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Green Reverse Supply Chain on the Way of Optimization: A Case of Dairy Sector

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Abstract

The achievement of chain greening objectives, besides costs minimization, can be realized when both reverse and forward flows are taken into account in the design of the supply chain network. It is possible to decrease the chain costs and have a greener chain by means of different strategies like vehicular routing, hub location, inventory management, and simultaneous pickup and delivery. The development of green reverse supply chains and the practice of the above-mentioned strategies are becoming increasing important with the appearance of perishable product chains. Considering the mentioned points, the current study attempts to design a green reverse supply chain network for the purpose of distributing dairy items such as yogurt drink where the strategy of simultaneous pickup and delivery under uncertainty is taken into consideration. This model focuses on the simultaneous costs reduction and also decrease of lost demands and presents a fuzzy solution for solving the bi-objective model.

Keywords: green reverse network; location-inventory-routing problem; mathematical programming model; fuzzy solution approach; dairy industry

1.Introduction

The flow of materials and information in traditional supply chains is usually linear from one end of the chain to the other. Therefore, the participation and transparency level in these types of chains is low and there is only limited information at the organizations' disposal about other partners' environmental problems in the supply chain (Mardan et al., 2019). Green supply chains, on the other hand, considers all the factors affecting the environment from the beginning of the chain to the end, that is, from the raw material to end consumer and even during product consumption and its recycling (Govindan et al., 2020). Through a green supply chain, efficient use of all the organization's resources is guaranteed; also, by creating a culture of green supply chain management, the organizational decision-making process is directed towards turning green resources into green products through an environmentally friendly process (Badi and Murtagh, 2019). In addition, green supply chain management leads to a process of reducing waste while increasing efficiency. By efficiently managing resources and suppliers, production costs can be reduced and the process of recycling and reusing raw materials can be accelerated (Nasr et al., 2021).

Long-term positive effect on the business performance of the organization is one of the main benefits of implementing green supply chains, which has been proven both scientifically and practically (Qazvini et al., 2016). By implementing a green supply chain, the organization has the opportunity to introduce its processes and products to customers as environmentally friendly products (Seman et al., 2019). In this way, in addition to attracting new customers, the organization can achieve a very good

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competitive advantage in marketing. Implementing a green supply chain can also strengthen the brand and gain a special place in the market. Furthermore, improving the quality and development of products can be expressed as other benefits of implementing a green supply chain (Tumpa et al., 2019; Gholipour et al., 2020). Efficient management of suppliers, technology development, application of new methods and knowledge distribution among chain partners, supply chain transparency, investment and risk sharing among chain partners, increasing sales and improving turnover, and profitable use of wastages can be considered as the other benefits of the supply chain. The present paper seeks to present a supply chain network based on green concepts in mind for managing the production, distribution and reuse of returned goods. In this regard, the present study will answer the following questions:

1. How can we develop a green reverse network for the supply chain of perishable products?

2. How can the location-inventory-routing problem with the probability of simultaneous pickup and delivery be taken into account in the chain under uncertainty conditions?

The remainder of this paper is structured as follows. In Section 2, we investigate the related literature. The proposed model is presented in Section 3. In Sections 4 and 5, we present our multi-objective solution approach and case study, respectively. Finally, the conclusions and future research directions are proposed in Section 6.

2.Literature Review

Song and Koo (2016) investigated a problem of vehicle routing involving both refrigerated and conventional vehicles for the delivery of perishable foods with the aim of comparing the performance and accessibility of a refrigerated vehicle for food delivery with conventional vehicles. In their research, a nonlinear mathematical model was developed and also an innovative algorithm, referred to as the priority-based innovative method was designed to produce effective vehicle routes with the aim of increasing the overall degree of customer satisfaction that depended on freshness and food delivery. Avsi and Topaloglu (2016) presented a hybrid meta-heuristic algorithm for routing a heterogeneous vehicle which allows for the simultaneous pickup and delivery. They addressed the heterogeneous vehicle routing problem as an NP-hard problem with simultaneous delivery and pickup. For solving it, they developed a hybrid local search algorithm that developed a non-uniform threshold adjustment strategy with Tabu search. Their proposed algorithm was used in a set of randomly generated problems and the results of their research showed that the developed approach can produce efficient and effective solutions.

The vehicle routing and scheduling problem for perishable products with cross warehouses and under uncertainty was also investigated in Iran by Rahbari et al. (2019). In their study, they embarked on developing a two-objective mixed integer linear programming model for the cross-storage vehicle routing problem and scheduling for perishable products, including fruits and vegetables. Two robust models were developed by considering the uncertain vehicle travel time and product life. According to their research results, the effect of apparent uncertainty during travel is greater than the impact of product longevity and the freshness of delivered products increased by an average of 74.14% using the proposed model, without increasing the cost of distribution, which could lead to waste reduction.

Soleimani et al. (2018) formulated a multi-objective mixed integer nonlinear programming model to create two objective functions to minimize the total distribution cost as well as total energy consumed by vehicles in the distribution system) for the green vehicle routing problem, which includes the distribution (both delivery and pickup) of raw and refurbished products. In their research, the linear model was validated and solved through appropriate fuzzy approach. According to the results obtained from solving the model using the data produced with the software, the proposed mathematical model is able to decrease the fuel cost, the cost of establishing distribution centers and supply of vehicles, as well as air pollution minimization.

In this regard, Vahdani et al. (2017) investigated the routing-inventory-production problem with time window and capacity constraints for perishable products by means of innovative and meta-heuristic algorithms. They developed a mathematical planning approach to maximize profits from product sales. In the production stage, they envisioned a multi-stage, multi-cycle, multi-sectorial capacity-constrained production system in which inventory was used at each stage of production to calculate maintenance costs as well as planning for the most appropriate design. At the delivery level, the vehicle routing problem was also considered for transporting different vehicles with varying capacities in multi-cycle conditions. In their research, they used several numerical tests for evaluating the performance, effectiveness, and efficiency of the two proposed methods, and their results indicated that the performance of the heuristic algorithm is lower than that of the developed meta-heuristic algorithm with regard to the objective function value.

