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A novel model for a network of a closed-loop supply chain with recycling of returned perishable goods: A case study of dairy industry

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Abstract

Recently, following the raise in expense pressures led to lower economic growth, an increasing number of manufacturers have begun to investigate eventuality of handling returned product in a more cost-effective and proper procedure. Significance of Reverse Logistics (RL) is becoming greater due to various governmental, societal, and environmental reasons. Number of papers present in the literature on RLs is a well index of its importance. In some industries, appropriately collected returned products could be used as raw material for another product, increasing Supply Chain (SC) profits and reducing the waste. Since, perishable goods have a limited shelf -life, they can be reusable if they are collected before they reach a critical time. Accordingly, in the present study, a Mixed Integer Linear Programming (MILP) model was introduced for a network of closed-loop SC with recycling of returned perishable goods, involving suppliers, producers, retailers, together with collection and disposal centers, in a multi-product, multi-period, and multi-level basis. To do this, a case study was performed on milk and yogurt products of a company in dairy industry. The model was solved and analyzed using GAMS software. Results obtained from assessment of the model indicated that, timely collection of perishable goods and their use in production of new products reduces total costs of perishable SC network.

Keywords: Closed-loop supply chain, forward and reverse logistics, mixed integer programming, perishable products.

1-Introduction

Today, a large number of organizations make an effort to remanufacture and reuse returned products due to economic inducements and expanding environmental legislations (Francas & Minner, 2009). Development of the societies in the world has highlighted a dramatic growth regarding the need for supply chain resources and proceedings like materials, food, and energy, leading to considerable extent of environmental matters. Expansion of modern techniques in SC management investigation is mentioned in relation to advancement of effective application of resources and decrement of environmental issues, all of which need to be considered while noticing gainfulness and efficiency of all SC- related points (Toma, Massari & Miglietta, 2016).

During the last decades, manufacturers and educational scholars have paid substantial attention to the Closed -Loop Supply Chain (CLSC) (Zhang and Feng, 2014).

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RL is a serious issue giving special importance on reusing and reducing the disposal (Petek & Glavic, 1996). RL is described as action of material or product movement in the reverse direction aimed at reproducing or recreating the benefit, or for appropriate recycling (Rogers & Tibben-Lembke, 2001). Accomplishment of RL would not be just for reducing cost of waste and transportation, but also for advancement of consumer's allegiance and subsequent incomes (Lee, Gen & Rhee, 2009; Li & Olorunniwo, 2008; Amin & Zhang, 2012). There are a multitude of goods, which are quite suitable for recycling or remanufacturing goals (Das and Chowdhury, 2012). Perishable goods are the most proper goods for remanufacturing because of their short shelf -life, kinds of raw material and design systems (Heydari, Govindan, & Sadeghi, 2018). Portion of perishable goods in the market is getting bigger while customers' priorities have changed towards safety, quality, and freshness (Diop, et al., 2005). Construction of perishable supply chains is more complicated due to their short shelf -life and their worth reduces slowly during the time, furthermore, they are becoming progressively worse, and these goods are declined and lost during warehousing and transportation (Noya, et al., 2016). Regular disturbances have been newly observed in perishable products SC, hence, recycling has begun to be a precious objective in SC of perishable products. (Deng, et al., 2019)

Although, to the best of our knowledge, there are a few numbers of studies focused on mathematical model of a CLSC for returned perishable products that can be recycled as a raw material for production of another product. Therefore, with the purpose of growing productivity of perishable SC, the current study is conducted aimed at increasing the concerns regarding developing shelf -life of perishable goods. In this study, a supply network is presented based on perishable and recovery of returned products. The CLCS network involves manufacturer, retailer, supplier, as well as disposal and collection centers. Retailer's demand could be met by production processes in manufacturer center. The manufacturer applies raw materials from suppliers and recycled products to produce new goods. The products returned by the retailers are sent to centers of collection and recycling and, if reusable, they are then transported to production centers to be used as raw material for another product. Otherwise, they are sent to disposal centers. To the best of our knowledge, there is not a large number of research on a perishable network for recovery of returned products. Thus, in this study, a MILP model is introduced to maximize the profit and minimize the waste. Mathematical model is generated in a multi-period, multi-product, and multi-level basis. Validity of proposed MILP model is checked and proved by applying a real-data case of recycling milk products in PKB dairy industry. In addition, analyses of sensitivity are organized and carried out on different parameters to determine strength of presented model. The current paper is categorized as follows :

A brief review on relevant literature is presented in section 2. Section 3 demonstrates problem description of proposed supply chain, assumptions, and notations of mathematical model. Section 4 presents model formulation. A case study and numerical consequences are presented in section 5. Section 6 provides insights of model for managers and decision makers; finally, conclusions and suggestions for future works are provided in section 7.

2-Literature review

Remanufacturing planning and Reverse SCs are nearly related to our work. First, in the current research, the studies conducted on CLSC and RL are evaluated. In the following, a consideration is organized on the literature of perishable SC having these concepts. Eventually, to clarify the situation of current study with regard to previous studies, this study concentrates on research gap.

2-1-CLSC and RL models

Recognized operations implicated in a forward SC involve production planning, preparing raw materials, delivery of products, and selling goods (Krikke, Bloemhof-Ruwaard & Van, 2003). Meantime, RL includes collection of returned goods, reusing of raw materials and returned products classifying as starred by remanufacturing of them, repairing, refurbishing, and also quality and appropriate recycling of returned goods. Moreover, a network of a CLSC incorporates all the processes mentioned above in both logistics for purpose of profitability and recreating of products' value (Taleizadeh, Haghighi, & Niaki, 2019). There are many studies in the field of CLSC such as management of disposal (Mutha and Pokharel [31]; Kurdve, et al., 2015; Song, Li & Zeng, 2015) remanufacturing (Shi, et al., 2010; Demirel and Gökçen, 2008; Chung, Wee & Chung, 2008; Hasanov, Jaber, & Tahirov, 2019; Heydari, Govindan, & Sadeghi, 2018 ; Taleizadeh, Haghighi, & Niaki , 2019; Scalia, et al., 2019) recycling (Debo, Toktay & Van, 2006); Du and Evans, 2008; Pati, Vrat & Kumar, 2008) reusing (Kim, et al., 2006; 7; Rowshannahad, et al., 2018) disassembling (Tahirov, Hasanov, & Jaber, 2016; Go, et al., 2011) ,and recovery (Eskandarpour, et al., 2014; Liao, 2018). Among studies in the literature, studies by De Giovanni (2016), Junior & Filho (2012), and Sasikumar & Kannan (2009) have been mostly cited for comprehensive reviews in works related to CLCS.

