returned products were classified into two categories: defective and non-defective items. The Steckelberg game was used considering the money back guarantee and pricing (Assarzadegan and Rasti-Barzoki, 2020). Xiang and Xu (2020) explored the influence of technological innovation, overconfidence and Big Data marketing on CLSC by applying the game theory. They resulted in decreasing the suppliers' profit but increasing the total profit of CLSC by the Internet recycling platforms overconfidence. Liu et al. (2020) constructed decentralized and centralized pricing CLSC models by employing the Steckelberg game. Wu et al. (2020) proposed a CLSC under game theory in which the demand was sensitive to environmental investment and price. They explored corporate environmental responsibility effort pricing and recycling decisions in CLSC. Shekarian (2019) investigated game theory studies in CLSC field. Overall, they reviewed 215 papers in 12 categories.

Uncertainty is another issue, which has been widely discussed in the CLSC literature. Atabaki et al. (2020) formulated a robust optimization CLSC problem to investigate supplier selection, transportation mode, location allocation, recovery level decision, and transportation mode. Almaraj and Trafalis (2020) developed a robust CLSC budget dynamic uncertainty set based on Vector Autoregressive models. The proposed model involves supplier, manufacturer, distributor centers, customer zone, collection center and disposal center. Using robust optimization, Samuel et al. (2020) considered presorting centers in which poor quality items are segregated at the start of the backward logistic cycle for reducing emission and transportation costs. Robust optimization method was applied in a bi-objective build-to-order model considering preventive maintenance (Ebrahimi and Tavakkoli-Moghaddam, 2020). Govindone et al. (2019) developed a bi-objective inventory-location-routing program to minimize cost and shortage using fuzzy solution approach. Peng et al. (2020) reviewed 302 papers published from 2004 to 2018 in CLSC field to investigate the reason of uncertainties. Hafezalkotob and Zamani (2019) suggested a non-linear model considering uncertainty in sale price and market demand. Farahani et al. (2020) presented a new mixed integer nonlinear programming model to investigate overall equipment effectiveness (OEE) with integrated optimization of preventive maintenance and quality control. Babaeinesami et al. (2020) studied an integrated model that mutually optimizes the strategic and tactical decisions of a multi-product closed loop supply chain. Yu and Solvang (2020) generated a multi-objective model considering environmental efficiency and cost effectiveness with fuzzy-stochastic consideration.

Ponte et al. (2020) investigated the bullwhip effect in CLSC. They studied the inventory and order variance consolidation in four prototypes. Yavari and Zaker (2019) developed a bi-objective program to explore the perishable goods and disruption risk in both power networks and supply chain. Fu and Meng (2020) proposed a dynamic model in CLSC field in order to analyze the performance and benefits of CLSC systems in different conditions. They sold the remanufactured and new products in different prices. Collection rate of used products is an important decision in CLSC. Mondal and Giri (2020) explored collection rate, marketing effort and green innovation in CLSC with one manufacturer and one retailer. Also Wen et al. (2020) studied collection rate and pricing in CLSC using game theory. Jalali et al. (2020) investigated the complementary products in CLSC. Profits, prices and several trade-offs among the issues related to collection performance, which complementary products entail them and where investigated in this study. Wang et al. (2020) proposed two CLSC models to study multiple collecting channels aiming to investigate the impact of customer preferences. Similarly, Zhang et al. (2019) studied dual-channel management in CLSC. They investigated two kinds of product return, including waste product return and defective item return considering price and product quality Dual-channel was investigated in another study considering manufacturers, retailers and online recyclers using centralized and decentralized decision pricing models (Yuan et al. 2020). Jia and Li (2020) proposed a CLSC model consisting of manufacturer and e-retailer. The e-retailer offers emerging online market place. They investigated different decisions of manufacturer and different distribution channel modes.