Also, Memari et al. (2017) examined the location-routing problem by considering several warehouses and difficult time windows for customers with the possibility of simultaneous picking and delivery. In their research, they chose the best warehouse construction location considering the timing and routing of heterogeneous vehicles, which reduced the chain costs and optimal routing of vehicles. Since that their model is among the NP-hard problems, they used a multi-objective evolutionary algorithm called the unsuccessful sorted genetic algorithm to solve the large-sized problems. A mixed integer linear programming model was formulated by Komijan and Delavari (2017) to structure a perishable supply chain network with the aim of minimizing total costs. A mathematical model is proposed by Nadizadeh and Kafash (2019) for designing an uncertain suppl chain considering vehicle routing problem with pickup and delivery. Abdi et al. (2020) formulated a bi-objective mathematical model to design a green supply chain network considering green vehicle routing problem with simultaneous pickup and delivery. They evaluated the efficiency of their model and solution approach by data from a food industry in Iran. In this vein, Navazi et al. (2021) presented a mathematical programming model for designing a perishable closed-loop supply chain considering location-inventory-routing problem with simultaneous pickup and delivery. They employed two meta-heuristic algorithms to solve their proposed problem in large size. Paul et al. (2021) formulated a bi-objective mathematical model to structure a two-echelon green routing problem with simultaneous pickup and delivery. They considered the multiple time windows and minimized the both fuel consumption and travel time, simultaneously. Tavana et al. (2022) formulated a multi-objective mixed-integer linear programming model to design a closed-loop supply chain network considering location-inventory-routing problem with pickup and delivery. They applied a fuzzy goal programming approach to solve their proposed multi-objective model.

According to the research background, many researches related to the green supply chain and routing with homogeneous and heterogeneous vehicles have been performed separately; however, no comprehensive research has been carried out upon designing the green supply chain network while taking into account the location-inventory-routing problem with the possibility of simultaneous delivery and pickup, vehicle scheduling, use of heterogeneous vehicles, corruption in products, soft and hard time window, warehousing and dealing with shortages under conditions of uncertainty. In this regard, an attempt is made in the present study to fill the existing research gap.

3.Problem Statement and Proposed Model

This study aimed at designing a green reverse supply chain network for perishable products. The network examined in this study is multi-product and multi-cycle with the option of returning products from customers. To cover this problem, the term simultaneous pickup and delivery is employed in the vehicle routing. In this way, heterogeneous vehicles that travel from customers to production centers, receive returned products after receiving the product. Also, because customer demand is highly volatile, the use of homogeneous vehicles leads to increased transportation costs, and the use of heterogeneous vehicles makes it possible to use vehicles with adequate capacity to distribute products. This in turn will affect pollution and fuel consumption. It should be noted that attention to strategic issues such as location of centers and selection of suppliers are also among the key decisions of this research. Therefore, in this research, the proposed integrated model will also address the location-inventory-routing problem, simultaneously. In the chain under study, the production center buys raw material (milk) from suppliers, and after producing the product (dairy), delivers the products to the customers using the optimal routing and scheduling of vehicles and, simultaneously, picks up the returned products. At the separation centers, the recycled products are inspected and their recyclable materials are dispatched to the separation centers and the rest are transferred to the disposal centers. These products get processed at the separation centers and the final processed product is sold at recycling market. One of the most important things in delivering perishable products is the time it takes to transport them in vehicles and deliver them to customers at specific times that the soft and hard time windows are used simultaneously to plan it and prevent the products from spoiling. The proposed network includes supply, production, distribution, customer, collection centers, reproduction centers and waste centers. A multi-objective mixed-integer linear programming model was developed to formulate the network under study in order to minimize chain costs including startup costs, transportation costs, inventory costs, vehicle fuel consumption costs, supplier connection costs, production and processing costs in centers, cost of purchasing raw materials, etc., and minimizing lost demand. Finally, the proposed model is converted to single-objective one using a fuzzy solution approach. The general scheme of the studied chain is shown in Figure 1. In order to describe the network in more detail, the problem assumptions are presented below:

- The network under study includes both forward and reverse flows.
- The network under study is multi-period and multi-product.
- The centers are located by model.
- A multi-depot and capacitated vehicle routing problem is considered between customers and production centers.
- Also, simultaneous pickup and delivery problem is allowed in vehicle routing problem.
- The vehicles are considered heterogeneous.
- The product storage in warehouses of retailers is allowed.
- Shortage has been considered as lost demand.
- Time window is considered.
- Lifetime is defined for products.

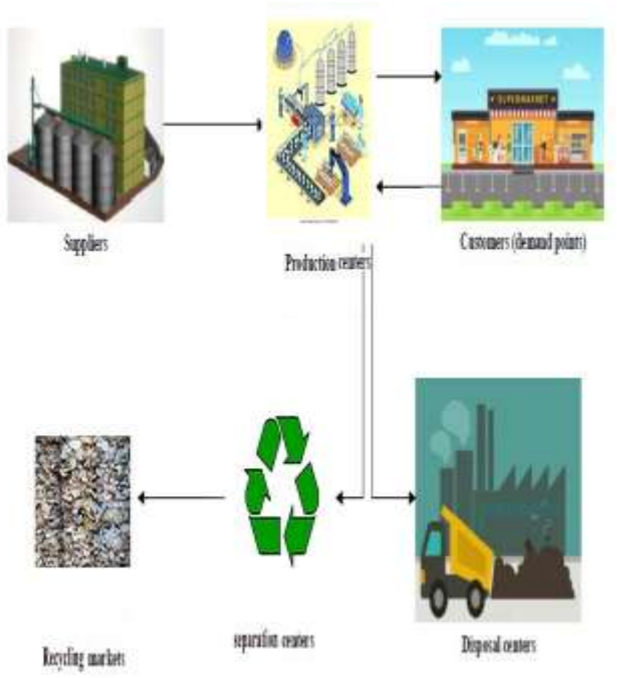

Fig1. The general structure of the studied supply chain network

4.Mathematical Model

4.1.Index

p	Product	$1 \leq p \leq P$
a	Raw material	$1 \leq a \leq A$
x	Disposal center	$1 \leq x \leq X$
r	Separation center	$1 \leq r \leq R$
s	Supplier	$1 \leq s \leq S$
d	Production center	$1 \leq d \leq D$
z	Recycling market	$1 \leq z \leq Z$
p,q	Retailer	$1 \leq p,q \leq Q$
m,n	Vehicle	$1 \leq m,n \leq M$
c	Capacity level	$1 \leq c \leq C$
t	Time period	$1 \leq t \leq T$