Reviews on CLCS literature have shown that, implementation of the closed-loop supply chain can save resources and decrease loss of the company. It is more advantageous to cut down production cost, raise the profit of the enterprise, and enhance overall image of the enterprise.

2-2-Perishable SCs

In case of perishable products SC, a majority of the studies have mostly focused on the aspect of game, order ,and inventory (Jia & Hu, 2011; Diabat, Abdallah & Le, 2014; Rijpkema, et al., 2014; Kim, et al., 2014; Nakandala, Lau & Zhang, 2016; Azadeh, et al., 2017; Vahdani, Niaki & Aslanzade, 2017; Crama, et al., 2018). Designing of supply chain network for perishable products is very complicated, because these products have a limited shelf -life. (Radzi, Saidon & Ghani, 2016; Liu & Liu., 2013; Deng, et al., 2019).

Studies on perishable supply chain indicated that, in today's competitive market, it is necessary to state a suitable solution for better management of perishable goods, so it is possible to recognize importance of reusing of returned perishable goods as a raw material for production of another product.

2-3-Research gap

Literature review shows that, closed -loop supply chain and returned products is among issues that have been considered by the researchers in recent years. In addition, today's competitive market seems to offer a proper way for better management of perishable goods demand. In above-mentioned models, the manufacturers of these goods have collected perishable goods from retailers to alleviate environmental concerns and reduce system costs. The manufacturers tried to return these goods to production line for repair and reconstruction and to resell these items. However, in the present study, a model was presented in which perishable goods collected at an accurate time can be used as raw material for production of another commodity, leading to an increase in the supply chain profit and reduction of returned and waste products. Thus, objectives of the present study are as follows:

- Proposing a MILP model for CLSC networks for perishable products where returned goods can be reused as a raw material of another product
- Proposing a multi-period and multi-level SC for perishable products with finite shelf-life
- Maximizing the benefit of the SC and minimizing product waste by considering returned product and economic preference associated with reusing or recycling of end-of-use products

3-Problem description

Assume a multi-period CLCS with both forward and reverse logistics, while the forward supply chain contains three echelons: suppliers, producers, and retailers, the reverse supply chain includes two: collection and disposal centers. Retailer demands are known based on customer demand and, no shortage is allowed. In fact, the demand is fully met by production centers which could produce one or more types of products in each period. One or more kinds of raw materials are needed for each product. As mentioned earlier, some returned products could be used as raw materials for the production of another product. In this regard, raw materials received from suppliers and a part of returned products obtained from collection and disposal centers can be used for the production process. Since perishable products have a limited useful life, it possible to reuse a part of returned products whose useful life is about to end. Therefore, the returned products are sent to collection and recycling centers and, if reusable, they are then transported to production centers to be used as raw material for another product. On the other hand, they are sent to the center of disposal site. In the current study, homogenous vehicles with a limited capacity are used for the transportation of products between different facilities. Figure 1 shows the current SC model proposed in the current paper.

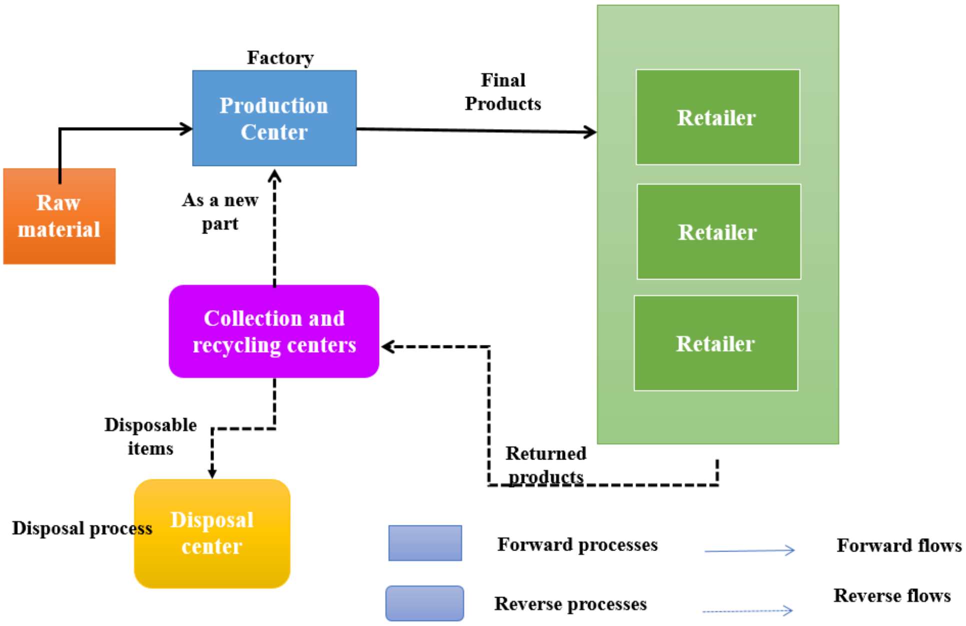

Fig 1. A symbolic view of the proposed SC

3-1-Model assumptions

Given the definition of the problem presented, the model assumptions are as below:

- The proposed supply chain has two paths and is closed-loop.
- The forward supply chain contains three echelons: suppliers, producers, and retailers.
- The reverse supply chain includes two echelons: disposal center together with collection and recycling centers.
- Several types of products are produced and distributed in each period.
- Products are perishable with a fixed useful life.
- Products useful life is integer multiple of a single demand period.
- Retailers demand can be change based on the needs of customers in each period.
- Retailers demand is fulfilled in each period and, no shortage is allowed.
- The cost of inspecting each product unit at the collection and recycling centers is included in the collecting cost.
- Homogenous vehicles with limited capacity are used for the transportation of products.
- Returned products are sent either to the center of production if they are reusable or to the disposal center.