Some researchers had case studies in CLSC field. Schenkel et al. (2019) considered four European brand owners in capital goods to investigate value creation in CLSC. The cases were baggage handling equipment and global electronic industries. Implementing CLSC in Indian automotive section was studied and critical factors were derived. The Evaluation Laboratory Technique and Grey-Decision Making Trial were examined and some excellent recommendations were offered for managers (Bhatia et al. 2020). A non-linear program was proposed for reducing transportation cost involving carbon emissions in Whirlpool washing machine in India (De and Giri, 2020). Liao et al. (2020) formulated a new problem to minimize cost and carbon emissions in a real case study of citrus fruits. They applied a met heuristic approach solving model. Berlin et al. (2022) studied the relation between open-loop supply chain (OLSC) and CLSC. They explored remarketing and recovering products in order to minimize waste and present a conceptual framework of OLSC and CLSC.

Problem Definition

The developed multi-echelon and multi-period model includes preparator, producers, distributions, customers, separation centers and disposal centers. New products are produced in the manufacturing centers, while coming back products are collected in the segregation centers. The throwback products are separated into raw materials; good-quality raw materials are transmitted to the manufacturing centers and low-quality raw materials are sent to disposal centers. Distance between facilities and type of vehicles make different transportation costs. It is worth mentioning that new disassembling and disposal centers can be added to the existing forward flow and new distribution centers can be added to the existing backward flow. Technology and quality level influence on the demand and the influence of carbon emission related to transportation on the environment is considered in the model All distances are deterministic and there are several vehicles with different cost, capacity, and carbon emission. Shortage is allowable. Some centers have limited capacity for inventory or processing, which has been stated in the restrictions.

Indices:

r	Indicator of raw material
p	Indicator of final product
s	Index of suppliers
m	Indicator of manufacturers
d	Index of potential distributors
c	Index of clients
se	Index of possible separation centers
di	Index of possible disposal centers
v	Index of vehicle
t	Index of time

***Parameters*:**

$Db_{p,c,t}$	Basic demand of product p for client c in t period
α	Sensitivity factor of green technology in the demand

Υ	Sensibility agent of demand's quality
τ	Investment created by the producer for pursuing green technology
$Cr_{r,s,t}$	Purchasing cost related to provide preparatory s raw material r in t period
$Cp_{m,p,t}$	Producing expense related to p product in m producer in t period
$Cpd_{d,p,t}$	Cost of processing product p in distributor d in period t
$Cb_{p,t}$	Shortage expense related to p product in m producer in t period
$Cd_{se,p,t}$	Disassembling expense related to return product p in separation center se in t period
$Cdi_{di,p,t}$	Disposal expense related to crop p in disposal center di in t period
$Ced_{d,t}$	Expense of establishing distribution center in potential location d in t period
$Cese_{se,t}$	Expense of establishing separation center in potential location se in period t
$Cedi_{di,t}$	Expense of organizing disposal center in potential location di in t period
$CQ_{p,t}$	Expense of quality improvement related to manufacturer m for crop p in t period
$Em_{m,p,t}$	Carbon emissions in zero green technology level related to product p in manufacturer m
$Bm_{m,p,t}$	Parameter of the green technology influence on lessening carbon emissions created from manufacturer m per unit of crop p
$Cvs_{s,m,v,t}$	Shipping expense of vehicle v from supplier s to producer m in t period
$Cvdm_{m,d,v,t}$	Shipping expense of vehicle v from producer m to distributor d in t period
$Cvm_{d,c,v,t}$	Shipping expense of vehicle v from distributor d to client c in t period
$Cvd_{c,se,v,t}$	Shipping expenditure of transport v from customer c to separation center se in period t
$Cvn_{se,m,v,t}$	Transportation expenditure of transport v from segregation center se to manufacturer m in t period
$Cvndi_{se,di,v,t}$	Forwarding expenditure of vehicle v from segregation center se to disposal center *di* in period t
$\gamma_{p,r}$	Quantity of r raw material needed in p crop
$Ls_{s,m}$	Interval between preparatory s and producer m
$Lm_{m,d}$	Interval amongst producer m and distributor d
$Ldc_{d,c}$	Interval amongst distributor d and client c
$Ld_{c,se}$	Distance amongst client c and separation center se
$Ldm_{se,m}$	Interval amongst separation center se and constructor m
$Lddi_{se,di}$	Interval amongst separation center se and disposal center di
Puv_{v}	Environmental damage of vehicle v for each kilometer
gr_{r}	Heaviness of each raw material r
gp_{p}	Heaviness of each product p
$Tp_{p,m}$	Needed time for manufacturing each crop p by constructor m
$Td_{p,se}$	Needed time for separating of throwback crop p in segregation center se
$Hr_{r,m,t}$	Expenditure of inventory related to raw material r in constructor m in period t
$HIP_{p,m,t}$	Inventory expenditure of product p in constructor m in period t
$Hdd_{p,d,t}$	Expenditure of inventory related to crop p in distribution center d in t period
$Hd_{p,se,t}$	Inventory expenditure of crop p in segregation center se in period t
Wei_{v}	Maximum valence of transport v
$Mrs_{r,s,t}$	Maximum providence valence of preparatory s related to raw material r in t period
$Mri_{r,m,t}$	Maximum valence for stoking the raw material r of manufacturer m in t period
$Mqp_{p,m,t}$	Maximum inventory valence of producer m for product p in period t
$Mqd_{p,d,t}$	Maximum inventory valence of distribution center d for crop p in period t
$Mnm_{m,t}$	Maximum valence of producer m for making component in period t
$Mpm_{m,t}$	Maximum valence of constructor m for producing crops in period t
$Mpd_{se,t}$	Maximum valence of separation center se for separating products in period t
$Sat_{p,c}$	Minimal satisfying demand fulfillment rate of crop p for client c