4.2.Parameters

$H\alpha_{st}$: Ordering cost of supplier s in period t

$H\beta_{d}$: Cost of establishing the production and separation center d

$W\beta_{pdc}$: Cost of setting up machines with capacity level c to produce product p in the production center d

$H\mu_{r}$: Cost of establishing the separation center r

$H\theta_{x}$: Cost of establishing the waste center x

$H\varphi_{m}$: Cost of purchasing a vehicle m

$F\alpha_{ast}$: Cost of purchasing each unit of raw material a from supplier s in period t

$F\beta_{pdt}$: Cost of producing each unit of product p in the production center d in period t

$F\beta'_{pdt}$: Separation cost of each unit of product p in the separation center d in time period t

$F\delta^{+}{}_{ppt}$: Cost of maintaining each unit of product p in the retail warehouse p in period t

$F\delta^{-}{}_{ppt}$: Cost of lost demand for each unit of product p at the retailer location p in period t

$F\mu_{prt}$: Cost of separating each unit of product p in the separation center r in time period t

$F\theta_{pxt}$: Cost of disposal each unit of product p in the disposal center x in time period t

$F\varepsilon_{zt}$: Selling price of each unit of product processed (kilogram) in the recycling market z in period t

$C\alpha_{ast}$: Supply capacity s to supply the raw material a in period t

$C\beta^{+}{}_{pdc}$: Maximum capacity level c to produce product p in the production center d

$C\beta^{-}{}_{pdc}$: Minimum capacity level c to produce product p in the production center d

$C\delta_{ppt}$: Demand of retailer p for product p over time t

$C\beta_{dt}$: Capacity of the separation center d to collect products in time period t

$C\mu_{rt}$: Capacity of the separation center r in the period t

$C\theta_{xt}$: "Capacity of the center of the waste x in the time period t

$C\varphi_{m}$: Vehicle capacity m (cubic meters)

$C\varepsilon_{zt}$: Maximum capacity of the recycling market z to sell processed products in period t

WK_{p}: Weight of each unit of processed product p (in kilograms)

VL_{p}: Volume of each product unit p (in cubic meters)

ω_{ap}: Amount of raw material a needed to produce each product unit p

$\alpha\beta_{asdt}$: Cost of transporting each unit of raw material a from supplier s to the production center d in period t

$\beta\mu_{pdrt}$: Transportation cost for each unit of product p from the separation center d to the separation center r in period t

$\theta\beta_{pdxt}$: Transportation cost for each unit of product p from the separation center d to the disposal center x in time period t

$\mu\varepsilon_{rzt}$: Transportation cost per kilogram processed from separation center r to recycling market z at the time t

$\beta\delta_{dp}$: Distance between production center d and retailer p

δ_{pq}: Distance between retailer p and retailer q

$T\delta_{pqm}$: Distance between retailer p and q by vehicle m

$T\beta\delta_{mdp}$: Time interval between production center d and retailer p by vehicle m

TS_{mp}: Time needed to serve retailer p by vehicle m

$R\delta_{ppt}$: Return rate of product p from retailer p in the period t

PR_{pdt}: Percentage of recyclable product p sent from production center d to reuse in separation centers in period t

($TW^{-}{}_{pt}, TW^{+}{}_{pt}$): Time interval allowed for the products delivery to the retailer p without penalty in the period t

TWF: Maximum time allowed to return vehicles to production centers

LT_{p}: Product life p

Eφ: Amount of environmental degradation caused by the consumption of each unit of fuel by vehicles

PE: Disposal cost of each environmental unit

PP: Penalty of each unit exceeding the time window

φ_m: Fuel consumption by vehicle m per kilometer traveled

Pφ: Price per liter of fuel

BM: A very large number

4.3.Variables

$Y\alpha_{sat}\begin{cases}1\\0\end{cases}$: If the supplier s is chosen to purchase raw material a in time period t/ otherwise.

$Y\beta_d\begin{cases}1\\0\end{cases}$ If the production and separation center d is established/ otherwise.

$Y'\beta_{pdc}\begin{cases}1\\0\end{cases}$ If machines with capacity level c are installed to produce product p in production center d/ otherwise.

$Y\mu_r\begin{cases}1\\0\end{cases}$ If the separation center r is set up/ otherwise.

$Y\theta_x\begin{cases}1\\0\end{cases}$ If the disposal center x is established/ otherwise.

$Y\varphi_m\begin{cases}1\\0\end{cases}$ If vehicle m is purchased/ otherwise.

$Y_{mpqt}\begin{cases}1\\0\end{cases}$ If vehicle m travels between retailer p and q over the time t/ otherwise.

