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REDESIGNING A CLOSED LOOP FOOD SUPPLY CHAIN NETWORK CONSIDERING SUSTAINABILITY AND FOOD BANKS WITH DIFFERENT RETURNS

Abstract. *Increasing the importance of sustainability in supply chain has motivated companies to redesign networks considering social and environmental responsibilities along with economic concerns. Food shortage, food waste and air pollution introduced as the main issues of global food and environmental problems. We propose a new mathematical model for redesigning food network in all aspects of sustainability. The objectives of the model are to minimize costs, transportation emissions, and unsatisfied foodbanks' demand. Foodbank as the main pillar of social responsibility has been introduced in food chain. In this paper, returned products divide into usable and recoverable products based on health security, in which usable products are not sellable but beneficial for those who do not care about appearance and can cover foodbank demand. Finally, computational study is made based on an Iranian food company data. The results reveal that more geographical diversity, using new distribution centers, and adding foodbanks helps to a sustainable network.*

Keywords*: Food supply chain, Sustainability, Foodbank, Substitutable, Tri-objective problem.*

JEL Classification: C02, C61, C63

1. Introduction

During past decades, people's awareness on environmental and social impacts of food supply chain (FSC) has been increased. The addressed concerns have been led the more pressure from consumers, organizations, non-governmental organizations (NGOs), and policy-makers to consider sustainability aspects when managing FSC (Allaoui et al. 2018). Meanwhile, the adoption of sustainability development goals (SDGs) was expressed by the United Nations general assembly (UNGA). The aim of this plan is to ending poverty, protecting the planet, and improving the lives of people by the year 2030. The statement encourages policymakers, organizations, NGOs, and other decision-makers to implement

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economic, social, and environmental strategies (GA 2015). Therefore, the current structure of companies established by economic requirement may operate non-efficiently in the term of sustainability and forced to be redesigned.

from another aspect, the diversity of the population in most of urban sectors will be changed in the future and food supply should be planned to provide future population needs. As stated in United Nations predictions, the global population will put it over 9.3 billion in 2050 and at this time the urban population will move upward from 3.6 billion (2011) to 6.3 billion (2050)(Division 2011). Such geographical transition will change the configuration of supply chain network, especially in food industries. From the environmental view, one of the main challenges belongs to the amount of greenhouse gas (GHG) emission emitted during the supply chain network. Based on last surveys, transportation activities have been introduced as the key elements of GHG problems in the supply chain network (EPA 2014; Windsperger et al. 2019). Since, FSC is of high transportation cost and GHG emission -due to the high frequency of transportation-, it is essential to pay more attention to design or redesign such supply chain network. Furthermore. the rate of food wastages has been progressively increased, over multiple periods. According to Stenmarck et al. (2016), 20 to 30 percent of products made in EU is spoiled through the FSC network per year with € 143 billion worth in 2012. Since food loss has been increasing around the world, it is critical for policymakers and organizations to find various ways to reduce food losses. In this regard, food bank (FB) as a new concept was emerged in the United States and developed in other countries over the past three decades. Food banks are non-profit organizations whose mission is to provide aids directly or indirectly to those in need (Orgut et al. 2016).

In this paper, we bring up three dimensions of sustainability including economic, environmental and social responsibilities in redesigning the network of a given food company. The paper describes a new multi-objective mixed-integer linear programming (MOMILP) model that integrates all three pillars of sustainability. The rest of this paper is structured as follows: In the next sub-section, a literature review of the sustainable supply chain network redesign is presented. In section 2, the problem description, mathematical formulation, and solution approach are provided and section 3 examines a case study and the experimental results. Finally, section 4 concludes with a summary of our findings, managerial insights, and future research ideas.

2. Literature review

A brief literature review of the sustainable food supply chain (SFSC) has been presented in this section. In this context, Van Der Vorst et al. (2009) provided a new simulation model for redesigning FSC in which logistic and environmental issues, as well as food quality concerns, are fully explored. The model not only is aimed to optimize logistic costs but also improve service level in relation to product quality, and availability aspects. Soysal et al. (2014) presented a new multi-objective model to design food logistic networks with emission considerations. The model minimizes the amount of cost and GHG emissions generated during transportation activities. In the addressed model, the amount of GHG emission depends on road characteristics, fleet and fuel modes, product weight and temperature requirement, and transportation distance. Allaoui et al. (2018) also developed a SFSC problem that takes into account all three pillars of sustainability including GHG and water pollution as environmental impacts and created jobs as social responsivity and economic aspect. Boukherroub et al. (2015) identified a new approach to put sustainable development assumption into the SC planning model and applied to the Canadian food industry. This method optimizes multi-objective mathematical programming problem along with economic, social and environmental responsibility, simultaneously. The cost indicators calculate strategic and tactical costs as an economic impact, employment indicators measure social performance by assessing local employee numbers, and “climate change” indicators calculate environmental efficiency.