RR_p	Mean rate of throwback crop p
RS_p	Mean rate of good materials after separating the products

Decision Variables:

$Dp_{p,c,t}$	Demand rate of crop p for client c in period t
$Q_{p,t}$	Quality level of final crop p **/by producer** m in period t
$Gt_{p,t}$	Green technology level of crop p in t period
$QP_{p,m,t}$	Production amount of crop p by manufacturer m in t period
$IQP_{p,m,t}$	Inventory of crop p in manufacturer m in t period
$IQd_{p,d,t}$	Inventory of crop p in distribution center d in t period
$Qtr_{r,s,m,v,t}$	Quantity of raw material r shifted from preparatory s to constructor m by transport v in period t
$Qtp_{p,m,d,v,t}$	Quantity of crop p shifted from constructor m to distributor d by transport v in period t
$Qtpd_{p,d,c,v,t}$	Quantity of crop p transferred from distributor d to client c by vehicle v in t period
$Rp_{c,p,se,v,t}$	Quantity of crop p coming back from client c to segregation center se by transport v in period t
$Qrr_{r,m,se,v,t}$	Quantity of returned material r separated in segregation center se and shifted to constructor m by transport v in period t
$Rd_{r,se,di,v,t}$	Quantity of low-quality material r separated in segregation center se and shifted to disposal di by transport v in period t
$Nir_{r,m,t}$	Inventory of raw material r in constructor m in t period
$Nin_{n,m,t}$	Inventory of n component by constructor m in t period
$B_{p,t}$	Shortage of crop p in t period
$Xtr_{r,s,m,v,t}$	1 if raw material r is shifted from preparatory s to constructor m by transport v in period t
$Xtp_{p,m,d,v,t}$	1 if crop p is shifted from constructor m to distributor d by transport v in t period
$Xtcp_{p,d,c,v,t}$	1 if crop p is transferred from distributor d to client c by vehicle v in t period
$Xtd_{p,c,se,v,t}$	1 if crop p is returned from customer c to separation center se by transport v in t period
$Xtdr_{r,m,se,v,t}$	1 if high-quality material r is separated in segregation center se and shifted to constructor m by transport v in period t
$Xtdir_{r,se,di,v,t}$	1 if low-quality material r which is separated in segregation center se and shifted to disposal center di by transport v in t period
$distri_d$	$\begin{cases} 1 & if\ distribution\ center\ d\ established \\ 0 & otherwise \end{cases}$
$sepera_{se}$	$\begin{cases} 1 & if\ seperation\ center\ d\ established \\ 0 & otherwise \end{cases}$
$dispos_{di}$	$\begin{cases} 1 & if\ disposal\ center\ d\ established \\ 0 & otherwise \end{cases}$

