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Maximizing the Flow of Used Goods by Designing a Reverse Logistics Network Using Meta-Heuristic Methods

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ABSTRACT

In supply chains, the goal is usually to meet demand at the lowest cost. However, there are cases where either the transportation costs are insignificant or, in critical situations, the supply of more goods has a much higher priority than the costs. In such cases, instead of minimizing the cost, we should maximize the transfer flow values. In this case, the supply chain network minimization problem (minimum cost flow) becomes a type of flow maximization problem (maximum flow). In this paper, we have addressed a type of flow maximization problem in supply chains, which is first defined and modeled. Subsequently, considering its complex structure, we have obtained a suitable approximate solution for it by using a meta-heuristic method. In supply chains, the goal is usually to meet demand at the lowest cost. However, there are cases where either the transportation costs are insignificant or, in critical situations, the supply of more goods has a much higher priority than the costs.

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1) Introduction

Supply chains are one of the most important practical issues in today's world. In fact, a supply chain is a communication network that fulfills the defined needs of a system. Optimization problems on supply chains are problems that address issues such as minimizing costs, maximizing flows, improving quality, increasing the speed of operation, resilience, etc. Given the importance of supply chain issues, many research studies have been conducted in these fields, some of which we will mention. In 2008, an interactive probabilistic programming approach for comprehensive planning of multi-objective supply chains was presented by Torabi et al (2008). Between 2008 and 2013, many works have been done, of which we will mention two of the most important. One is the work of Baghalian et al. (2013) who designed a resilient supply chain network with high service levels to address disruptions and uncertainties, and the other is the work of Ren et al. (20131) who addressed the issue of supply chain sustainability and implemented it in the hydrogen supply problem. Farahani et al. (2014) addressed the issue of designing competitive supply chain networks and Madadi et al. (2014) addressed the design of a supply chain network to deal with quality disorders and implemented it in the problem of contaminated materials. Gonela et al. (2015) addressed the issue of stochastic optimization of supply chains and implemented their results in the problem of bioethanol supply. Meneghetti et al. (2015) underscored green supply chains and presented and implemented an optimization model for the sustainable design of automated refrigerated food warehouses. Sajjad et al. (2015) highlighted efficient management of sustainable supply chains. Colicchia et al. (2016) addressed environmentally friendly supply chain networks, while Saif et al. (2016) focused on optimizing green supply chains with environmental considerations and using simulation. Ugarte et al. (2016) highlighted consumer goods supply chains. Banasik et al. (2017) addressed the optimization problem in closed-loop supply chains using multi-objective programming and implemented it in mushroom supply chains. Behzadi et al. (2017) presented robust and flexible strategies for managing disruptions in supply chains and implemented them in agricultural supply chains. Bustos et al. (2017) presented a multi-objective optimization model for supply chain design and implemented it in mining supply chains. Hombach et al. (2018) addressed robust and sustainable supply chains under conditions of uncertainty and risk and implemented it in the German biodiesel market. Mangla et al. (2018) investigated the barriers to effective circular supply chain management in a developing country. Chang et al. (2019) addressed blockchain in global supply chains and cross-border trade. Roshan et al. (2019) presented a two-stage approach for managing agile supply chains with product substitution capability in crises and implemented it in pharmaceutical supply chains. Saberi et al. (2019) investigated blockchain technology and its relationship with sustainable supply chain management. Additionally, Tavakkoli et al. (2019) presented a mathematical model of the reverse logistics chain for a sustainable production system of perishable goods based on demand optimization. In 2020, numerous research studies was conducted in the field of supply chains and their applications. The first is the work of Goodarzian et al. (2020) who presented a multi-objective supply chain network based on a robust fuzzy model for the drug supply problem and solved it using meta-heuristic algorithms. Sharma et al. (2020) presented a framework for increasing the sustainability of sustainable supply chains. Taleizadeh et al. (2020) designed a resilient network of two competing supply chains and solved it using decomposition algorithms and game theory. Tat et al. (2020) presented a mathematical model for coordinating pharmaceutical supply chains and used it in the resale of drugs in an alternative market. Yakavenka et al. (2020) developed a multi-objective model for designing sustainable supply chains and implemented it in the problem of perishable food products. Alinezhad et al. (2021) presented a multi-objective optimization model for designing a sustainable closed-loop supply chain network and used it in supplying the food industry. Aslam et al. (2021) examined the factors affecting the adoption of blockchain in supply chain management practices and used the results of their research in the oil industry. Hajipour et al. (2021) addressed the problem of designing and optimizing location and inventory in supply chains and used it in relief and healthcare supply chains. Kouhizadeh et al. (2021) addressed the issue of using blockchain technology and sustainable supply chains. Nayari et al. (2021) presented a robust multi-objective fuzzy stochastic model for designing sustainable-resilient-responsive supply chain networks. Baghizadeh et al. (2022) designed a sustainable agricultural supply chain network considering the water-energy-food nexus and implemented it using a hybrid robust possibilistic programming based on a queuing system. Fatemi et al. (2022) presented a multi-functional three-objective mathematical model for pharmaceutical chains considering the density of drugs in factories. Iftikhar et al. (2022) addressed digital innovation, data analysis, and resilience in supply chains. Modgil et al. (2022) investigated the use of artificial intelligence for supply chain resilience. They used the experiences and lessons learned from Covid-19 in their study and research. Singh et al. (2022) outlined several methods for creating resilient supply chains using artificial intelligence. Vali-Siar et al. (2022) designed a sustainable, resilient, and responsive mixed supply chain network under conditions of hybrid uncertainty and disruption, considering the type of disruptions as that caused by the COVID-19 pandemic. Demir et al. (2023) proposed a model to use in smart and sustainable supply chains to reach the maximum possible level of readiness and maturity. Singh et al. (2023) presented and examined methods for measuring the impact of digital twins on the sustainability, resilience, and performance of manufacturing supply chains. Purwaningsih et al. (2024) studied how blockchain technology can be used to increase the efficiency of supply chains. They tested the results of their research on exports and financial performance of companies. Rashid et al. (2024) examined the role of information processing and digital supply chains in the resilience of supply chains through supply chain risk management. Sadeghi et al. (2024) investigated the issue of supply chain resilience in logistics problems. They used strong computational intelligence methods to empirically validate resilience. Yuan et al. (2024) evaluated the effects of digital transformations on supply chain resilience in adjusted intermediary models. As mentioned, previous research focuses on the flow with the least cost. In this research, we intend to focus on sending the maximum flow in the supply chain network and model and solve it. In fact, this is considered an innovation in the field of research.