Chabada et al. (2012) studied the seven main waste procedures from lean theory and classified the categories of fresh food wastages in supply chain into transportation, inventory, motion, waiting, overproduction, over-processing, and defects. The authors showed how waste minimization can improve competitiveness especially in environmental and social responsibilities. Krishnan et al. (2020) provided a new model to redesign a FSC and improve environmental sustainability. The authors studied resource and functional ineffectiveness and proposed a novel structure to redesign FSC by considering LCA approach for assessment of environmental impact. The presented structure is utilized in a mango FSC in India. Martins et al. (2019) identified a new mathematical problem to redesign FB network with sustainability requirements. The model redesigns the real multi-layers products aided network collected money and food products from donors. The authors developed a MOMILP to identify a network configuration to minimize total cost, amount of food wastages and amount of CO_2, and to maximize the access of FBs to the aided money or products. Miranda-Ackerman et al. (2017) presented a nonlinear model in the processed food industry to optimize economic and environmental performances during multiple periods. The addressed model maximizes net present value, minimizes global warming potential on climate impact, and minimizes the variable production and transportation costs. Rohmer et al. (2019) addressed a new method in FSC regarding nutritional requirements. The model optimizes economic and environmental goals and analyzes the changes in the food usage culture. The overall purpose of such a model is to maintain a sufficient dietary intake level besides the minimization of various economic and environmental indicators.

Based on our knowledge, there are several research gaps in the literature review of SFSC that can be summarized as below:

- Most previous researchers have focused on designing new CFSC while redesigning an existing CFSC network has been investigated in few researches.

- From the mathematical perspective, some opportunities exist to develop sustainability aspects associated with environmental and social concerns as well as economic impacts on FSC.
- Classification of retuned products into usable and recoverable returned products has not been considered in FSC.
- Substitutability of some products together and the necessity of allocation of special fleets to some products in FSC have not been considered.
- Foodbank as a new social responsibility and product substitution as a strong point of supply demand requires further investigations in SFSC.

This paper seeks to fill the addressed gaps and consider the distinctive characteristics of food company produces different types of food products.

3. Materials and methods

Figure 1 depicts a schematic view of the under study CFSC network inspired by the existing famous Iranian food company. The network structure consists of three different echelons including production/recovery center (PRC), regional distribution/collection center (RDC), distribution/collection center (DC) and disposal center. In this paper, it is assumed that DCs deliver the final products to customers/consumers with constant demand so each DC feeds its own local consumers. In this paper, we have aggregated consumer demands and represented them in DCs.

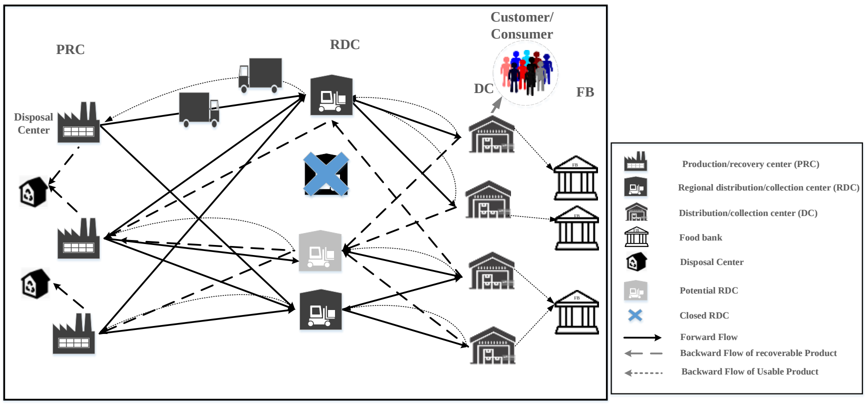

Figure 1. Schematic view of a CFSC.

RDC receives products from different PRCs, integrates and aggregates them based on downstream demands. It is notable, distribution and collection operations of this network are incorporated in each RDC to maximize the utilization of facilities. In the reverse flow of the network, returned products have been divided into two different categories based on health security: 1) usable products 2) recoverable products. Usable products are not sellable due to physical problems such as printing error, packaging failure, appearance, and etc. but there are still secure and beneficial for those who do not care about product's appearance or needy people(Martins et al. 2019). Such products can be donated to FBs as social responsibility or back to PRCs through RDCs. Recoverable products are those that have a quality problem and need to be recovered or disposed after inception in PRCs.