$$\min Z_1 = \sum_t^T \sum_v^V \sum_c^C \sum_p^P \sum_n^N \sum_r^R \sum_m^M \sum_s^S Cr_{r,s,t} \,.\, Qtr_{r,s,m,v,t} + Cvs_{s,m,v,t}.\, Ls_{s,m}.\, Xtr_{r,s,m,v,t} + \tag{1}$$
$$Hr_{r,m,t}.\, Nir_{r,m,t} + HIP_{p,m,t} \,.\, IQP_{p,m,t} + Cp_{m,p,t}.\, QP_{p,m,t} +$$
$$Hdd_{p,d,t} \,.\, IQd_{p,d,t} + Cvdm_{m,d,v,t}.\, Lm_{m,d}.\, Xtp_{p,m,d,v,t}$$
$$Cpd_{d,p,t}.\, Qtpd_{p,d,c,v,t} + Cvm_{d,c,v,t}.\, Xtcp_{p,d,c,v,t}.\, Ldc_{d,c}$$
$$+Cd_{se,p,t}.\, Rp_{c,p,se,t} + Cvd_{c,se,v,t}.\, Ld_{c,se}.\, Xtd_{p,c,se,v,t}$$
$$+Cvn_{se,m,v,t}.\, Ldm_{se,m}.\, Xtdr_{r,m,se,v,t} +$$
$$Cvndi_{se,di,v,t}.\, Lddi_{se,di}.\, Xtdir_{r,se,di,v,t} +$$
$$Cb_{p,t}.\, B_{p,t} + \frac{1}{2}.\, \tau.\, (Gt_{p,t} - Gt_{p,t-1})^2 + CQ_{p,t}.\, (Q_{p,t} - Q_{p,t-1})^2$$
$$Ced_{d,t}.\, distri_d + Cese_{se,t}.\, sepera_{se} + Cedi_{di,t}.\, dispos_{di}$$

$$\max Z_2 = \sum_p \sum_t incom_{p,t}. \sum_d \sum_c \sum_v Qtpd_{p,d,c,v,t} - \sum_t^T \sum_v^V \sum_c^C \sum_p^P \sum_n^N \sum_r^R \sum_m^M \sum_s Puv_v.(Ls_{s,m}.Xtr_{r,s,m,v,t} +.Lm_{m,d}.Xtp_{p,m,d,v,t} + Xtcp_{p,d,c,v,t}.Ldc_{d,c} + Ld_{c,se}.Xtd_{p,c,se,v,t} + Ldm_{se,m}.Xtdr_{r,m,se,v,t} + Lddi_{se,di}.Xtdir_{r,se,di,v,t}) \tag{2}$$

$$+(Em_{m,p,t} - Bm_{m,p,t}.Gt_{p,t}).\sum\sum Qtp_{p,m,d,v,t}$$

$$Dp_{p,c,t} = Db_{p,c,t} + \alpha.Gt_{p,t} + \gamma.Q_{p,t} \tag{3}$$

$$IQP_{p,m,t} + QP_{p,m,t} = IQP_{p,m,t+1} + Qtp_{p,m,d,v,t} \tag{4}$$

$$\sum_m Qtp_{p,m,d,v,t} + IQd_{p,d,t} = \sum_c Qtpd_{p,d,c,v,t} + IQd_{p,d,t+1} \tag{5}$$

$$B_{p,t} \leq (1 - Sat_{p,c}).Dp_{p,c,t} \tag{6}$$

$$\sum_v \sum_d Qtpd_{p,d,c,v,t} + B_{p,t} = Dp_{p,c,t} + B_{p,t-1} \tag{7}$$

$$\sum_{se} Rp_{c,p,se,t} = \sum_v \sum_d Qtpd_{p,d,c,v,t}.RR_p \tag{8}$$

$$\sum_m \sum_v Qrr_{r,m,se,v,t} = Rp_{c,p,se,t}.RS_p.\gamma_{p,r} \tag{9}$$

$$\sum_{di} \sum_v Rd_{r,se,di,v,t} = (1 - RS)\sum_c \sum_p Rp_{c,p,se,t} \tag{10}$$