$Y_{md}\begin{cases}1\\0\end{cases}$ If vehicle m is assigned to production center d, otherwise

$X_{mnpt}\begin{cases}1\\0\end{cases}$ If in period t vehicle m reaches vehicle location p before vehicle n, otherwise

$x\alpha\beta_{asdt}$: The quantity of raw material a purchased from supplier s by the production center d during period t

$x\beta\delta_{pmdpt}$: The quantity of product p delivered to the retailer p from the production center d by vehicle m in period t

$V\delta\beta_{pmpdt}$: "The value of product p returned from retailer p to separation center d by vehicle m in time period t

$x\beta\mu_{pdrt}$: The quantity of product p transferred from the separation center d to the separation center r in time period t

$V\beta\theta_{pdxt}$: The quantity of product p transferred from the separation center d to the disposal center x over time t

$V\mu\xi_{rzt}$: The quantity of processed products transferred from the breakdown center r to the recycling market z in period t

DLV_{pmpt}: The quantity of product p deliverable in vehicle m after leaving the retailer p in period t

PCK_{pmpt}: The quantity of product p returned in vehicle m before entering the retailer p in period t

λT_{mpt}: Time vehicle m arrives at the retailer location p in period t

λP_{mpt}: Time window exceeded for retailer p by vehicle m in period t

η_{ppt}: Inventory level for product p in retail warehouse p in time period t

η^{+}_{ppt}: Quantity of product p in the retail warehouse p in period t

η^{-}_{ppt}-: Quantity of lost demand for product p in the retail warehouse p in period t

4.4.Objective Functions

$$
\begin{aligned}
\text{Min } Z_1 = & \sum_{a,s,t} F\alpha_{ast} * Y\alpha_{sat} + \sum_{d} \beta_d * Y\beta_d + \sum_{p,d,c} w\,\beta_{pdc} \\
& * Y'\beta_{pdc} + \sum_{r} H\mu_r * Y\mu_r + \sum_{x} H\theta_x \\
& * Y\theta_x + \sum_{m} H\varphi_m * Y\varphi_m \\
& + \sum_{a,s,d,t} X\,\alpha\beta_{asdt} * \alpha\beta_{asdt} + \sum_{asdt} F\alpha_{ast} \\
& * X\alpha\beta_{asdt} + \sum_{p,m,d,p,t} F\beta_{pdt} * X\beta\delta_{pmdpt} \\
& + \sum_{p,p,t} F\delta^{+}_{ppt} * \eta^{+}_{ppt} + \sum_{p,p,t} F\delta^{-}_{ppt} * \eta^{-}_{ppt} \\
& + \sum_{p,m,p,d,t} F\beta'_{pdt} * X\delta\beta_{pmpdt} \\
& + \sum_{p,d,r,t} F\mu_{prt} * X\beta\mu_{pdrt} + \sum_{p,d,x,t} F\theta_{pxt} \\
& * V\beta\theta_{pdxt} + \sum_{p,d,r,t} \beta\mu_{pdrt} * X\beta\mu_{pdrt} \\
& + \sum_{p,d,x,t} \beta\theta_{pdxt} * V\beta\theta_{pdxt} + \sum_{r,z,t} \mu\varepsilon_{r,z,t} \\
& * V\mu\varepsilon_{r,z,t} + P\varphi * \sum_{m,p>1,q>z,t} \varphi_m * \delta_{pq} \\
& * Y_{mpqt} + P\varphi * \sum_{m,d,p>z,t} \varphi_m * \beta\delta_{pq} \\
& * \left(XY_{mdzpt} + XY_{mdzpt}\right) + E\varphi \\
& * \sum_{m,p>1,q>z,t} \varphi_m * \delta_{pq} * Y_{mpqt} \\
& + \sum_{m,p,t} PP * \lambda P_{mpt} - \sum_{r,z,t} F\varepsilon_{zt} * V\mu\varepsilon_{rzt}
\end{aligned}
\qquad (1)
$$

The first objective function aims at minimizing the total costs.

$$Min\, Z_2 = \sum_{p,p,t} \eta^{-}_{ppt} \quad (2)$$

This function minimizes lost demand.

$$\sum_{m,p} X\beta\delta_{pmdpt} \qquad \forall a,p,d,t \quad (3)$$

Constraint (3) is related to controlling the balance of inventory in production centers. Accordingly, the amount of the purchased raw material from suppliers should not be less than the amount of the transferred product from production centers to retailers.

$$\eta_{ppt} = \sum_{m,d} X\beta\delta_{pmdpt} - C\delta_{ppt} - R\delta_{ppt} \qquad \forall a,p,t = 1 \quad (4)$$

$$\eta_{ppt} = {\eta^{+}}_{pp(t-1)} + \sum_{m,d} X\beta\delta_{pmdpt} - C\delta_{ppt} - R\delta_{ppt} \qquad \forall p,p,t > 1 \quad (5)$$

The inventory balance in the retailer warehouse for the first and the subsequent periods is given in the constraints (4) and (5), respectively.

$$\eta_{ppt} = {\eta^{+}}_{ppt} + {\eta^{-}}_{ppt} \qquad \forall p,p,t \quad (6)$$

The relationship between inventory level, storage level and lost demand has been expressed in Constraint (6).

$$V\delta\beta_{pmpdt} \geq R\delta_{ppt} * X\beta\delta_{ppt} \qquad \forall p,m,d,p,t \quad (7)$$

$$V\delta\beta_{pmpdt} \leq R\delta_{ppt} * X\beta\delta_{ppt} + 1 \qquad \forall p,m,d,p,t \quad (8)$$

The following constraints calculate the amount of returned product from retailers to separation centers.

$$\sum V\delta\beta_{pmpdt} \leq \sum_{r} X\beta_{pdrt} + \sum_{x} X\beta\theta_{pdrt} \qquad \forall p,d,t \quad (9)$$

Constraint (9) shows the balance of inventory in separation centers.

$$\sum_{r} X\beta\mu_{pdrt} = PR_{pdt} * \sum_{m,p} V\delta\beta_{pmpdt} \qquad \forall p,d,t \quad (10)$$

The amount of product transferred from the isolation centers to the separation center is calculated in the Constraint (10).

$$\sum_{r} V\mu\varepsilon_{rzt} = \sum_{p,d} KG_p * X\beta\mu_{pdrt} \qquad \forall r,t \quad (11)$$

The amount of transferred product from reuse centers to the recycling market is calculated by constraint (11).

$$\eta_{ppt} \leq \sum_{t'=t}^{t+zT_p} C\delta_{ppt'} \qquad \forall p, p, t \leq T - ZT_p \qquad (12)$$

$$\eta_{ppt} \leq \sum_{t'=t}^{T} C\delta_{ppt'} \qquad \forall p, p, t \leq T - zT_p \qquad (13)$$

Specifying Inventory level is controlled by constraints (12) and (13) to prevent spoilage of products.