In this model, there are different products that require specific transportation conditions by pre-specific temperature. Chilled, frozen, dry, and ready meal products are such products that need to be stored at specific temperatures. Thus, Ambient, chilled, and frozen fleets have been considered to meet such temperature requirements. Other assumptions are briefly given as:

- The model integrates main pillars of sustainability including supply chain costs as economic impact, CO_2 footprint as an environmental aspect, and FBs' demand satisfaction as social responsibility.
- FBs are governmental organizations with fixed locations.
- Location, capacity, and fleet costs are restricted by a given budget; therefore, closing or opening of facilities is authorized for once.
- If one center expands the capacity level, such center should continue its operation in the following periods.
- If new RDCs install in potential locations then the capacity spaces should be allocated at the same time.
- Unsatisfied demand is lost with a penalty cost.
- All centers and fleets are of capacity limit.

4. Mathematical modeling

In this paper, Tone is the unique measurement used for food product quantities, storage and transport capacities, Kilometer is applied for distance unit between locations and Rial is used for financial parameters.

Sets:

T	Set of periods ($t \in T$)
I	Set of PRCs ($i \in I$)
$J = J^e \bigcup J^n$	Set of RDCs ($j \in J$)
J^e	Set of existing RDCs ($j \in J^e$)
J^n	Set of potential locations to establish new RDCs ($j \in J^n$)
K	Set of DCs ($k \in K$)
F	Set of FBs ($f \in F$)
P	Set of product types ($p \in P$)
M	Set of fleet modes ($m \in M$)
Q	Set of discrete capacity levels which can establish in RDC ($q \in Q$).
L	Set of discrete fleet capacity levels ($l \in L$)

For notational simplification, set OD defines all possible origin-destination routs:

$$OD:\{(i,j),(j,k),(k,f),(j,i),(k,j)\}$$

Since frozen or chilled fleets have special equipment (i.e. freezer or Refrigerator) to cool storage space (at -18°C or -4°C), fixed costs, fuel consumption and consequently fleet costs of such fleets are more than ambient ones. The cost and budget parameters are as follows:

Fo_j^t Fixed cost of establishing a new RDC at location $j \epsilon J^n$ in period $t \epsilon T$.

Fc_j^t Fixed cost of closing an existing RDC at location $j \epsilon J^e$ in period $t \epsilon T$.

Sc_{jp}^{tq} Fixed cost of capacity $q \epsilon Q$ for product $p \epsilon P$ at location $j \epsilon J$ in period $t \epsilon T$.

Vc_m^{tl} Fixed cost of fleet mode $m \epsilon M$ using capacity level $l \epsilon L$ in period $t \epsilon T$

Pc_p^t Cost of manufacturing product $p \epsilon P$ in period $t \epsilon T$

Rc_p^t Cost of remanufacturing recoverable returned product $p \epsilon P$ in period $t \epsilon T$

$Rc_p'^t$ Cost of remanufacturing usable returned product $p \epsilon P$ in period $t \epsilon T$

SH_{kp}^t Shortage cost of lost demand for product $p \epsilon P$ at location $k \epsilon K$ in period $t \epsilon T$

Tc_m^t Transportation cost of fleet mode $m \epsilon M$ in period $t \epsilon T$.

TB^t Total available budget in period $t \epsilon T$

Decision variables:

Y_j^t 1 if status of RDC $j \in J$ varies in period $t \in T$, 0 otherwise (i.e. if $j \in J^n$, $Y_j^t = 1$ means that a new RDC is opened at location J^n in period $t \epsilon T$, if $j \in J^e$, $Y_j^t = 1$ means that an existing RDC is closed at location J^e in period $t \epsilon T$.)

U_{jp}^{tq} 1 if capacity $q \in Q$ is installed at location $j \in J$ for product $p \in P$ in period $t \epsilon T$, 0 otherwise

X_{odp}^t Quantity of product $p \epsilon P$ transported in period $t \epsilon T$ from origin o to destination d, $(o,d) \epsilon OD$.

$X_{odp}'^t$ Quantity of usable returned product $p \epsilon P$ transported in period $t \epsilon T$ from node o to node d, $(o,d) \epsilon OD$.

N_{mod}^{lt} Number of fleets transported in period $t \epsilon T$ from node o to node d, $(o,d) \epsilon OD$ via mode $m \epsilon M$ and capacity level $l \epsilon L$

Pro_{ip}^t Quantity of product $p \epsilon P$ manufactured at PRC $i \epsilon I$ in period $t \epsilon T$

δ_{kp}^t Shortage of product $p \epsilon P$ at DC $k \epsilon K$ in period $t \epsilon T$

S_{odm}^t Unused capacity of fleet mode $m \epsilon M$ between pair $(o,d) \epsilon OD$ in period $t \epsilon T$