3-2-Model notation

Notations applied in the current model are presented below:

Indices:

s	Index of suppliers	$s=1,...,S$
t	Index of periods	$t=1,...,T$
p	Index of products	$p=1,...,P$
m	Index of production centers	$m=1,...,M$
r	Index of raw materials	$r=1,...,R$

c Index of retailers $c = 1,...,C$

k Index of collection and recycling centers $k = 1,...,K$

d Index of disposal centers $d = 1,...,D$

v Index of vehicles $v = 1,...,V$

Parameters:

tcd_{pkd}^{tv} Unit cost of transportation of returned Product *p* from Collection and Recycling centers *k* to Disposal center *d* using Vehicle *v* in Period *t*

hcr_{rm}^{t} Unit cost of holding of Raw material *r* in Production center *m* in Period *t*

bc_{rsm}^{t} Unit cost of purchasing of Raw material *r* from Supplier *s* by Production center *m* in Period *t*

CMV_v The capacity of Vehicle *v* for transporting products from production centers to retailers

pc_{pm}^{t} Unit cost of production of Product *p* by Production center *m* in Period *t*

ccp_{pck}^{t} Unit collecting cost of returned Product *p* from Retailer *c* to Collection and Recycling centers *k* in Period *t*

tcs_{rsm}^{tv} Unit cost of transportation of Raw material *r* from Supplier *s* by Production center *m* using Vehicle *v* in Period *t*

hcp_{pc}^{t} Unit cost of holding of Product *p* by Retailer *c* in Period *t*

dcp_{pd}^{t} Unit cost of disposing of returned Product *p* in Disposal center *d* in Period *t*

tcm_{pmc}^{tv} Unit transportation cost of Product *p* from Production center *m* to Retailer *c* using Vehicle *v* in Period *t*

CR_m The storage capacity of Raw materials in Production center *m*

tck_{pkm}^{tv} Unit transportation cost of returned Product *p* from Collection and Recycling centers *k* to Production center *m* using Vehicle *v* in Period *t*

tcc_{pck}^{tv} Unit cost of transportation of returned Product *p* from Retailer *c* to Collection and Recycling centers *k* using Vehicle *v* in Period *t*

CDV_v The Vehicle *v* capacity for transporting unusable returned products from collection and recycling centers to disposal centers

D_{pc}^{t} The demand of Retailer *c* for Product *p* in Period *t*

CQ_m The production capacity of Production center *m*

CSV_v The capacity of Vehicle *v* for transporting raw materials from suppliers to production centers

CK_k The Production capacity of Collection and Recycling centers *k*

CKV_v The capacity of Vehicle *v* for transporting reusable returned products from collection and recycling centers to production centers

CCV_v The capacity of Vehicle *v* for transporting returned products from retailers to collection and recycling centers

X_{rp} If returned Product *p* can be used as Raw material *r*, it is equal to 1. Otherwise it is 0

λ_p The ratio of Product *p* returned to collection and recycling centers at each order quantity

τ_p The ratio of inventory of the Product *p* remaining from the previous period; it is transported to the collection and recycling centers as the returned products

φ_{rp} The requested amount of Raw material *r* used for producing one unit of Product *p*

α_p The ratio of Product *p* transferred to collection and recycling centers as return product ($\alpha_p = \tau_p + \lambda_p$)

β_{pm} The ratio of reusable returned Product *p*, which is sent to Production center *m*

Variables:

$qpck_{pck}^{tv}$ Quantity of Product *p* returned from Retailer *c* to Collection and Recycling centers *k* using Vehicle *v* in Period *t*

Ir_{rm}^{t} Level of inventory of Raw material *r* in Production center *m* in Period *t*

qsr_{rsm}^{tv} Quantity of Raw material *r* shipped from Supplier *s* to Production center *m* by Vehicle *v* in Period *t*

q_{pmc}^{tv} Quantity of Product *p* transported from Production center *m* to Retailer *c* by Vehicle *v* in Period *t*

Ip_{pc}^{t} Inventory level of Product *p* in Retailer *c* in Period *t*

$qpkm_{pkm}^{tv}$ Quantity of reusable returned Product *p* sent from Collection and Recycling centers *k* to Production center *m* using Vehicle *v* in Period *t*

Qc_{pc}^{t} Quantity of Product *p* ordered by Retailer *c* in Period *t*

$qpkd_{pkd}^{tv}$ Quantity of unusable returned Product *p* sent from Collection and Recycling centers *k* to Disposal center *d* using Vehicle *v* in Period *t*