$$\lambda T_{mpt} + BM * (1 - Y_{mpzt}) \geq \lambda T_{mpt} + TS_{mp} + T\delta_{mp} \qquad \forall m, p, q > 1, t \qquad (14)$$

$$TWF + BM8(1 - Y_{mpzt}) \geq \lambda T_{mpt} + TS_{mp} + T\delta_{mp} \qquad \forall m, d, p > 1, t \qquad (15)$$

Constraints (14) and (15) guarantee the subtour elimination constraints. Constraint (15) also ensures that the hard time window is not exceeded.

$$\lambda T_{mpt} \geq TW_{pt}^{-} \qquad \forall m, p, t \qquad (16)$$

$$\lambda T_{mpt} - TW_{pt}^{+} \leq \lambda P_{mpt} \qquad \forall m, p, t \qquad (17)$$

Controlling the lower limit of time window is considered by the constraint (16) and the constraint (17) shows the violation from the specified time window.

$$\lambda T_{mpt} - \lambda T_{npt} + BM * X_{mnpt} \leq TS_{np} \qquad \forall m \neq n, p > 1, t \qquad (18)$$

$$\lambda T_{npt} - \lambda T_{mpt} + BM * (1 - X_{mnpt}) \leq TS_{mp} \qquad \forall m \neq n, p > 1, t \qquad (19)$$

Constraints (18) and (19) show the vehicles schedule in visiting retailers.

$$\sum_{m,p} X\beta\delta_{pmdpt} + BM * (1 - Y'\beta_{pdc}) > C\beta_{pdc}^{-} \qquad \forall p, d, c, t \qquad (20)$$

$$\sum_{m,p} X\beta\delta_{pmdpt} \leq BM * (1 - Y'\beta_{pdc}) + C\beta_{pdc}^{+} \qquad \forall p, d, c, t \qquad (21)$$

Determining the production capacity level is considered by constraints (20) and (21).

$$\sum_{m,p} X\alpha\,\beta_{asdt} \leq C\alpha_{asdt} \qquad \forall a, s, t \qquad (22)$$

$$\sum_{m,p} V\delta\,\beta_{pmpdt} * Vz_p \leq C\beta_{dt} \qquad \forall d, t \qquad (23)$$

$$\sum_{m,p} X\,\beta\mu_{pdrt} * VZ_p \leq C\mu_{dt} \qquad \forall r, t \qquad (24)$$

$$\sum_{m,p} V\,\beta\theta_{pdxt} \leq C\theta_{xt} \qquad \forall x, t \qquad (25)$$

Ensuring no violation from suppliers' capacity, separation centers, reuse centers and disposal centers are stated in constraints (22) to (25), respectively.

$$\sum_{m,p} V\,\mu\varepsilon_{rzt} \leq C\varepsilon_{rt} \qquad \forall z, t \qquad (26)$$

Every livestock food market purchases processed products to the maximum of its capacity. This capacity constraint is controlled by this constraint.

$$DLV_{pmpt} + BM * \left(1 - Y_{mpqt}\right) \geq DLV_{pmpt} + X\beta\delta_{pmdpt} \quad \forall p, m, d, p > 1, t \tag{27}$$

$$\mathrm{DLV_{pmpt}} \geq \sum_{\mathrm{p}} \mathrm{X\beta\delta_{pmdpt}} \quad \forall \mathrm{p, m, d, t} \tag{28}$$

The constraints (27) and (28) calculate the amount of product deliverables available in vehicles when leaving retailers.

$$PCK_{pmpt} + BM * \left(1 - Y_{mpqt}\right) \geq PCK_{pmpt} + X\delta\beta_{pmdpt} \quad \forall p, m, d, p > 1, t \tag{29}$$

$$PCK_{pmpt} \geq \sum_{p} V\delta\beta_{pmpdt} \quad \forall p, m, d, t \tag{30}$$

The amount of products returned to vehicles before entering the retail location is expressed in the constraints (29) and (30).

$$\sum_{p} DLV_{pmpt} * VZ_p + \sum_{p} PCK_{pmpt} * VZ_p + \sum_{p} X\beta\delta_{pmdpt} * VZ_p \leq C\varphi_m \quad \forall m, d, p > 1, t \tag{31}$$

$$\sum_p DLV_{pmpt} * VZ_p + \sum_p PCK_{pmpt} * VZ_p + \sum_p V\delta\beta_{pmpdt} * VZ_p \leq C\varphi_m \quad \forall m, d, p > 1, t \tag{32}$$

The stated constraints ensure that the capacity of the vehicles is not exceeded.

$$\sum_{p} DLV_{pmpt} * VZ_p \leq C\varphi_m \quad \forall m, p > 1, t \tag{33}$$

$$\sum_{p} PCK_{pmpt} * Vz_p \leq C\varphi_m \quad \forall m, p > 1, t \tag{34}$$

$$\sum_{p} Y_{mpqt} \leq 1 \quad \forall m, q, t \tag{35}$$

Up to once at any time period, all the vehicles can freely visit every retailer. It is noteworthy that each retailer has the possibility to be visited by more than a single vehicle at any certain time. This status is covered by constraint 35.

$$\sum_p Y_{mpqt} - \sum_p Y_{mqpt} = 0 \quad \forall m, q, t \tag{36}$$

This constraint states that if we enter the location of a retailer, we must leave it after serving it.

$$X\beta\delta_{pmdqt} \leq BM * \sum_p Y_{mpqt} \quad \forall m, q, t \tag{37}$$

$$V\delta\beta_{pmqdt} \leq BM * \sum_p Y_{mpqt} \quad \forall p, m, q, d, t$$

The condition for delivering the products to the retailer and picking up the returned products from retailers is that the retailer has visited the vehicle which is considered within the stated constraints.

$$X\beta\delta_{pmdqt} \leq BM * Y\varphi_m \quad \forall p, m, d, q, t \quad 38$$

$$V\delta\beta_{pmqdt} \leq BM * Y\varphi_m \quad \forall p,m,q,d,t \qquad 39$$

Another condition for delivering the product to and picking up the returned products from retailers is that the vehicle should be purchased, which has been covered in constraints (39) and (40), respectively.