Some homogeneous products are substitutable; we define this assumption as a logical matrix (product × product). In this matrix shown in Fig.2, entity one represents which products can be substituted and entity zero represents which products cannot (Zahiri et al. 2018) We also used another logical matrix (product×fleet) to show how the products assign to related fleet modes (Fig. 3)

$$p\overset{p}{\begin{bmatrix}1&0&0&0\\0&1&1&0\\0&0&1&0\\0&0&0&1\end{bmatrix}}$$

Figure2. Product restriction

$$p\overset{m}{\begin{bmatrix}1&0&0\\0&1&0\\0&1&1\\1&0&0\end{bmatrix}}$$

Figure3. Fleet allocation matrix

Other parameters:

Cap_j^p Capacity of level $q\epsilon$Q that can be established at RDC $j\epsilon$J

$Cape_j$ Capacity of existing facility $j\epsilon$J^e at the beginning of time horizon

ω_p Capacity usage by each product $p\epsilon$P

Cap'^l Capacity of fleet at level $l\epsilon$L

d_{kp}^t Demand for product $p\epsilon$P at DC $k\epsilon$K in period $t\epsilon$T

d'^t_{fp} Demand for product $p\epsilon$P at FB $f\epsilon$F in period $t\epsilon$T

dis_{od} Distance between origin–destination pairs $(o,d)\epsilon$OD

λ_{kp} Rate of returned product $p\epsilon$P at DC $k\epsilon$K

ψ_p Rate of usable returned product $p\epsilon$P

$1-\psi_p$ Rate of recoverable returned product $p\epsilon$P

Ω_p Approved proportion of recoverable product $p\epsilon$P

$1-\Omega_p$ Rejected proportion of recoverable product $p\epsilon$P

$\Lambda_{pp'}$ Logical matrix (1 if products p, p' are substitutable; and 0, otherwise)

Γ_{pm} Logical matrix(1if product p shipped by fleet mode $m\epsilon$M; and0, otherwise)

The economic objective function calculates total cost (TC) for the network redesign problem such that as:

$$TC=TFC+TVC \tag{1}$$

where TFC shows the total fixed cost of opening, closing, expanding the capacity of RDCs and fleets:

$$TFC=\sum_t\sum_{j\in J^n}Fo_j^tY_j^t+\sum_t\sum_{j\in J^e}Fc_j^tY_j^t+\sum_t\sum_q\sum_p\sum_{j\in J}Sc_{jp}^{tq}U_{jp}^{tq}+\sum_t\sum_l\sum_m\sum_{od\in OD}Vc_m^{tl}N_{mod}^{tl} \tag{2}$$

The first two terms of Eq.2 depict the fixed costs of opening new RDCs and closing existing RDCs, respectively. The third statement illustrates capacity installation costs of RDCs and the fourth statement represents rental cost of fleet.
TVC describes the total variable cost of transportation, production, recovering, and shortage. The first two statements in Eq. (3) represent variable transportation costs and unused fleet capacity costs. The last four terms are production costs, shortage cost, and recovering costs of recoverable and usable returned products, respectively

$$TVC = \sum_t \sum_m \sum_{od \in OD} Tc_m^t dis_{od} \sum_p \Gamma_{pm} \left(X_{odp}^t + X_{odp}''^t \right) + \sum_t \sum_m \sum_{od \in OD} Tc_m^t dis_{od} S_{odm}^t + \sum_t \sum_p \sum_i Pc_p^t Pro_{ip}^t + \sum_t \sum_p \sum_k SH_{kp}^t \delta_{kp}^t + \sum_j \sum_t \sum_p \sum_i Rc_p^t X_{jip}^t + \sum_j \sum_t \sum_p \sum_i Rc_p''^t X_{jip}''^t \quad (3)$$

The Environmental objective calculates GHG emissions as the main concern of human health created during the transportation sector. Generally, the amount of GHG emissions depends on the amount of fuel consumed during transportation so, the amount of emissions is generally estimated based on fuel consumption (Stellingwerf et al. 2018a):

$$E_a = f_a \times e_f \quad (4)$$

where e_f as the emission factor is multiplied by the amount of consumed fuel f_a to estimate CO_2 emissions (E_a). Fuel consumption depends on different variables originated from fleet and road characteristics by complex calculations. We estimate fuel consumption in the same approach as Simpson and Bektaş (2011). The related parameters are represented in Tables 1 and 2.

Table 1. Fuel consumption parameters (Koç et al. 2014)

Symbol	Description	Typical Value
a	Fleet acceleration (m/s^2),	0
C_r	Coefficient of rolling resistance,	0.01
ρ	Air density (kg/m^3),	1.2041
g	Gravitational constant (m/s^2),	9.81
ϑ_{od}^{lo}	Lower speed limit (m/s)	5.5 (or 20 km/h)
ϑ_{od}^{up}	Upper speed limit (m/s)	27.8 (or 100 km/h)

Table 2. Fleet parameters (Koç et al. 2014).