$$Nir_{r,m,t} = Nir_{r,m,t-1} + \sum_s \sum_v Qtr_{r,s,m,v,t} + Qrr_{r,m,se,v,t} - \sum_n \sum_o \gamma_{p,r}.Qp_{p,m,t} \tag{11}$$

$$\sum_m \sum_v Qtr_{r,s,m,v,t} \leq Mrs_{r,s,t} \tag{12}$$

$$\sum_p \sum_d \sum_v QP_{p,m,t}.Tp_{p,m} \leq Mpm_{m,t} \tag{13}$$

$$Rp_{c,p,se,t}.Td_{p,se} < Mpd_{se,t} \tag{14}$$

$$\sum_r Qtr_{r,s,m,v,t}.gr_r \leq Wei_v \tag{15}$$

$$\sum_p Qtp_{p,m,d,v,t}.gp_p \leq Wei_v \tag{16}$$

$$\sum_p Qtpd_{p,d,c,v,t}.gp_p \leq Wei_v \tag{17}$$

$$\sum_p Rp_{c,p,se,v,t}.gp_p \leq Wei_v \tag{18}$$

$$\sum_r Rd_{r,se,di,v,t}.gr_r < Wei_v \tag{19}$$

$$\sum_{se} \sum_p \sum_m \sum_c \sum_n Qrr_{r,m,se,v,t}.gr_r < Wei_v \tag{20}$$

$$Qtr_{r,s,m,v,t} \leq Mbig.Xtr_{r,s,m,v,t} \tag{21}$$

$$Qtp_{p,m,d,v,t} \leq Mbig.Xtp_{p,m,d,v,t} \tag{22}$$

$$Qtpd_{p,d,c,v,t} \leq Mbig.Xtcp_{p,d,c,v,t} \tag{23}$$

$$Rp_{c,p,se,v,t} < M.Xtd_{p,c,se,v,t} \quad (24)$$
$$Qrr_{r,m,se,v,t} < M.Xtdr_{r,m,se,v,t} \quad (25)$$
$$Rd_{r,se,di,v,t} < M.Xtdir_{r,se,di,v,t} \quad (26)$$
$$Nir_{r,m,t} \leq Mri_{r,m,t} \quad (27)$$
$$IQP_{p,m,t} \leq Mqp_{p,m,t} \quad (28)$$
$$IQd_{p,d,t} < Mqd_{p,d,t} \quad (29)$$
$$Qtp_{p,m,d,v,t} \leq Mbig\ .distri_{d} \quad (30)$$
$$Rp_{c,p,se,t} \leq Mbig\ .sepera_{se} \quad (31)$$
$$Rd_{r,se,di,v,t} \leq\ Mbig\ .dispos_{di} \quad (32)$$
$$Qtr_{r,s,m,v,t}, Qn_{n,m,o,t}, Qtp_{p,m,c,v,t}, Nir_{r,m,t}, Nin_{n,m,t}, Nid_{p,se,t}, Rp_{c,p,se,v,t} \quad (33)$$
$$Qrp_{p,m,c,se,v,t}, B_{p,m,t}, Rd_{r,se,di,v,t} \geq 0$$
$$Xtr_{r,s,m,v,t}, Xtp_{p,m,c,v,t}, Xtcp_{p,d,c,v,t}, Xtd_{p,c,se,v,t},, distri_{d}, sepera_{se},$$
$$dispos_{di}, Xtdr_{r,m,se,v,t}, Xtdir_{r,se,di,v,t} = 0,1$$