$$X\beta\delta_{pmdqt} \leq BM * X_{md} \quad \forall p,m,d,q,t \qquad 40$$

$$V\delta\beta_{pmqdt} \leq BM * X_{md} \quad \forall p,m,q,d,t \qquad 41$$

Another condition for delivering the product to retailers and picking up the returned products from them is that the purchased vehicle be delivered to a production center, which is stated in the stated constraints.

$$\sum_d X_{md} \leq 1 \quad \forall m \qquad 42$$

This constraint asserts that every vehicle should be allocated to a maximum of one production center.

$$Y'\beta_{pdc} \leq BM * Y\beta_d \quad \forall p,d,c \qquad 43$$

This condition guarantees the installation of equipment in the launched production center.

$$\sum_m X_{md} \leq BM * \sum_{p,c} Y'\beta_{pdc} \quad \forall b \qquad 44$$

The constraint (45) shows that no vehicle is allocated to production center if it has not been established.

$$\sum_c Y'\beta_{pdc} \leq 1 \quad \forall p,d \qquad 45$$

Constraint (46) maintains that it is possible to use the maximum production capacity to produce each product unit in every production center.

$$X\alpha\beta_{asdt} \leq BM * Y\alpha_{ast} \quad a,s,d,t \qquad 46$$

The condition for purchasing raw material from suppliers is that the suppliers be ordered that is expressed by constraint (47).

$$X\alpha\beta_{asdt} \leq BM * \sum_c Y'\beta_{pdc} \quad \forall a,p,s,d,t \qquad 47$$

$$X\beta\delta_{pmdpt} \leq BM * \sum_c Y'\beta_{pdc} \quad \forall p,m,d,p,t \qquad 48$$

$$V\delta\beta_{pmpdt} \leq BM * \sum_c Y'\beta_{pdc} \quad \forall p,m,p,d,t \qquad 49$$

$$X\beta\mu_{pdrt} \leq BM * \sum_c Y'\beta_{pdc} \quad \forall p,d,r,t \qquad 50$$

$$V\beta\theta_{pdxt} \leq BM * \sum_c Y'\beta_{pdc} \quad \forall p,d,x,t \qquad 51$$

(45)

According to the conditions of location, if the center is not established, that center should not serve. This condition is set for production and separation centers within the stated limits.

$$X\beta\mu_{pdrt} \leq BM * Y\mu_r \quad \forall p,d,r,t \tag{52}$$

$$V\mu\varepsilon_{rzt} \leq BM * Y\mu_r \quad \forall z,r,t \tag{53}$$

$$V\beta\theta_{pdxt} \leq BM * Y\theta_x \quad \forall p,d,x,t \tag{54}$$

The stated conditions are considered in constraints (53) and (54) for separation centers and in constraint (55) for waste centers.

3.1. Linearization Process

The expression $Y_{mpqt} \times X_{md}$ in the first objective function of the model causes it to be nonlinear. For this purpose, the objective function should be linearized. In this regard, in order to linearize this nonlinear expression, a new binary variable (XY_{pbmnt}) is defined and the nonlinear expression is replaced in the proposed model. Therefore, the objective function will be linearized as follows:

$$\text{Min } Z_1 = \sum_{a,s,t} H\alpha_{st} * Y\alpha_{sat} + \sum_d H\beta_d * Y\beta_d + \sum_{p,d,c} W\beta_{pdc} * Y'\beta_{pdc} + \sum_r H\mu_r * Y\mu_r + \sum_x H\theta_x * Y\theta_x + \sum_m H\varphi_m * Y\varphi_m + \sum_{a,s,d,t} X\alpha\beta_{asdt} * \alpha\beta_{asdt} + \sum_{asdt} F\alpha_{ast} * X\alpha\beta_{asdt} + \sum_{p,m,d,p,t} F\beta_{pdt} * X\beta\delta_{pmdpt} + \sum_{p,p,t} F\delta^{+}_{ppt} * \eta^{+}_{ppt} + \sum_{p,p,t} F\delta^{-}_{ppt} * \eta^{-}_{ppt} + \sum_{p,m,p,d,t} F\beta'_{pdt} * V\delta\beta_{pmpdt} + \sum_{p,d,r,t} F\mu_{prt} * X\beta\mu_{pdrt} + \sum_{p,d,x,t} F\theta_{pxt} * V\beta\theta_{pdxt} + \sum_{p,d,r,t} * X\beta\mu_{pdrt} + \sum_{p,d,x,t} \beta\theta_{pdxt} * V\beta\theta_{pdxt} + \sum_{r,z,t} \mu\varepsilon_{r,z,t} * V\mu\varepsilon_{r,z,t} + P\varphi * \sum_{m,p>1,q>z,t} \varphi_m * \delta_{pq} * Y_{mpqt} + P\varphi * \sum_{m,d,p>z,t} \varphi_m * \beta\delta_{pq} * \left(XY_{mdzpt} + XY_{mdzpt}\right) + E\varphi * \sum_{m,p>1,q>z,t} \varphi_m * \delta_{pq} * Y_{mpqt} + \sum_{m,p,t} PP * \lambda P_{m,pt} - \sum_{r,z,t} P\varepsilon_{rt} * V\mu\varepsilon_{rzt} \tag{55}$$

Then the relationship between the two variables Y_{mpqt} and X_{md} and the new binary variable should be determined (Qazvini et al., 2021). These relationships are shown as follows:

$$XY_{mdpqt} \leq Y_{mpqt} + BM * (1 - X_{md}) \tag{56}$$

$$XY_{mdpqt} \leq Y_{mpqt} + BM * (1 - X_{md}) \tag{57}$$

$$XY_{mdpqt} \leq X_{md} + BM * (1 - Y_{mpqt}) + BM * (X_{md} + Y_{mpqt} - 2) \tag{58}$$

$$XY_{mdpqt} \leq BM * (X_{md} + Y_{mpqt}) \tag{59}$$

4. Multi-Objective Solution Approach

"Here, the proposed two-objective model is expressed as a single-objective model under uncertainty conditions. This approach is composed of two phases, which are as follows:"