Symbol	Description	Light(L)	Medium(M)	Heavy(H)
W^l	Curb weight (kg)	3500	5500	14,000
C_d	Coefficient of aerodynamic drag	0.6	0.7	0.9
A	Frontal surface area (m^2)	7.0	8.0	10.0

The authors consider the total used fuel in transportation as a linear function of the motive energy (*ME*) depends on the driven distance, total fleet weight TW_{odm}^{lt} (curb weight and payload), fleet mode(ξ_m), road slope (θ_{od}), average speed ($\bar{\vartheta}_{od}$) between origin–destination (*o*,*d*)ϵOD and the air density ρ such that:

$$ME = \sum_{t}\sum_{m}\sum_{l}\sum_{od\in OD} \xi_m (\alpha_{od} TW_{odm}^{lt} dis_{od} + \beta \bar{\vartheta}_{od}^2 dis_{od} N_{mod}^{lt}) \quad (5)$$

where α_{od} and β show route and fleet-specific constant, respectively (Eqs.6 and 7).

$$\alpha_{od} = a + gsin\theta_{od} + gc_r Cos\theta_{od} \quad (6)$$

$$\beta = 0.5 c_d A\rho \quad (7)$$

Then, the motive energy is converted to use fuel by Eq.8:

$$f_a = \frac{ME}{P_f \eta} \quad (8)$$

Where η is a conversion factor to convert fuel chemical energy to motive energy and P_f is a chemical energy of per liter diesel. Finally, the amount of CO_2 emissions can be estimated as:

$$E_a = f_a \times e_f = \frac{ME}{P_f \eta} \times e_f \quad (9)$$

The refrigerated fleets consume more energy and emit more CO_2 emissions because such fleets use extra fuel for cooling storage space (Stellingwerf et al. 2018b). The calculation of the exact fuel consumption for the refrigerated fleet is too complex because extra parameters and terms should be added in the formulation. For simplicity, we use Babagolzadeh et al. (2020) estimation for fuel consumption in refrigerated fleets. The authors estimated that f_a increases in refrigerated fleets by 20% further fuel consumption for ambient fleets.

Social objective function minimizes unsatisfied FBs' requests to give social value to the company by supplying FBs' need as far as possible (Eq.10).

$$Obj_3 = \sum_{f}\sum_{t}\sum_{p}\left(d_{fp}^{t} - \sum_{p'}\sum_{k} X_{kfp}^{\prime\prime t} \Lambda_{pp'} \right) \quad (10)$$

Constraints (11) impose the status of RDCs that can change at most once entire the time periods. In other words, if a new RDC is opened in potential center, it cannot be closed in the following periods and if an existing RDC is closed in period *t*, it cannot be reopened in following periods. Constraints (12) show that at most one capacity level can be installed at RDC $j\in J^n$ for product $p\in P$ during the planning periods. At new RDC, constraints (13) and (14) ensure that storage capacity can be established whenever a new RDC is operated in that location. Constraints (15) state that if a new capacity level is allocated to the existing center, this center must remain open in the following periods.

$$\sum_{t} Y_j^t \le 1 \qquad \forall j \qquad (11)$$

$$\sum_{t}\sum_{q} U_{jp}^{tq} \le \sum_{t} Y_j^t \qquad \forall j^n, p \qquad (12)$$

$$\sum_{q} U_{jp}^{tq} \le \sum_{\tilde{t}=1}^{t} Y_j^{\tilde{t}} \qquad \forall j^n, p, t \qquad (13)$$

$$\sum_{q}\sum_{p} U_{jp}^{tq} \ge Y_j^t \qquad \forall j^n, t \qquad (14)$$

$$\sum_{t}\sum_{q} U_{jp}^{tq} \le 1 - \sum_{t=1}^{T} Y_j^{\tau} \qquad \forall j^e, p \qquad (15)$$

Constraints (16) and (17) ensure that customers' demand should be satisfied with limited shortage in such a way that the amount of unsatisfied demand cannot exceed the special percentage (σ%) of the demand. Constraints (18) calculate the amount of production and Equations (19) ensure the balance of product flow in RDC during forward logistic.

$$\sum_{j} X_{jkp}^{t} + \delta_{kp}^{t} = d_{kp}^{t} \qquad \forall k, p, t \qquad (16)$$

$$\delta_{kp}^{t} < \sigma\% \times d_{kp}^{t} \qquad \forall k, p, t \qquad (17)$$

$$\sum_{j} X_{ijp}^{t} = \Omega_p \times \sum_{j} X_{jip}^{t} + \sum_{j} X_{jip}''^{t} + Pro_{ip}^{t} \qquad \forall i, p, t \qquad (18)$$

$$\sum_{i} X_{ijp}^{t} = \sum_{k} X_{jkp}^{t} \qquad \forall j, p, t \qquad (19)$$