The first object minimizes total cost and the second object minimizes the carbon emission. The impacts of the quality level of final crop and level of green technology on demand are shown in Eq. (3). Inventory balance restrictions of products in manufacturers and distributors are stated in Eqs. (4) and (5), respectively. Eq. (6) is related to the quantity of allowable backordered products. The shortage balance restriction of products is stated in Eq. (7). Eq. (8) explains the communication between the quantity of coming back products from customer and the amount of delivered products. Eq. (9) displays the connection among the amount of returned crops hand over to distributions and quantity of raw materials sent from distributions to manufacturers. Inventory balance restriction of products in manufacturers is explained in Eq. (10). Maximum capacity of suppliers is shown in Eq. (11). Maximum capacity of manufacturers for producing products is stated in Eq. (12). Eq. (13) indicates the maximum valence of separation centers. The maximum capacity of vehicles transferring raw materials, transferring crops from manufacturers to distribution centers, transferring products from distribution centers to clients, transferring returned products and transferring raw materials gained from returned products are shown in Eqs. (14-18), respectively. Equation (19) states that there is quantity of raw material r in preparatory s if and only if raw material r transferred from preparatory s. Also product p is fabricated by manufacturer m if and only if and only if crop p is shifted to distribution centers (Eq. 20). If there is distribution d which send product p to customer c then there is amount of crop p in customer c (Eq. 21). There is returned product p in separation center se if and only if there is customer c sends it to separation center se (Eq. 22). There is raw material r in disposal center di if and only if separation center se sends it (Eq. 23). Maximum inventory capacities for products and raw materials in manufacturers are stated in Eqs. (24-25), respectively. Also maximum inventory capacity for products in distributions is shown in Eq. (26). For using distribution d, separation se and disposal di, it is necessary to establish them, which are shown in Eqs. (27-29) respectively. All of the variables are stated in Eq. (30).

Empirical Results

The developed model /was validated by a numerical example involving raw material, final product, supplier, manufacturer, customer, potential distributor, potential separation center, potential disposal center, vehicle, and period.
The solution /was accomplished with exact approach. The new model /was solved by GAMS win64/24.7.3 software and the numeric examples were operated with a computer with ram 4 GB. Table 1 show a summary the numeric input information.

The Solution Procedure

The developed bi-objective model was transformed to a single-objective problem by two methods: LP-metric technique (Farughi and Mostafayi, 2016) and total weighted or utility function approach (Pishvaee et al. 2014). Table 1 present the parameters of the model.

TABLE I
MODEL PARAMETERS

Parameter	Value range	P	Value range
Db(p,c,t)	20-30	Cb(p,t)	20-25
Cr(r,s,t)	18-30	Cd(se,p,t)	7-12
Cp(m,p,t)	30-35	Cdi(di,p,t)	5-9
Cpd(d,p,t)	7-14	Ced(d,t)	70-100

Table 2 presents the values of two objectives with different values of the first goal coefficient (w1) and the second goal coefficient (w2). using the total weighted method.

TABLE 2
COMPUTATIONAL RESULTS UNDER DIFFERENT IMPORTANCE WEIGHTS OF OBJECTIVES IN TOTAL WEIGHTED METHOD

Importance weights of objectives	First objective value	Second objective value	Aggregated Objective Function value
W1=0.1, w2=0.9	7.05093E+17	2.65131E+12	-7.0507E+16
W1=0.3, w2=0.7	5.118981E+7	1.870718E+8	1.155933E+8
W1=0.4, w2=0.6	2.109039E+7	1.713450E+8	9.437082E+7
W1=0.5, w2=0.5	9523022.667	1.620718E+8	7.627441E+7
W1=0.6, w2=0.4	4314402.886	1.558219E+8	5.974011E+7
W1=0.7, w2=0.3	1869618.394	1.513575E+8	4.409853E+7
W1=0.8, w2=0.2	733798.124	1.480091E+8	2.901478E+7
W1=0.9, w2=0.1	263634.993	1.454050E+8	1.430323E+7

Table 3 indicates the amount of two objectives with P=1 and different values of the first goal coefficient (γ1) and the second goal coefficient (γ2). using the LP metric method.