"Phase One: First, using the fuzzy solution approach proposed by Zimmerman (1978), the proposed two-objective model will be converted into a single-objective model as follows:"

Max ω *s.t.* $\omega \leq \psi_{z_g}^{Min}$	(60)

4.1.System Constraints

Where $\psi_{Z_h^{max}}$ and $\psi_{Z_g^{min}}$ represent the membership functions for the maximization and minimization objective functions, respectively, and $\omega = \left\{\psi_{Z_g^{min}}, \psi_{Z_h^{max}}\right\}$. moreover, the system constraints indicate the constraints pertaining to the proposed model. The membership functions of the model are defined as below:

$$\psi_{Z_h^{min}} \begin{cases} 1 & Z_g > Z_g^+ \\ 0 & Z_g > Z_g^- \\ \dfrac{Z_g^* - z_g}{Z_g^* - Z_g^-} & Z_g^- \leq Z_g \leq Z_g^+ \end{cases} \tag{61}$$

$$\psi_{Z_h^{Max}} \begin{cases} 1 & Z_h > Z_h^+ \\ 0 & Z_h > Z_h^- \\ \dfrac{Z_h^+ - Z_h}{Z_h^+ - Z_h^-} & Z_h^- \leq Z_h \leq Z_h^+ \end{cases} \tag{62}$$

where Z_g^- and Z_g^+ represent the lower limit and upper limit of the minimization objective functions, respectively, and Z_h^- and Z_h^+ represent the lower limit and upper limit of the maximization objective functions, respectively. The optimal value of ω (ω^*) is achieved by executing the proposed model in GAMS software.

Phase Two: utilizing the ω^* obtained from the first phase, a weighted fuzzy solution approach proposed by Tavana et al. (2020) was developed in this phase for solving the two-objective model which is as follows:

$$\text{Max } \overline{\omega} = \textstyle\sum_g w_g * \omega_g + \sum_h w_h * \omega_h \tag{63}$$

St:

$$\begin{aligned} &\omega^* \leq \omega_g \leq \psi_{Z_g^{min}} \\ &\omega^* \leq \omega_h \leq \psi_{Z_g^{max}} \\ &\sum_g w_g + \sum_h w_h = 1 \end{aligned} \tag{64}$$

4.2.System Constraints

Where W_g denotes the importance of the gth minimum function of the minimization objective and W_h shows the hth importance of the maximization objective function and their values are decided upon by decision makers.

5. Case Study

This section examines a production-distribution chain of a dairy factory in Rasht, Iran to validate the proposed model. The chain under study produces and sells two types of products, including large and small-bottle yogurt drink. The process of yogurt drink production in the production line is as follows: First, milk enters the laboratory and after that its quality is approved, it is sent to milk tanks. Yogurt drink production is done in two ways: 1- diluting the milk and 2- producing yogurt and then, preparing the yogurt drink. It should be noted that the number of yogurt drink considered in the research is based on the box. Although different products are produced in the dairy factory, the main raw material for dairy production is raw milk. Therefore, planning for this raw material is done in the given model. Four areas around Rasht were considered as potential centers for raw material production. Three areas in and around Rasht were also selected as the potential production and separation centers. Ten heterogeneous vehicles are obtainable for the distribution of products among customers. Six districts in Gilan province, which were purchased in bulk, were also considered as demand points. Dairy products are distributed in these areas twice a week. In this regard, four time periods (2 weeks) were considered in the present study.

5.1.Implementing a multi-objective solution approach

"For solving the model proposed here using the presented data, the two-objective model must first turned into a single-objective one utilizing the method presented by Tavana et al. (2020). The following is the process of making the proposed model single-objective in two phases":

Phase 1: For this purpose, the upper limit and lower limit of the objective functions should be first determined. To calculate the lower limit of the first and the upper limit of the second objective function, the model must be run for the first objective function (without considering the second objective function). In the same way, the intended model should be run exclusively for the second objective function for the calculation of the upper limit of the first and the lower limit of the second objective function. The lower limit of the second objective function, which equals zero, is at play in the case that there is no lost demand at each time period. On the other hand, the upper limit of the second objective function will be at play when all customer demand remains unmet at all time periods. In other words, the total customer demand in all time periods ($\sum_{p,p,t} C\delta_{p,p,t}$) is regarded as the upper limit of the second objective function." Thus, for the first and second objective functions, the membership functions can be shown as follows:

$$\psi_{Z_g^{min}} = \frac{Z_1^+ - Z_1}{Z_1^+ - Z_1^-} = \frac{5.766.825.742 - Z_1}{5.766.825.742 - 381.353.000} = \frac{5.766.825.742 - Z_1}{5.385.472.742}$$
$$\psi_{Z_h^{max}} = \frac{Z_2^+ - Z_2}{Z_2^+ - Z_2^-} = \frac{9606 - Z_1}{9606} \qquad (65)$$

Therefore, given the method proposed by Zimmerman (1978), the two-objective model is transformed as follows:

Max ω

St:

$$\omega \leq \frac{5.766.825.742 - Z_1}{5.385.472.742}$$
$$\omega \leq \frac{9.606 - Z_2}{9.606} \qquad (66)$$

Constraints (3)-(55)

By implementing the model obtained using CPLEX solver in GAMS software, the optimal value of ω (i.e. ω^*) was obtained 0.687.

Second phase: the two-objective model is proposed in this phase as a single-objective model as follows using ω^* obtained from the first phase and the weighted fuzzy solution approach provided by Tavana et al. (2020) (w1 = 0.6, w2 = 0.4).

$$\text{Max } \varpi = 0.6 \times \omega_1 + 0.4 \times \omega_2 \qquad (67)$$

St:

$$0.687 \leq \omega_1 \leq \frac{5.766.825.742 - Z_1}{5.385.472.742}$$
$$0.687 \leq \omega_2 \leq \frac{9.606 - Z_2}{9.606} \qquad (68)$$

Constraints (3)-(56)

5.2. Results and discussion

The optimal value of objective functions and decision variables is obtained as follows by executing a single-objective model using CPLEX solver in GAMS software:

The optimal value was 20654616530 Rials (2065461653 Tomans) for the first objective function, while it was 2869, i.e. in 4 time periods for the second objective function. Then, we have faced a sum of 2869 units of lost demand.