In reverse flow, equations (20) show the amount of recoverable returned products transported to PRCs through RDCs for recovering or disposal operations. As it was mentioned, the usable returned products can either send to FBs or back to the PRCs through RDCs (Equations. 21). Constrains (22) show the balance equation of retuned products (usable and recoverable) sent back to PRCs through RDCs.

$$\sum_{j} X_{kjp}^{t} = \lambda_p \left(1 - \psi_p\right) d_{kp}^{t} \qquad \forall k, p, t \qquad (20)$$

$$\sum_{f} X_{kfp}''^{t} + \sum_{j} X_{kjp}''^{t} = \lambda_p \times \psi_p \times d_{kp}^{t} \qquad \forall k, p, t \qquad (21)$$

$$\sum_{k} X_{kjp}''^{t} + \sum_{k} X_{kjp}^{t} = \sum_{i} X_{jip}''^{t} + \sum_{i} X_{jip}^{t} \qquad \forall j, p, t \qquad (22)$$

Constraints (23) and (24) restrict the capacity of the new and existing RDCs, respectively. We use constant τ as a coefficient multiplied by maximum capacity to give us capacity lower bound and ensure that facilities operate at a meaningful level. Constraints (25) show fleet capacity restriction for fleet mode (m) with capacity level (l).

$$\tau_j \times \sum_q Cap_{jp}^q \sum_{\tilde{t}=1}^{t} U_{jp}^{q\tilde{t}} \le \omega_p (\sum_i X_{ijp}^t + \sum_k X_{kjp}^t + \sum_k X'^t_{kjp}) \le \sum_q Cap_{jp}^q \sum_{\tilde{t}=1}^{t} U_{jp}^{q\tilde{t}} \qquad \forall j^n, p, t \quad (23)$$

$$\tau_j \times \left(Cape_{jp} \left(1 - \sum_{\tilde{t}=1}^{t} Y_j^{\tilde{t}}\right) + \sum_q Cap_{jp}^q \sum_{\tilde{t}=1}^{t} U_{jp}^{q\tilde{t}} \right) \le \omega_p (\sum_i X_{ijp}^t + \sum_k X_{kjp}^t + \sum_k X'^t_{kjp}) \le Cape_{jp} \left(1 - \sum_{\tilde{t}=1}^{t} Y_j^{\tilde{t}}\right) + \sum_q Cap_{jp}^q \sum_{\tilde{t}=1}^{t} U_{jp}^{q\tilde{t}} \qquad \forall j^e, p, t \quad (24)$$

$$\sum_p \omega_p \left(X_{odp}^t + X'^t_{odp} \right) \times \Gamma_{pm} + S_{odm}^t = \sum_l Capv^l N_{odm}^{lt} \qquad \forall od, m, t \quad (25)$$

Constraints (26) present the total fleet weight including curb weight and payload shipped from node *o* to node *d* in period *t*.

$$TW_{odm}^{lt} \ge W^l N_{mod}^{lt} + \sum_{pt} \left(X_{odp}^t + X'^t_{odp} \right) \Gamma_{pm} \qquad \forall od, m, l, t \quad (26)$$

Budget constraints are stated by equations (27). The budget expenditure is exerted to open new RDCs at potential centers, close existing RDCs, establish storage spaces for both new and existing centers and fleets rent. Finally, constraints (28) show non-negativity and binary conditions.

$$\sum_t \sum_{j \in J^n} Fo_j^t Y_j^t + \sum_t \sum_{j \in J^e} Fc_j^t Y_j^t + \sum_t \sum_q \sum_p \sum_{j \in J} Sc_{jp}^{tq} U_{jp}^{tq} + \sum_t \sum_l \sum_m \sum_{od \in OD} Vc_m^{tl} N_{mdb}^{tl} \le TB^t \qquad \forall t \quad (27)$$

$$Y_j^t, U_{jp}^{tq} \in \{0,1\} \; \& \; N_{\mathrm{mod}}^{tl} \in \mathrm{int}, X_{odp}^t, X'^t_{odp}, S_{odm}^t, W_{odm}^{lt}, \delta_{kp}^t \ge 0 \quad (28)$$