2) Modeling of Problem

To model the problem, we first specify symbols as follows:

Table 1. Description of Decision Parameters and Variables

Parameter	Parameter description	Parameter	Parameter description
m	Consumer	M	Number of consumers
k	Local collection center	K	Number of local collection centers
j	Collection center	J	Number of collection centers
q	Repair center	Q	Number of repair centers
e	Charity center	E	Number of charity centers
b	Recycling center	B	Number of recycling centers
r	Disposal center	R	Number of disposal centers
T	Number of commodities	N	Number of vehicles
t	Kind of commodity	n	Type of vehicle
s_t	The amount of commodity t used by consumers	z_{tk}	The capacity of local collection center k for commodity t
z_{ti}^{j}	The capacity i^{th} of collection center j for commodity t	z_{ti}^{q}	The capacity i^{th} of repair center q for commodity t
z_{ti}^{e}	The capacity i^{th} of charity center e for commodity t	z_{ti}^{b}	The capacity i^{th} of recycling center b for commodity t
z_{ti}^{r}	The capacity i^{th} of disposal center r for commodity t	d_1	The percentage of commodities transferred from collection centers to repair centers
e_τ	$(\tau = m, k, j, q, e, b, r)$ The total of commodities entering node τ minus the total of commodities leaving node τ.	d_3	The percentage of commodities transferred from collection centers to recycling centers
d_2	The percentage of commodities transferred from collection centers to charity centers	d_4	The percentage of commodities transferred from collection centers to disposal centers