TABLE 3
COMPUTATIONAL RESULTS UNDER DIFFERENT GOAL COEFFICIENT OF OBJECTIVES IN LP-METRIC METHOD

The goal coefficient	First objective value	Second objective value	Aggregated Objective Function value
γ1=0.1, γ2=0.9	1.63405E+14	6.52696E+10	-0.9990E+13
γ1=0.2, γ2=0.8	7.84131E+13	5.656634E+9	-0.9990E+13
γ1=0.3, γ2=0.7	4.98870E+13	1.26995E+10	-0.9990E+13
γ1=0.4, γ2=0.6	3.56114E+13	3.04829E+10	-0.9990E+13
γ1=0.5, γ2=0.5	2.70748E+13	2.65889E+10	-0.9990E+13
γ1=0.6, γ2=0.4	2.13859E+13	1.75236E+10	-0.9990E+13
γ1=0.7, γ2=0.3	1.73144E+13	2.11157E+10	-0.9990E+13
γ1=0.8, γ2=0.2	1.42661E+13	7.089493E+9	-0.9990E+13
γ1=0.9, γ2=0.1	1.18906E+13	6.153544E+9	-0.9990E+13

According to Tables 2 and 3, the different goal coefficient creates different results in the LP-metric technique. One reason that reduces the efficiency of LP-metric technique is enhancement of the problem size by increasing the value of P, which cannot be solved by the existing algorithm in GAMS. Table 4 shows the sensitivity analysis of the basic demand by the total weighted method (w1=0.7, w2=0.3). It is completely reasonable that by increasing the basic demand, the first and second objectives are enhanced. It is very noticeable that a small increase in the basic demand can lower the cost (Table 4, second row).
Table 5 indicates the sensitivity analysis of the producing cost by the LP-metric technique (P=1, y1=0.1, y2=0.9). As shown, the first object reduces and the second aim enhances by increasing the production cost. It is worth noting that the change of production cost has a little influence on the objectives.

TABLE 4
SENSITIVITY ANALYSIS OF THE BASIC DEMAND

Basic demand	First objective value	Second objective value	Gathered objective
$Db_{p,c,t} - Db_{p,c,t} * 0.5$	1867348.800	1.263874E+8	3.660907E+7
$Db_{p,c,t} - Db_{p,c,t} * 0.1$	1866543.686	1.463575E+8	4.260067E+7
$Db_{p,c,t}$	1869618.394	1.513575E+8	4.409853E+7
$Db_{p,c,t} + Db_{p,c,t} * 0.1$	1872643.989	1.563575E+8	4.559639E+7
$Db_{p,c,t} + Db_{p,c,t} * 0.5$	1884909.821	1.763575E+8	5.158782E+7

TABLE 5
SENSITIVITY ANALYSIS OF THE PRODUCING COST

Basic demand	First objective value	Second objective value	Gathered objective
$Cp_{m,p,t} - Cp_{m,p,t} * 0.5$	1.63410E+14	6.47402E+10	-0.9990E+13
$Cp_{m,p,t} - Cp_{m,p,t} * 0.1$	1.63410E+14	6.47234E+10	-0.9990E+13
$Cp_{m,p,t}$	1.63405E+14	6.52696E+10	-0.9990E+13
$Cp_{m,p,t} + Cp_{m,p,t} * 0.1$	1.63405E+14	6.52692E+10	-0.9990E+13
$Cp_{m,p,t} + Cp_{m,p,t} * 0.5$	1.63405E+14	6.52677E+10	-0.9990E+13

CONCLUSIONS

In this lecture, a new bi-objective program which is mixed-integer non-linear, was developed with the two objectives of minimizing the influence of carbon emissions and decreasing the total cost. The developed multi-period and multi-echelon CLCS model is an inventory-location problem. The demand in this model is depended on green technology and quality level. The LP-metric and utility function or total weighted methods were applied to gain Pareto optimal solutions. The utility function was efficient but increasing the value of P in the LP-metric method made the model to be NP-hard.

Future research and Managerial implications

The presented inventory-location CLSC problem is very useful for manufacturers to minimize cost and reduce carbon emissions in order to have good inventory control. For future research, it is recommended that metaheuristics approaches be used to solve large-size problems.

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