5. Solution Methodology

The model is applied to a multi-objective optimization problem to investigate main policies. The FSC redesign is a challenging issue due to high transportation frequency, related costs and pollution as well as social concerns, so intertwined decisions need to be made. There are numerous methods for solving multi-objective models. One of the best introduced by Torabi and Hassini (2008) is TH method to convert multi-objective function into a single-objective one. Such method can measure and tune the satisfaction levels through policy-maker preferences for each objective function. Initially, the best and worst solutions of each function must be determined. In the proposed model, three objective functions included economic, environmental and social objectives, should be minimized to obtain the ideal positive solution (PIS) and then, ideal negative solution (NIS) for each objective function is calculated as below:

$$Z_1^{PIS} = \min Z_1 \qquad Z_1^{NIS} = \max\left(Z_1(x_2), Z_1(x_3)\right) \quad (29)$$

$$Z_2^{PIS} = \min Z_2 \qquad Z_2^{NIS} = \max\left(Z_2(x_1), Z_2(x_3)\right) \quad (30)$$

$$Z_3^{PIS} = \min Z_3 \qquad Z_3^{NIS} = \max\left(Z_3(x_1), Z_3(x_2)\right) \tag{31}$$

In the next step, a linear membership function has been calculated such that:

- if the objective value is less than PIS and more than NIS, it is accepted with utility functions 1 and 0, respectively
- if the value is a number between PIS and NIS, it is accepted as the below utility function (*k:1,2,3*):

$$\mu_k(x) = \begin{cases} 1 & if \;\; Z_k \prec Z_k^{PIS} \\ \dfrac{Z_k^{NIS} - Z_k}{Z_k^{NIS} - Z_k^{PIS}} & if \;\; Z_k^{PIS} \le Z_k \le Z_k^{NIS} \\ 0 & if \;\; Z_k \succ Z_k^{NIS} \end{cases} \tag{32}$$

Then the multi-objective model is converted into a single-objective by equations (33)-(35):

$$\max \;\; (v) = \lambda\, \chi_0 + (1-\lambda)\sum_k \phi_k \mu_k(v) \tag{33}$$

s.t.

$$\chi_0 \le \mu_k(v), \qquad k = 1,2,3 \tag{34}$$

$$v \in F(v),\; \omega_0 \;\in [0,1] \tag{35}$$

where $\mu_k(x)$ and ϕ_k state the utility degree of k-th objective function and the importance degree of k-th objective function $(\sum_k \phi_k = 1, \phi_k > 0)$ and $F(v)$ represents the feasible space. The optimal value of variable χ_0 illustrates the minimum satisfaction degree of all objective functions. The risk of finding worse solution for each objective decrease by maximizing (χ_0). The values of parameters λ and ϕ_k show the significant importance of the objective functions and minimum satisfaction degree, respectively.

6. Computational study

The computational study is provided by the real data collected from the Iranian famous food company and estimations of some expert's judgements. Kalleh Company as one of the biggest food producers in Iran has a considerable share of the Iranian food product market. The proposed model reflects the general configuration and characteristics of the current network. The addressed structure allows the generalization of intuition concluded from the results of the model to another same CFSC networks.

The proposed network is composed of three existing PRCs, eight existing RDCs, twenty-six existing DCs and six potential RDCs. The potential centers for opening new RDCs have been defined in feasible and reasonable locations to reduce the problem size. Thus, the number of indices and constraints have been decreased and infeasible points have been eliminated from solving space. This study seeks to manage and redesign the CFSC by considering sustainability. The existing location of RDCs and the potential locations for the establishment of new RDCs based on experts' knowledge are presented in Table 3 and the details of other input data are given Table 4.

Table 3. Existing and candidate locations of RDC in Iran

Existing	Tehran	Tabriz	Mashhad	Isfahan	Ahwaz	Rasht	Shiraz	Kerman
Potential	Qazvin	Kermanshah	Yazd	Bandarabas	Amol	Qom		

Table 4. Other input data

Parameters Value						
Fc_j^t	Fo_j^t	IC_{jp}^{tq}	$Cape_j$	Cap_j^1	Cap_j^2	Cap_j^1
(3) Billion	(9) Billion	(5)Billion	(1248)ton	(700)ton	(1200)ton	(2000)ton
Parameters Value						
TC_p^t	VC_m^{tl}	Pc_{ip}^t	SC_{kp}^t	τ_j	λ_{kp}	ψ_p
0.04	(0.3) Billion	1500	3000	10%	1%	20%

The proposed MOMILP model is tested by GAMS software v.22.9 on a computer with core i7 CPU and 16.0 GB RAM to show the validity and functionality of model. In this model, the fleet number is assumed to be a positive variable instead of being integer and as a result, a remarkable reduction in solution time is obtained. At first, the model minimizes each objective function, separately to calculate the ideal positive solution (PIS value shown in table 5 by stars). Then, each objective function is minimized by the optimal value of variables in two other objectives and the worst solution is depicted as the ideal negative solution (NIS value depicted in table 5 by underline). The results show the conflicts between objective functions (Table 5).