z_n	Vehicle capacity of *n*	v_t	Commodity volume of *t*
x_{tkjn}	Amount of transportation of commodity *t* from local collection center *k* to collection center *j* by vehicle n	x_{tjqn}	Amount of transportation of commodity *t* from collection center *j* to repair center *q* by vehicle *n*
x_{tjen}	Amount of transportation of commodity *t* from collection center *j* to charity center *e* by vehicle *n*	x_{tjbn}	Amount of transport of commodity *t* from collection center *j* to recycling center *b* by vehicle *n*
x_{tjrn}	Amount of transportation of commodity *t* from collection center *j* to disposal center *r* by vehicle *n*	x_{tqbn}	Amount of transportation of commodity *t* from repair center *q* to recycling center *b* by vehicle *n*
x_{tqen}	Amount of transportation of commodity *t* from repair center *q* to charity center *e* by vehicle *n*	x_{tqrn}	Amount of transportation of commodity *t* from repair center *q* to disposal center *r* by vehicle *n*
x_{tbrn}	Amount of transportation of commodity *t* from recycling center *b* to disposal center *r* by vehicle *n*	x_{tben}	Amount of transportation of commodity *t* from recycling center *b* to charity center *e* by vehicle *n*
x_{tmkn}	Amount of transportation of commodity *t* from costumer *m* to local collection center *k* by vehicle *n*	*deg.* *in-deg.* *out-deg.*	Degree of a node Input-degree of a node Output-degree of a node

we make a seven-partite graph by the following properties. First, we specify the seven partite of the graph as follows: Partite One: Consumers, Partite two: Local collection centers, Partite three: Collection centers, Partite four: Repair centers, Partite five: Disposal centers, Partite six: Recycling centers, Partite Seven: Charity centers. The diagram can be displayed as follows:

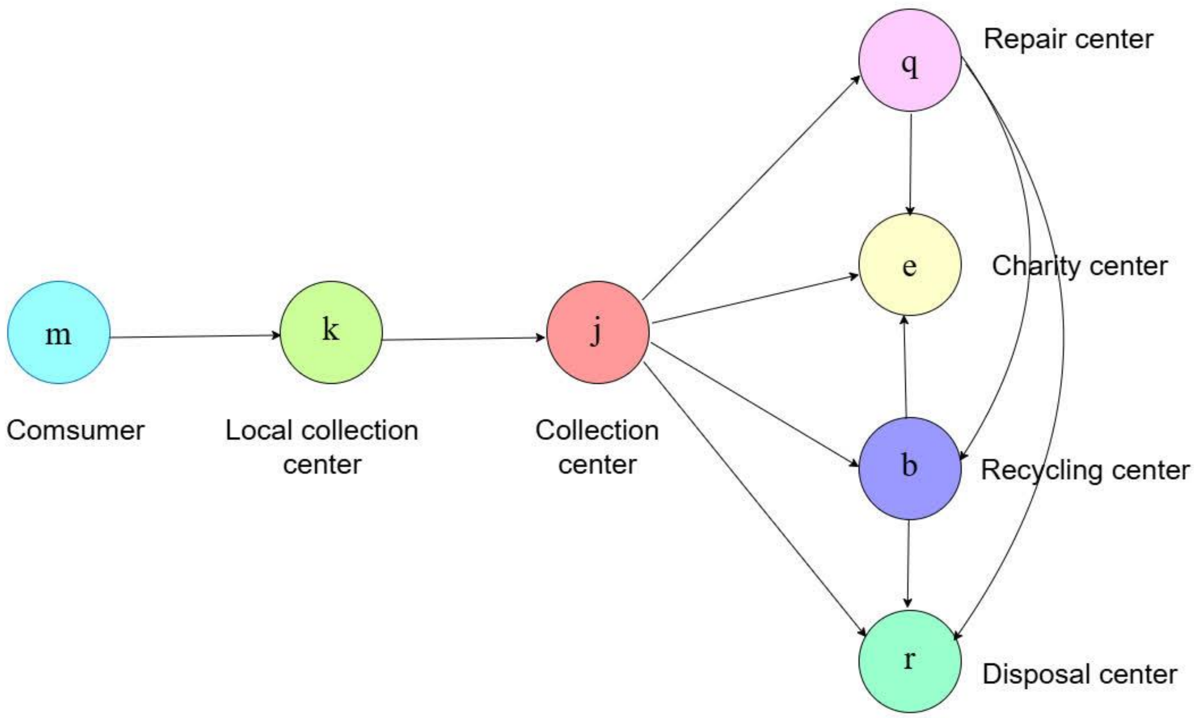

Figure 1. The Underlying Graph of the Seven-Part Underlying Network

2-1) Model Assumptions

- The model data is considered constant during the programming period.
- The genetic algorithm designed to solve the model does not depend on the type of initial population selection.
- This model is a new innovative design, and therefore, a real exact sample does not currently exist. However, it can be designed in practical conditions.
- If the conditions expressed in this model change, a new research will be necessary. We present this issue in the form of suggestions for future work.

2-2) Model Expansion

In this section, we explain the number of members in each of the seven partites and how the partites members relate to one another as follows.

1. The nodes of the graph are as follows. The nodes of Section one: consumers; the nodes of section two: local collection centers; the nodes of section three: collection centers; the nodes of section four: repair centers; the nodes of section five: charity centers; the nodes of section six: recycling centers, and the nodes of section seven: disposal centers.
2. There is a directed edge from every node of partite one to all nodes of partite two.
3. There is a directed edge from every node of partite two to all nodes of partite three.
4. There is a directed edge from every node of partite three to all nodes of partite four.
5. There is a directed edge from every node of partite three to all nodes of partite five.
6. There is a directed edge from every node of partite three to all nodes of partite six.
7. There is a directed edge from every node of partite three to all nodes of partite seven.
8. There is a directed edge from every node of partite four to all nodes of partite five.
9. There is a directed edge from every node of partite four to all nodes of partite six.
10. There is a directed edge from every node of partite four to all nodes of partite seven.
11. There is a directed edge from every node of partite six to all nodes of partite five.
12. There is a directed edge from every node of partite six to all nodes of partite seven.

The degree, input degree, and the output degree of each node are determined as follows.

Members of Partite One (m): Consumers

m_1	m_2	…	m_M

$$deg(m_l) = K \quad , \quad l = 1, 2, \dots, M$$
$$\begin{cases} in - \deg\ (m_l) = 0 \quad , \quad l = 1, 2, \dots, M \\ out - \deg\ (m_l) = K \ , \quad l = 1, 2, \dots, M \end{cases}$$

Members of Partite Two (k): Local collection centers

k_1	k_2	…	k_K

$$deg(k_l) = M + J \quad l = 1, 2, \dots, K$$
$$\begin{cases} in - \deg\ (k_l) = M \quad , \ l = 1, 2, \dots, K \\ out - deg\ (k_l) = J \quad , \quad l = 1, 2, \dots, K \end{cases}$$

Members of Partite Three (j): Collection centers

j_1	j_2	…	j_J

$$deg(j_l) = K + Q + E + B + R \quad , \quad l = 1, 2, \dots, J$$
$$\begin{cases} in - \deg\ (j_l) = K \quad , \quad l = 1, 2, \dots, J \\ out - \deg\ (j_l) = \ Q + E + B + R \quad , \quad l = 1, 2, \dots, J \end{cases}$$

Members of Partite Four (q): Repair centers

q_1	q_2	…	q_Q

$$deg(q_l) = J + R + B + E$$
$$\begin{cases} in-\deg\ (q_l) = J & , \quad l = 1,2,\dots,Q \\ out-\deg\ (q_l) = R + B + E & , \quad l = 1,2,\dots,Q \end{cases}$$

Members of Partite Five (e): Charity centers

e_1	e_2	…	e_E

$$deg(e_l) = J + Q + B$$
$$\begin{cases} in-deg(e_l) = J + Q + B & , \quad l = 1,2,\dots,E \\ out-\deg(e_l) = 0 & , \quad l = 1,2,\dots,E \end{cases}$$