4-Mathematical modeling of the problem

Considering the definition of the problem of the CLSC for perishable products with the possibility of reusing returned products as the raw material of another product, the objective functions of the problem, including the cost of different levels of supply chain, are as follows:

$$Total\ Cost = BC + PC + HC + CC + DC + TC \tag{1}$$

$$BC = \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{m=1}^{M}\sum_{v=1}^{V}\left(bc_{rsm}^{t} \times qsr_{rsm}^{tv}\right) \tag{2}$$

$$PC = \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{m=1}^{M}\left(pc_{pm}^{t} \times \sum_{c=1}^{C}\sum_{v=1}^{V} qp_{pmc}^{tv}\right) \tag{3}$$

$$HC = \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{m=1}^{M}\left(hcr_{rm}^{t} \times Ir_{rm}^{t}\right) + \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{c=1}^{C}\left(hcp_{pc}^{t} \times Ip_{pc}^{t}\right) \tag{4}$$

$$CC = \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{c=1}^{C}\left(ccp_{pck}^{t} \times \sum_{v=1}^{V} qpck_{pck}^{tv}\right) \tag{5}$$

$$DC = \sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{d=1}^{D}\left(dcp_{pd}^{t} \times \sum_{k=1}^{K}\sum_{v=1}^{V} qpkd_{pkd}^{tv}\right) \tag{6}$$

$$
\begin{aligned}
TC = &\sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{m=1}^{M}\sum_{v=1}^{V}\left(tcs_{rsm}^{tv}\times qsr_{rsm}^{tv}\right)\\
&+\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{c=1}^{C}\sum_{v=1}^{V}\left(tcm_{pmc}^{tv}\times q_{pmc}^{tv}\right)\\
&+\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{c=1}^{C}\sum_{v=1}^{V}\left(tcc_{pck}^{tv}\times qpck_{pck}^{tv}\right)\\
&+\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{v=1}^{V}\left(tck_{pkm}^{tv}\times qpkm_{pkm}^{tv}\right)\\
&+\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{d=1}^{D}\sum_{v=1}^{V}\left(tcd_{pkd}^{tv}\times qpkd_{pkd}^{tv}\right)
\end{aligned} \tag{7}
$$

Equation (1) calculates whole costs of the closed-loop SC including costs of purchasing, production, inventory holding, collection and recycling, disposal and transportation between facilities, which are presented by equations 2 to 7, respectively. Equations (8) to (22) show the constraints of the mathematical model.

$$Ir_{rm}^{t} = Ir_{rm}^{t-1} + \sum_{s=1}^{S}\sum_{v=1}^{V} qsr_{rsm}^{tv} + \sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{v=1}^{V} qpkm_{pkm}^{tv}\times X_{rp} - \sum_{p=1}^{P}\varphi_{rp}\times\left(\sum_{c=1}^{C}\sum_{v=1}^{V} q_{pmc}^{tv}\right) \quad \forall r,m,t \tag{8}$$

$$Qc_{pc}^{t} = \sum_{m=1}^{M}\sum_{v=1}^{V} q_{pmc}^{tv} \quad \forall p,c,t \tag{9}$$

$$Ip_{pc}^{t} = (1-\tau_p)Ip_{pc}^{t-1} + (1-\lambda_p)Qc_{pc}^{t} - D_{pc}^{t} \quad \forall p,c,t \tag{10}$$

$$\sum_{k=1}^{K}\sum_{v=1}^{V} qpck_{pck}^{tv} = \tau_p \times Ip_{pc}^{t-1} + \lambda_p \times Qc_{pc}^{t-1} \quad \forall p,c,t \tag{11}$$

$$\sum_{v=1}^{V} qpkm_{pkm}^{tv} = \sum_{c=1}^{C}\sum_{v=1}^{V} qpck_{pck}^{tv}\times\beta_{pm} \quad \forall p,k,m,t \tag{12}$$

$$\sum_{v=1}^{V} qpkd_{pkd}^{tv} = \left(1-\sum_{m=1}^{M}\beta_{pm}\right)\times\sum_{c=1}^{C}\sum_{v=1}^{V} qpck_{pck}^{tv} \quad \forall p,k,d,t \tag{13}$$

$$\sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{v=1}^{V} qsr_{rsm}^{tv} \le CR_m \quad \forall m,t \tag{14}$$

$$\sum_{p=1}^{P}\sum_{c=1}^{C}\sum_{v=1}^{V} q_{pmc}^{tv} \le CQ_m \quad \forall m,t \tag{15}$$

$$\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{v=1}^{V} qpck_{pck}^{tv} \le CK_k \quad \forall k,t \tag{16}$$

$$\sum_{r=1}^{R} qsr_{rsm}^{tv} \le CSV_v \quad \forall s,m,v,t \tag{17}$$

$$\sum_{p=1}^{P} q_{pmc}^{tv} \le CMV_v \quad \forall m,c,v,t \tag{18}$$

$$\sum_{p=1}^{P} qpck_{pck}^{tv} \le CCV_v \quad \forall c,k,v,t \tag{19}$$

$$\sum_{p=1}^{P} qpkm_{pkm}^{tv} \leq CKV_v \quad \forall k, m, v, t \tag{20}$$

$$\sum_{p=1}^{P} qpkd_{pkd}^{tv} \leq CDV_v \quad \forall k, d, v, t \tag{21}$$

$$qsr_{rsm}^{tv}, q_{pmc}^{tv}, Qc_{pc}^{t}, Ir_{rm}^{t}, Ip_{pc}^{t}, qpck_{pck}^{tv}, qpkm_{pkm}^{tv}, qpkd_{pkd}^{tv} \geq 0 \quad \forall r, p, m, c, k, d, t, v \tag{22}$$

Equation (8) shows the constraint of the balance of raw materials in production centers. The left side of the equation represents the inventory of Raw material *r* in Production center *m* in the current period and the right side denotes the inventory of Raw material *r* in Production center *m* in the previous period, the amount of Raw material *r* purchased from suppliers by Production center *m* in the current period, the amount of Returned product *p* reusable as Raw material *r* sent from collection and recycling centers to Production center *m* in the current period, and the amount of Raw material *r* required for producing Product *p* in Production center *m* in the current period. Equation (9) indicates that the amount of Product *p* ordered by Retailer *c* is equal to the amount of Product *p* sent by various vehicles to that center in each period. Equation (10) ensures the balance of inventory in retailer's centers. Equation (11) calculates the amount of Product *p* in Period *t* returned from Retailer *c* to Collection center *k*. Equation (12) shows that a fraction of Product *p* returned to collection center is reusable and is transported to the production center. In contrast equation (13) indicates that a fraction of returned Product *p* is unusable and is transported to the disposal center. Equation (14) shows the constraint on the storage of raw materials at each production center. Accordingly, total raw materials sent to each production center should not exceed the capacity of raw materials warehouse in that center in each period. Equation (15) indicates the limitation of production at each production center. Accordingly, total products produced at each center in each period should not overstep the production capacity of that center. Equation (16) indicates that total products returned from retailers should not exceed the capacity of the collection and recycling centers in each period. Equations (17) to (21) show the capacity of vehicles between supplier and production centers, production centers and retailers, retailers and collection centers, collection and production centers, and collection and disposal centers, respectively. Finally, equation (22) presents decision variables, which can have zero or positive values.