Table 5. Objective function values

	Economic Value	Environmental Value	Social Value
Economic objective	4.352×10^{13}	5.740×10^{12}	<u>1130576</u>
Environmental objective	<u>4.476×10^{13}</u>	5.377×10^{9}	0
Social objective	4.454×10^{13}	<u>1.018×10^{13}</u>	0*

In Fig. 4, PRCs, RDCs, and DCs are shown by triangles, pentagons, and stars items on the map, respectively. By considering the economic-objective function, the optimal cost turns out to be $4.352 \times 10^{13*}$ and new centers are opened in Qom as RDC. The capacity expansion has also occurred at Tehran, Amol, Isfahan, Rasht and Mashhad. The model confirms current RDCs locations and opens Qom as new a RDC to having better distribution to other sides. From economic aspect, the results show that all returned products are sent to PRCs and recovered. Next, by considering environmental-objective function, Qazvin, Qom, Kermanshah, Ahwaz and Yazd are opened as new RDCs to minimizing transportation pollution. Finally, by only considering social perspective, all food bank demands are supplied by opening all potential RDCs.

Finally, the problem is solved by considering social, economic, and environmental objectives, simultaneously. The economic objective values turn out to be 4.37×10^{13}, (increase 0.4% vs optimal value of single objective mode) environmental objective value turns out to be 5.91×10^{12} (increase 0.9% vs optimal value of single objective mode), and finally social objective value is converted into 4600.9. In the multi objective model, new RDCs are established in Qom and Kermanshah, Bandar abbas and Yazd as new RDCs (Fig.4). Due to the country span target, the results state that RDCs should be scattered entire the country to cover all sustainability targets, new RDCs have been opened and also about half of usable returned products have been sent to FBs to cover social responsibility.

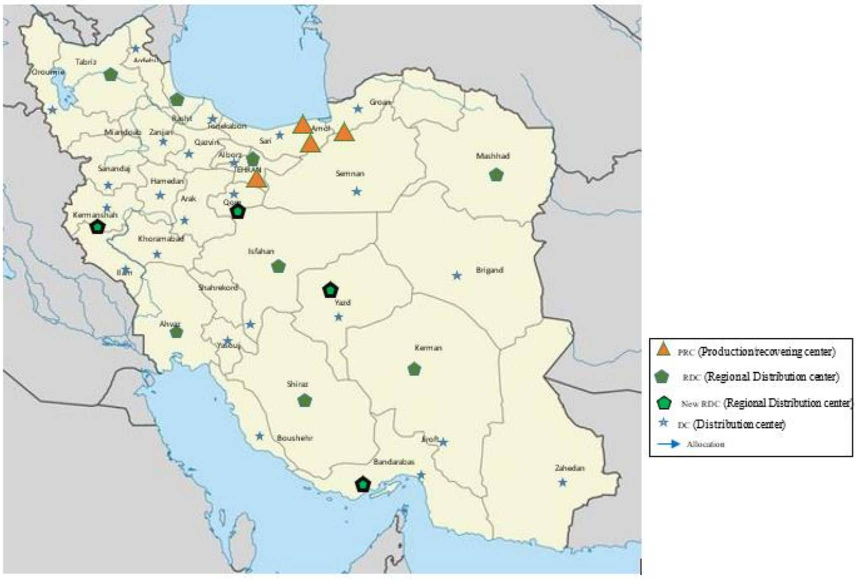

Figure 4. Proposed supply chain network of the company on the country

7. Conclusion and further research

This study proposes a novel MOMILP model to formulate a CFSC planning problem over a multi-period planning horizon. The focus of this paper is to model a strategic and tactical problems of redesigning CFSC in the context of sustainability which is motivated by a real case. Iranian food company as a case study helped to define the problem, in order to support managers in location-allocation decisions involving RDC location, allocation to up-stream and down-stream, and product distribution decisions. The main pillars of sustainability including economic, social, and environmental impacts were merged into the addressed problem. Several influential factors in the food industry network design such as product substitutability, and classification of the returned products, which are not considered in the existing literature, have been applied in the model. Meanwhile, we propose a new approach for quantifying the social impact of the CFSC to minimize unsatisfied FBs demand. In the food industries, usable returned products can be shipped to FBs alongside social responsibility along subsistence strategies to feed needy people. We added product substitutability to have more flexibility in supplying FBs' demand. The results showed that a scattered network structure is necessary for the FMCG network because of the vastness of the country (Iran). In the proposed sustainable model, total cost has been increased by 0.4% vs optimal value of a single objective, the amount of emission has been increased by 0.3% but the amount of unsatisfied demand has been decreased 100%. Finally, some suggestions and research directions are recommended for further researches based on this work, the model can be solved by a new and time limited solution approach. It is also worthy to extend the model by adding the perishability of products and considering resiliency measures.

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