Members of Partite Six (b): Recycling centers

b_1	b_2	…	b_B

$$deg(b_l) = J + Q + E + R \quad , \quad l = 1,2,\dots,B$$
$$\begin{cases} in-\deg(b_l) = J + Q & , \quad l = 1,2,\dots,B \\ out-\deg(b_l) = E + R & , \quad l = 1,2,\dots,B \end{cases}$$

The graph diagram can be displayed as follows:

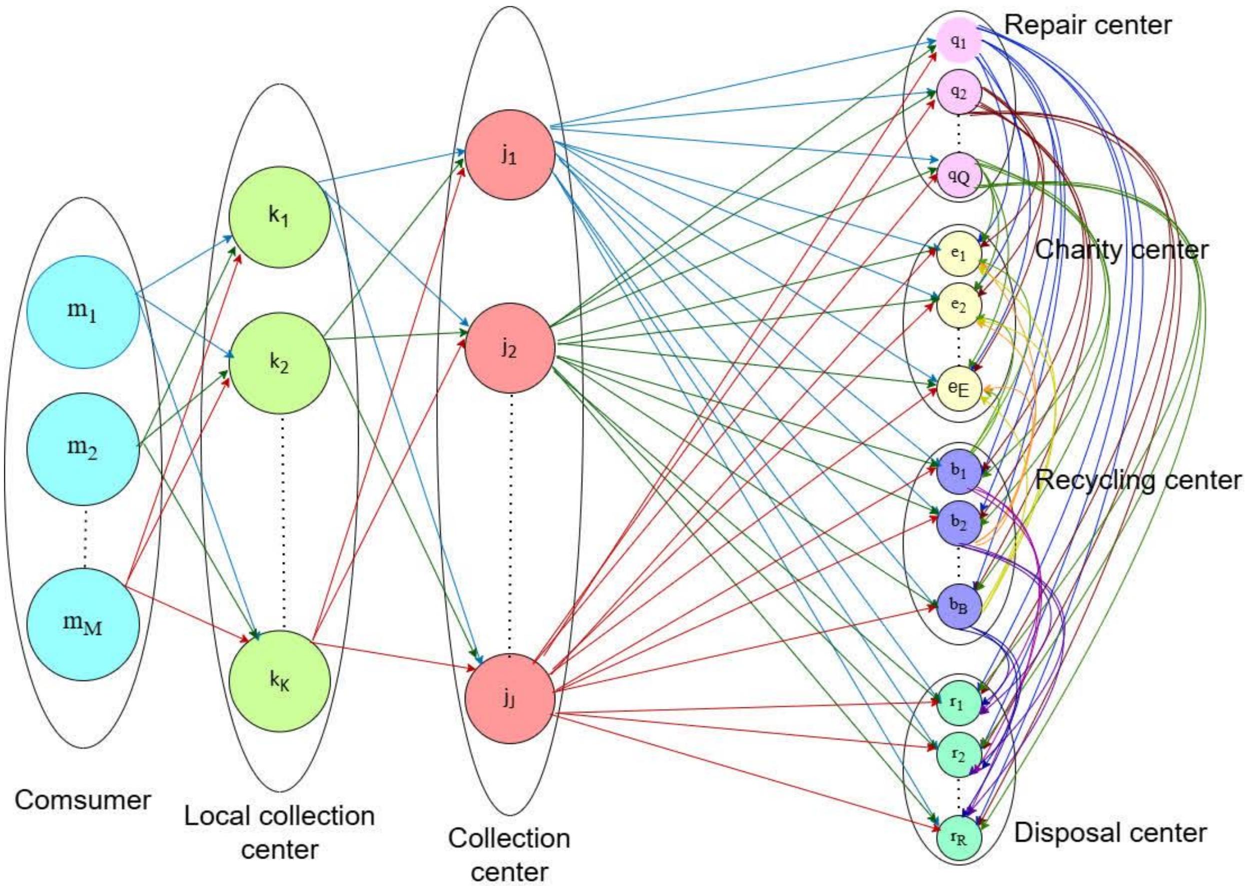

Figure 2. Multiple Superstructure Graph of a Seven-Partite Network

In this way, a graph with nodes $\boldsymbol{v} = M + K + J + Q + E + B + R$, and edges $\boldsymbol{\epsilon} = MK + KJ + JQ + JE + JB + JR + QR + QE + QB + BE + BR$ is created.