5-Computational results and presentation of the case study

PKB Food Industry Group, established in 1993, is a well-known company in Iranian dairy industry and follows the slogan "Healthy Society depends on Healthy Diet". In order to expand the market share, the company exerts its utmost efforts towards reducing production costs and providing quality level in compliance with the customer's requirements. The collection and disposal of the noticeable amount of returned products is a major concern for the top management. The supply chain design by considering the recycling of returned products prevents huge disposal costs and creates benefits through the recycling process. This seemed to be applicable in PKB, since there is no difference in selling price between the products based on recycled or regular raw material. In this regard, a pilot project was initiated on a sub division of PKB supply chain, which is responsible for milk and yogurt production. The pilot project was performed in a supply chain consisting of two suppliers, a production center, four retailers, a collection and recycling center, and a disposal center during three periods. The production of one-unit pasteurized milk requires one unit of raw milk (raw material 1), while two units of raw milk and one unit of cultured yogurt (raw material 2) are consumed in the production of one-unit yogurt. In addition, only the pasteurized milk can be returned to the collection and recycling centers, and shipped to the production center to be reused as the raw material of yogurt. The average return rate of milk equals 0.3, while only 60% of returned milk is suitable for recycling. The company uses homogenous vehicles for shipment of the products. The mathematical model was developed based on equations (1) to (22) as mentioned in section 4. The network of the case study could be conceptualized into a structure as indicated in figure 2.

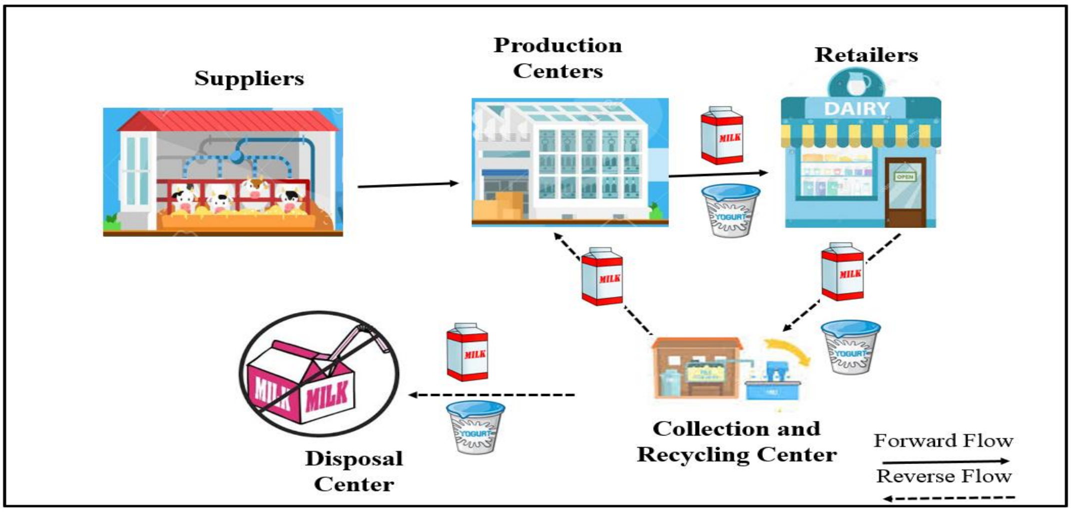

Fig 2. A symbolic vision of the case study SC

The optimal solution of the model was found using GAMS software. The cost of purchasing, holding, and transporting each of the raw materials is presented in table 1.

Table 1. The cost of purchasing, holding, and transporting each of the raw materials

Parameter	Supplier	Production center	Raw material r=1			Raw material r=2		
			t=1	t=2	t=3	t=1	t=2	t=3
bc^{t}_{rsm} (10^2\$/Ton)	s=1	m=1	10	12	13	10	12	13
	s=2		12	14	15	8	10	11
hcr^{t}_{rm} (10^{-3}\$)	-	m=1	5	6	7	7	8	9
tcs^{tv}_{rsm} (10^{-2}\$)	s=1	m=1	10	11	12	10	11	12
	s=2		10	11	12	10	11	12

The cost of producing, transporting, and retailer's demand for each of the products is shown in table 2.

Table 2. The cost of producing, transporting, and retailer's demand for each of the products

Parameter	Production center	Retailer	Product p=1			Product p=2		
			t=1	t=2	t=3	t=1	t=2	t=3
pc^{t}_{pm} (10\$/Ton)	m=1	-	20	22	23	21	20	18
tcm^{tv}_{pmc} (10^{-3}\$)	m=1	c=1	10	11	12	10	11	12
		c=2	10	11	12	10	11	12
		c=3	10	11	12	10	11	12
		c=4	10	11	12	10	11	12
D^{t}_{pc} (N)	-	c=1	1000	1200	1500	500	550	600
		c=2	800	900	1100	400	450	500
		c=3	500	800	1000	450	500	550
		c=4	800	1000	1300	600	650	700

Finally, the cost of relevant to return product between different levels is shown in tables 3.