The raw material (milk) in period 1, 2 and 4 must be purchased from supplier 1 and in period 3 from supplier 2.

Production Center 1 with a capacity level of 1 must be set up to supply both products.

Disposal Center 1 and separation Center 2 must be launched.Vehicles numbered 2, 3, 4, 9 and 10 should be purchased and assigned to the Production Center 1.The amount of purchased milk from each of the suppliers is indicated in the Table 1. The results shown in this table indicate that the necessary milk is supplied from suppliers 1 and 2. For instance, in period 1, 24 thousand kg was purchased by Production Center 1 (Rasht) from the supplier 1.

Table 1
The amount of milk purchased (thousand kilograms) from each supplier

$X\alpha\beta_{asdt}$			t= 1	t= 2	t= 3	t= 4
a= 1	s= 1	d= 1	12	3.5	0	2
a= 1	s= 2	d = 1	0	0	8	0

"In Tables 2 and 3, the amounts of products delivered to and picked up from each retailer in each time period are shown, respectively. For instance, the number 327 in the first row of the table represents that 327 units of Product 1 has been delivered by Vehicle 2 to retailer 6 in time period 4. In the same way, the number 36 in the first row of Table 3 indicates that 36 units of the product returned from the same retailer has been received by the vehicle in time period 4. Hence, the operations performed on the retailer 6, in period 4, by vehicle 2 can be explained as saying that the customer has received 327 units of product 1 in this period, has used 291 units as demand, and 36 units have been returned to the separation center. Therefore, the results accuracy for other customers can be examined similarly in each of the time periods. In addition, vehicles 2, 3, 4, 9 and 10 have been employed for the delivery and pickup of products to and from customers, and such vehicles have all been assigned to Production Center 1 (Rasht); the results are exactly the same as the results for the binary variables mentioned earlier."

Table 2
The amount of product delivered to each retailer by vehicles in each time period

$X\beta\delta_{pmdpt}$				T=1	T=2	T=3	T=4
Product 1	M= 2	D= 1	P= 6	-	-	-	164
	M = 3		P = 2	235	-	-	-
			P = 4	25	-	-	-
			P = 5	5	-	212	-
			P = 6	37	-	96	-
	M = 4		P = 2	-	-	121	-
			P = 3	-	-	255	-
			P = 4	99	-	-	-
			P = 5	227	-	-	36
			P = 6	44	46	-	-
	M = 9		P = 2	180	-	-	-
			P = 3	-	-	-	11
			P = 4	-	388	-	-
			P = 7	215	-	-	-
	M = 10		P = 3	152	-	-	-
			P = 6	230	-	73	-
			P = 7	-	-	224	-
Product 2	M = 2		P = 3	-	-	60	-
			P = 5	-	-	-	21
	M = 3		P = 7	-	59	-	-
	M = 4		P = 5	-	-	-	67
			P = 6	-	65	-	-
	M = 9		P = 2	-	-	81	-
			P = 3	-	-	-	76
			N= 4	-	3	-	-
	M = 10		P = 2	-	-	-	78
			P = 6	-	80	-	-

Table 3
Amount of product picked up from each retailer by each vehicle at each time period

$X\beta\delta_{pmdpt}$				T= 1	T= 2	T= 3	T= 4
Product 1	M= 2	D= 1	P= 6	-	-	-	18
	M = 3		P = 2	18	-	-	-
			P = 4	3	-	-	-
			P = 5	1	-	12	-
			P = 6	4	-	6	-
	M = 4		P = 2	-	-	8	-
			P = 3	-	-	14	-
			P = 4	10	-	-	-
			P = 5	16	-	-	4
			P = 6	5	5	-	-
	M = 9		P = 2	14	-	-	-
			P = 3	-	-	-	1
			P = 4	-	21	-	-
			P = 7	17	-	-	-
	M = 10		P = 3	18	-	-	-
			P = 6	25	-	4	-
			P = 7	-	-	19	-
Product 2	M = 2		P = 3	-	-	5	-
			P = 5	-	-	-	2
	M = 3		P = 7	-	7	-	-
	M = 4		P = 5	-	-	-	6
			P = 6	-	5	-	-
	M = 9		P = 2	-	-	5	-
			P = 3	-	-	-	7
			P = 4	-	1	-	-
	M = 10		P = 2	-	-	-	6
			P = 6	-	6	-	-

The obtained results of the analysis show that a reasonable relationship exists between the variables and parameters of the proposed model, which verifies the effectiveness and efficiency of the proposed model.

6. Conclusion

In this paper, a bi-objective mixed integer linear programming model was developed to design a green supply chain network considering location-inventory-routing with simultaneous pickup and delivery problem. The purpose of the proposed model was to minimize total costs and lost demands simultaneously. Because the proposed model included nonlinear expressions, we were linearized using operational research techniques. It should be noted that an efficient solution approach based on the fuzzy weighted solution approach was used to convert the bi-objective model to single objective one. Due to having weights, this approach allows decision makers to change the weight of the objective functions to reach the decision limit and make the best decisions accordingly. Finally, the effectiveness and efficiency of the proposed model and solution approach have been evaluated using the data of a dairy production and distribution chain.

The exact solution method and GAMS software were used in the present study for solving the proposed model. As the size of the problem increases, because of its NP-hard nature, it is recommended to develop an efficient meta-heuristic algorithm to solve it. Also, in the present study, green criteria, i.e. vehicle fuel consumption and reverse flow in the chain, have led to green chain. It is suggested that in addition to these criteria, social criteria such as job creation and development should be used and a sustainable supply chain should be developed to solve this problem. Also, issues such as vehicle breakdowns, fluctuations in demand, fluctuations in the supply of raw materials, etc. are among the real-world assumptions that have been ignored in this study and it is suggested to consider them in future research.

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