Now the question arises whether such a graph can exist? To address this question, we present the following lemma.

Lemma: A graph with $\boldsymbol{v}$=*M*+*K*+*J*+*Q*+*E*+*B*+*R* number of nodes, and $\boldsymbol{\epsilon}$=*MK*+*KJ*+*JQ*+*JE*+*JB*+*JR*+*QR*+ *QE*+*QB*+*BE*+*BR* number of edges can exist.

Proof. According to the degree of the nodes, we must have:

$2\epsilon = \sum_{i=1}^{v} d(w_i)$

= (MK) + (K(M+J)) +(J(K+Q+E+B+R)) + (Q(J+R+B+E)) + (E(J+Q+B)) + (B(J+E+Q+R)) + (R(J+Q+B))

= (MK) + (KM+KJ) + (JK+JQ+JE+JB+JR) +(QJ+QR+QB+QE) + (EJ+EQ+EB) + (BJ+BE+BQ+BR) + (RJ+RQ+RB)

= 2 (MK+KJ+JQ+JE+JB+JR+QR+QB+QE+EB+BR) = 2 ϵ

Obviously, this graph is connected. Therefore, if we define the flow of this connected graph, a network flow is produced.

In this section, we discuss the modeling of the designed network. According to the above description, the network has $\boldsymbol{v}$ nodes and $\boldsymbol{\epsilon}$ edges as follows:

$\boldsymbol{v}$ = M + K + J + Q + E + B + R, $\boldsymbol{\epsilon}$ = MK + KJ + JQ + JE + JB + JR + QR + QE + QB + BE + BR, t: kind of commodity, n: type of vehicle.

2-3) Model Constraints

Now, we specify the restrictions of the problem.

$$\sum_{m=1}^{M} x_{tmkn} = \sum_{k=1}^{K} x_{tkjn} \quad , \quad t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ n = 1,2,\dots,N \qquad (1)$$

Restrictions (1) states that the total number commodity t sent from consumers to collection center k by vehicle n must be equal to the total number of commodity t sent from local collection centers to collection center j by vehicle n.

$$\sum_{m=1}^{M} \sum_{k=1}^{K} \sum_{n=1}^{N} x_{tmkn} = s_t \quad , \quad t = 1,2,\dots,T \qquad (2)$$

Restrictions (2) states that the total number commodity t sent from consumers to local collection centers by vehicles must be equal to the number of consumer commodity of t.

$$d_1 \sum_{j=1}^{J} x_{tkjn} \le \sum_{j=1}^{J} x_{tjqn} \quad , \ n = 1,2,\dots,N \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots,K \ , \ q = 1,2,\dots,Q \qquad (3)$$

Restrictions (3) state that the total of commodity t sent from the local collection center k to the collection centers by the vehicle n must be less than or equal to the total of the commodity t sent from the collection centers to the repair center q by the vehicle n.

$$d_2 \sum_{j=1}^{J} x_{tkjn} \le \sum_{j=1}^{J} x_{tjen} \quad , \ n = 1,2,\dots,N \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots,K \ , \ e = 1,2,\dots,E \qquad (4)$$

Restrictions (4) state that the total of commodity t sent from the local collection center k to the collection centers by the vehicle n must be less than or equal to the total of the commodity t sent from the collection centers to the charity center e by the vehicle n.

$$d_3 \sum_{j=1}^{J} x_{tkjn} \le \sum_{j=1}^{J} x_{tjbn} \quad , \ n = 1,2,\dots,N \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots, \ , \ b = 1,2,\dots,B \qquad (5)$$