Table 3. The cost of relevant to return product between different levels

Parameter	Collection center	Disposal center	Production center	Retailer	Returned Product p=1		
					t=1	t=2	t=3
dcp^{t}_{pd} (10^{-2}\$)	-	d=1	-	-	50	70	80
tcc^{tv}_{pck} (10^{-2}\$)	k=1	-	-	c=1	10	11	12
				c=2	10	11	12
				c=3	10	11	12
				c=4	10	11	12
ccp^{t}_{pck} (10^{-2}\$)	k=1	-	-	c=1	8	9	10
				c=2	7	8	9
				c=3	9	10	11
				c=4	8	10	12
tck^{tv}_{pkm} (10^{-2}\$)	k=1	-	m=1	-	10	11	12
tcd^{tv}_{pkd} (10^{-3}\$)	k=1	d=1	-	-	10	11	12

The model was solved in GAMS software and reached the optimal solution. The objective function optimal value is equal to 1,656,427 of the monetary unit. Values of each of the objective functions are reported in table 4.

Table 4. Values of each of the objective functions

Objective Function	Value (10^{-3}\$)
Raw material purchase cost	392,198
Production cost	495,400
Raw material warehousing cost	10,950
Collecting and recycling cost	29,199
Disposal cost	88,680
Cost of transportation between centers	640,000
Total cost	1,656,427

The amount of raw material supplied by each of the supply centers is shown in table 5.

Table 5. The amount of raw material supplied by each of the supply centers

Supplier	Raw material	Period		
		1	2	3
1	1	10000	9900	10000
	2	-	-	-
2	1	-	-	-
	2	1950	1902	798

As shown in table 5, raw material 1 was purchased only from supplier 1 and raw material 2 was purchased only from supplier 2. Table 6 shows the amount of each product allocated to each retailer. As shown, the demand of each retailer was fully met according to its order and, there was no shortage in this regard.

Table 6. The amount of each product allocated to each retailer

Product	Retailer	Period		
		1	2	3
1	1	1957	1185	2143
	2	1143	1286	1517
	3	1857	-	1429
	4	1143	1429	1857
2	1	500	850	300
	2	400	450	500
	3	450	1050	-
	4	600	650	700

In addition, the amount of Product 1 returned from each of the retailers to the collection center after approaching the end of their useful shelf life is reported in table 7.

Table 7. The amount of returned product

Retailer	Collection center	Period		
		1	2	3
1	1	-	587	356
2		-	343	386
3		-	557	-
4		-	343	429
Total		-	1830	1171

As it is shown in table 7, there was no returned product in the first period, as expected. However, in the second and third periods, part of the returned products was reusable and sent to the production center to be used as the raw material of the second product. Finally, the amount of reusable returned product sent to the production center and the amount of unusable returned product sent to the disposal center are shown in tables 8 and 9, respectively.

Table 8. The quantity of returned product sent from the center of collection to the production center

Returned product	Collection center	Production center	Period		
			1	2	3
1	1	1	-	1098	702

Table 9. The quantity of returned product sent from the center of collection to the disposal center

Returned product	Collection center	Disposal center	Period		
			1	2	3
1	1	1	-	732	468

As it is shown in table 8, since there is no returned product in the 1st period, no product is sent to the production center. However, about 60% of the products returned from retailers are sent to the production center in the 2nd and 3rd periods. In addition, the rest of the returned product in these two periods is sent to the disposal center. For a better understanding of the resulting outputs, the graphic view of solving the numeric sample is presented in figure 3. In this figure, the number and type of centers are shown and the flow between them in each period is highlighted with a color. In addition, their values are shown on arcs.

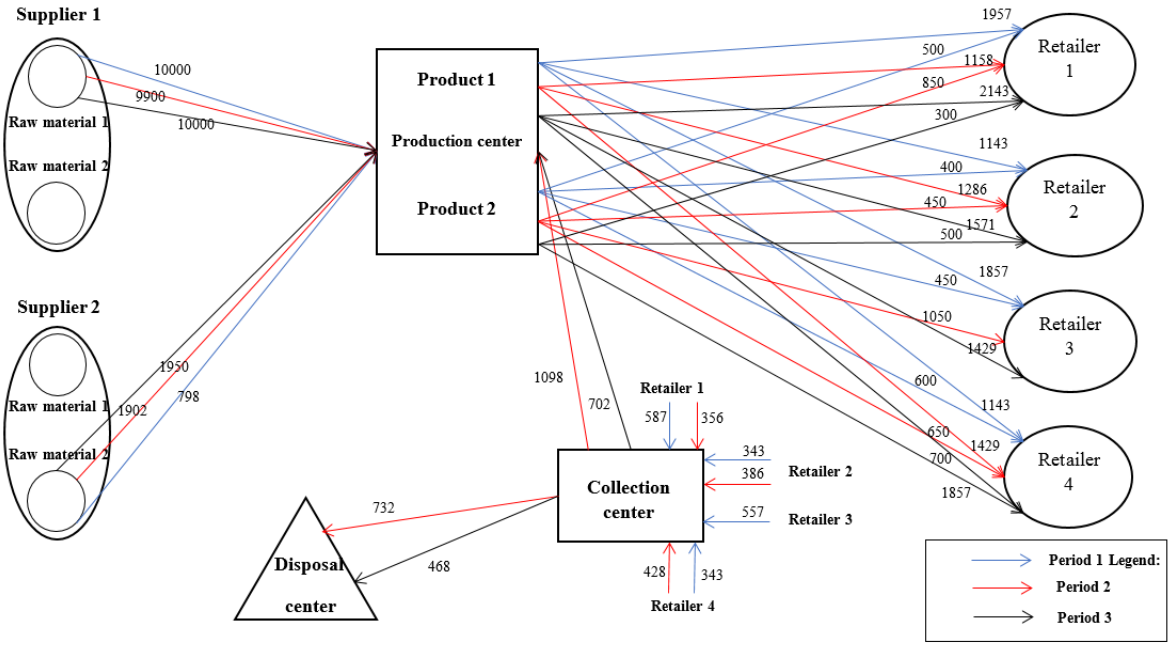

Fig 3. Graphical output of the numerical example

In current part, the validity and performance of the current mathematical model and the effective parameters in the model were evaluated. For this purpose, the values of two important parameters in the first model, including product return rate (α_p) and proportion of returned products reusable for production (β_{pm}), were varied, and their effects on the objective functions were analyzed. Figure 4 shows the effect of variation in the product return rate parameter on different objective functions.

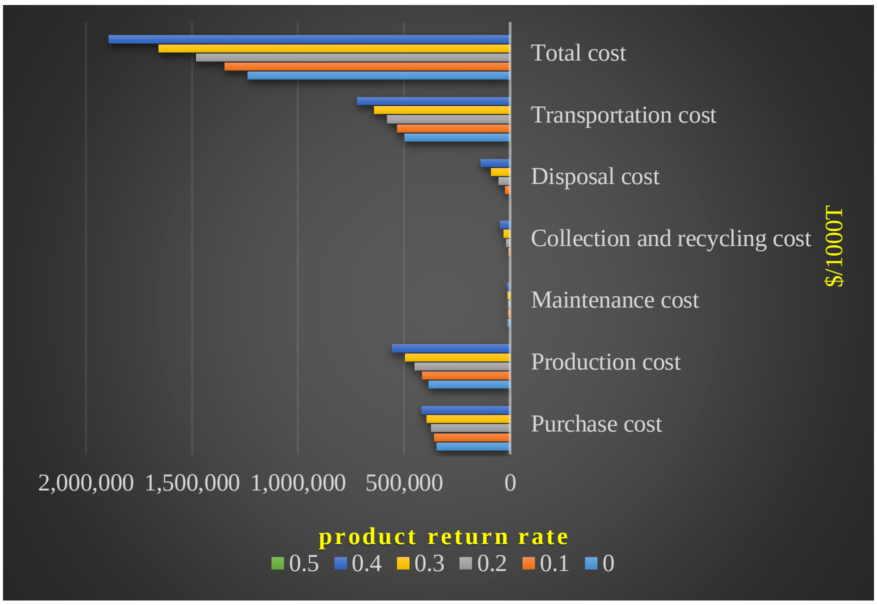

Fig 4. Effect of variation in the type-one product returns rate parameter on the objective functions

As it is shown in figure 4, total cost increased like type-one product return rate. It is obvious that the problem becomes infeasible when the rate oversteps a certain threshold. That is, if the value of product return rate oversteps a certain threshold, the product will not be economically viable for production.

As it was pointed previously, after the returned products are transported to the collection and recycling centers, some of them can be used again for the production of type-two product, and are transported to the production center, while the rest are transported to the disposal center. Thus, the value of the transfer can be effective on different costs of the supply chain. Therefore, the effects of the proportion of returned products reusable for production on different objectives have been examined separately next. Figure 5 shows the values of different objective functions regarding the proportion of usable returned products.

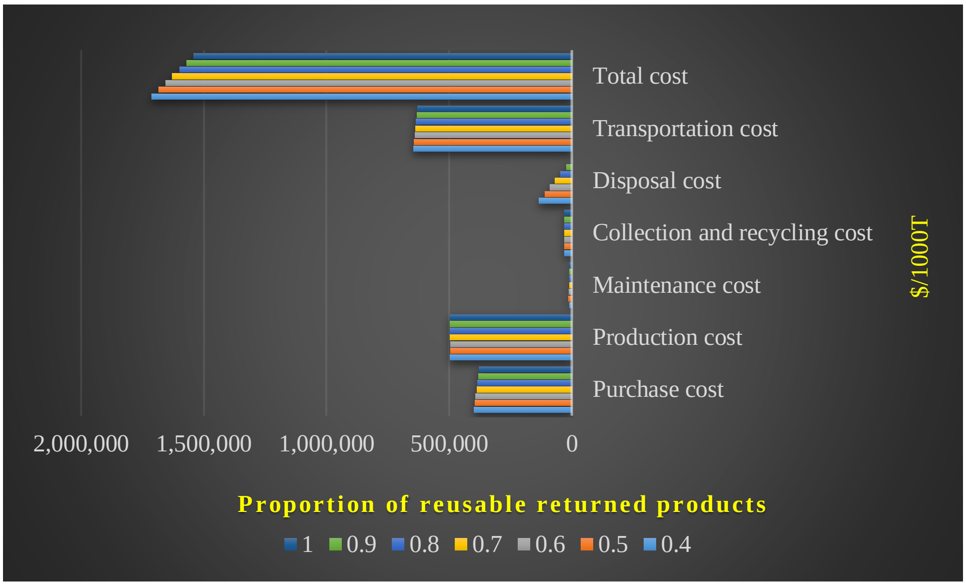

Fig 5. Effect of variation in the parameter, returned type-one product proportion reusable for production on the objective functions

It is shown in figure 5 that the whole cost of the supply chain decreased as proportion of returned type-one products reusable for production increased. It is observed that the problem is infeasible for values less than 0.3, since the value of the proportion is less than that of product return rate. It can, therefore, be concluded that the value of the usable returned product proportion should not be less than that of product return rate.

The effects of the product return rate parameter on the raw materials inventory, products inventory, and purchased raw materials variables were also studied, and the output is presented in table 10.

Table 10. Effect of change in the return rate parameter on the variables for type-one products

Type-one Product Return Rate	Raw material inventory	Product inventory at the end of the period	Purchased raw material	
			Type 1	Type 2
0	-	1,950	24,800	6,450
0.1	-	1,606	26,123	5,928
0.2	-	1,525	27,775	5,400
0.3	-	2,020	29,900	4,450
0.4	-	2,608	30,000	2,734
0.5	-	-	-	-

As it is shown in table 10, the first inventory for all type-one product return rate values were equal to zero. Next, the effect of two parameters, usable returned product rate on the variables: raw materials first inventory, products inventory, and the purchased raw material has been investigated, and the output is presented in table 12.

Table 12. Effect of change in the parameter, type-one product return rate on variables

Type-one Product Return Rate	Raw Material Inventory	Product Inventory at the end of the period	Purchased raw material	
			Type 1	Type 2
0.3	-	-	-	-
0.4	-	1,911	29,900	5,250
0.5	-	2,400	29,900	4,950
0.6	-	2,020	29,900	4,650
0.7	-	1,686	29,900	4,350
0.8	-	1,686	29,900	4,050
0.9	-	1,689	29,900	3,750
1	-	1,800	29,900	3,450

As presented in table 12, the amount of returned first inventory for all product return rate values used for reproduction is equal to zero.

After studying the separate effect of each of the two parameters: type-one product return rate and the ratio of returned product usable for reproduction, on each of the functions and variables of the problem, in present section, the simultaneous consequence of these two parameters on the total costs of the PKB supply chain, was investigated. Figure 6 shows changes in the function of total costs according to changes in the value of the two parameters. As shown, with the increase in the pasteurized milk return rate, total costs increased. In addition, for a fixed product return rate, with the increase in the usable pasteurized milk return rate, total costs decreased; and this trend was applicable to all product return rate values. It is worth mentioning that by increasing the return rate of the pasteurized milk, for a lower proportion of return product, the problem has a solution. In other words, for product return rates lower than 0.3, all products return rates have answers, and with increase of the product return rate to 0.3 or more, lower amounts of returned products ratios reach the solution.

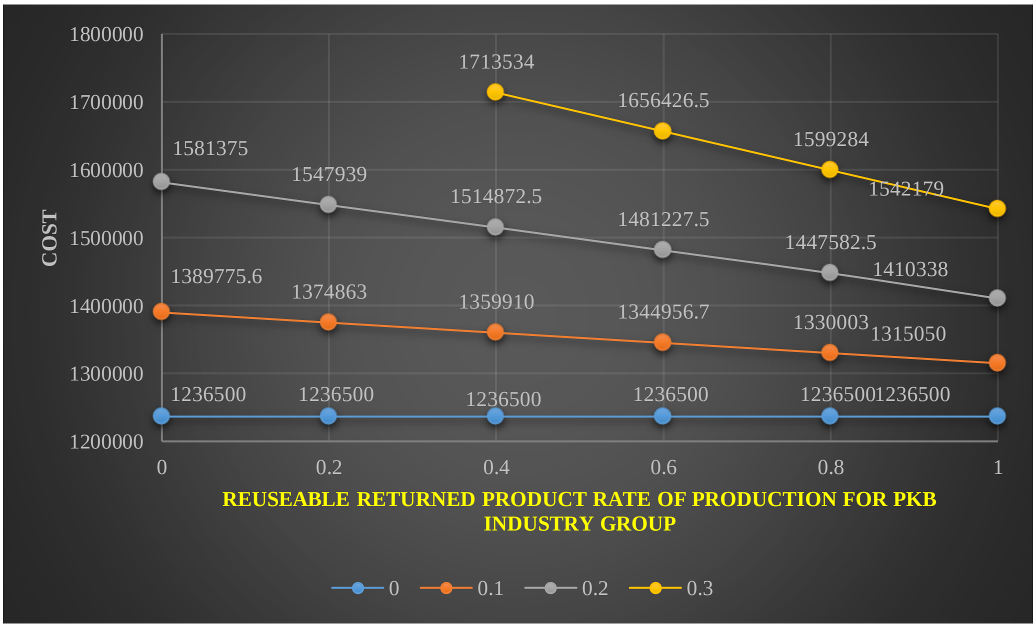

Fig 6. Simultaneous effect of two rates on total costs for PKB industry

The current paper indicates a new sustainable mathematical model of Closed Loop Supply Chain (CLSC) using and recovering returned perishable goods. In particular, this model reduces the total cost of perishable supply chain. Thus, this study makes a considerable contribution to obtaining a deeper knowledge on the role of collecting and recycling perishable products, which are close to their expiring date, by helping decision makers and managers to develop a more influential, minor cost and sustainable closed-loop systems according to PKB supply chain.

6-Managerial insights

Achievements of the current models can be applied by managers and authorities of companies or factories with perishable supply chain to promote their managerial standpoints towards more productive decisions. Key managerial insights of the current paper are as follows:

- Modeling is done to model actual condition based on the formulas and math symbols. This means that, the situation that needs to be decided can be formulated mathematically and by solving it, objective function is minimized or maximized. In the present paper, a novel mathematical model was proposed, which can analyze various decisions taken by a manager or a decision maker in different situations.
- In our perishable CLSC network, managers are able to know about returned perishable products, which can be reused as a raw material of another product. It is more essential for the managers of companies with perishable supply chain networks to estimate expected profit or loss.
- Results of the study showed that, collecting perishable returned products in a timely manner and reusing them as a raw material for producing another product reduces wastes and supply chain costs. Therefore, a manager needs to make the best decision in these conditions to maximize interests, which can be achieved using the model proposed herein as this model suggests the best solution to the managers.
- Furthermore, mathematical model of the research proposed strategic decisions in risky situations for the managers to reduce returned product rate based on reusing of them, so that a few numbers of returned products were disposed.

7-Conclusion

In this paper, the necessity for a new mathematical model for multi-period and multi-product CLCS was stated, especially for industries in which, time plays a crucial role. The literature review showed a research gap in relation to perishable supply chain networks about subject matters such as how returned products can be collected and recycled, and methods applied for production processes regarding reusing of returned products from perishable goods. Thus, in this study a case study of dairy industry group was analyzed, in which, returned pasteurized-milk was reused as a raw material for manufacturing of yogurt.

Results of mathematical model presented in this study showed that, collecting perishable returned products in a timely manner and reusing of them as a raw material for producing another product reduces supply chain costs, so that this factor can be a motivating factor for future researches in perishable goods industries. In addition, another fascinating aspect for future researches would be investigation on the extent of differences in structure of perishable goods supply chains in collecting and reusing of returned products.

Furthermore, regulatory provisions for sustainable supply chain are different among the countries. Therefore, it is suggested to conduct future studies in order to implement the current research model in different countries.

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