Restrictions (5) state that the total of commodity t sent from local collection center k to collection centers by vehicle n must be less than or equal to the total of commodity t sent from collection centers to recycling center b by vehicle n.

$$d_4 \sum_{j=1}^{J} x_{tkjn} \leq \sum_{j=1}^{J} x_{tjrn} \quad , \quad n = 1, 2, \ldots, N \quad , \quad t = 1, 2, \ldots, T \quad , \quad k = 1,2, \ldots, K \quad , \quad r = 1, 2, \ldots, R \qquad (6)$$

Restrictions (6) state that the total of commodity t sent from the local collection center k to the collection centers by the vehicle n must be less than or equal to the total of the commodity t sent from the collection centers to the disposal centers r by vehicle n.

$$\sum_{j=1}^{J} \mathrm{x}_{\mathrm{tjqn}} \leq \sum_{q=1}^{Q} \mathrm{x}_{\mathrm{tqen}} \quad , \quad \mathrm{t} = 1, 2, \ldots, \mathrm{T} \quad , \quad \mathrm{n} = 1, 2, \ldots, \mathrm{N} \quad , \quad \mathrm{q} = 1, 2, \ldots, \mathrm{Q} \quad , \quad \mathrm{e} = 1, 2, \ldots, \mathrm{E} \qquad (7)$$

Restrictions (7) state that the total amount of commodity t sent from collection centers to repair center q by vehicle n must be less than or equal to the total amount of commodity t sent from repair centers to charity centers e by vehicle n.

$$\sum_{j=1}^{J} \mathrm{x}_{\mathrm{tjbn}} \leq \sum_{b=1}^{B} \mathrm{x}_{\mathrm{tben}} \quad , \quad \mathrm{t} = 1, 2, \ldots, \mathrm{T} \quad , \quad \mathrm{n} = 1, 2, \ldots, \mathrm{N} \quad , \quad \mathrm{b} = 1, 2, \ldots, \mathrm{B} \quad , \quad \mathrm{e} = 1, 2, \ldots, \mathrm{E} \qquad (8)$$

Restrictions (8) state that the total amount of commodity t sent from collection centers to recycling center b by vehicle n must be less than or equal to the total amount of commodity t sent from recycling centers to charity center e by vehicle n.

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{n=1}^{N} x_{tjin} \leq \sum_{i=1}^{Q} y_i^q \sum_{t=1}^{T} z_{ti}^q \quad , \quad i = 1, 2, \ldots, Q \qquad (9)$$

Restrictions (9) state that the total amount of commodities sent from collection centers to repair center q by vehicles must be smaller than or equal to the capacity of repair center q.

$$\sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{k=1}^{K} v_t \; x_{tmkn} \leq z_n \quad , \quad n = 1, 2, \ldots, N \qquad (10)$$

Restrictions (10) state that the total amount of commodities sent from consumers to collection centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{j=1}^{J} v_t \; x_{tkjn} \leq z_n \quad , \quad n = 1, 2, \ldots, N \qquad (11)$$

Restrictions (11) state that the total amount of commodities sent from local collection centers to collection centers by vehicle n must be smaller than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{b=1}^{B} v_t \; x_{tjbn} \leq z_n \quad , \quad n = 1, 2, \ldots, N \qquad (12)$$

Restrictions (12) state that the total amount of commodities sent from local collection centers to recycling centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{q=1}^{Q} v_t \; x_{tjqn} \leq z_n \quad , \quad n = 1, 2, \ldots, N \qquad (13)$$

Restrictions (13) state that the total amount of commodities sent from local collection centers to repair centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{e=1}^{E} v_t \; x_{tjen} \leq z_n \quad , \quad n = 1, 2, \ldots, N \qquad (14)$$

Restrictions (14) state that the total amount of commodities sent from local collection centers to charity centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{r=1}^{R} v_t \; x_{tjrn} \leq z_n \quad , \quad n = 1, 2, \ldots, N \qquad (15)$$

Restrictions (15) state that the total amount of commodities sent from local collection centers to disposal centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T} \sum_{q=1}^{Q} \sum_{e=1}^{E} v_t \; x_{tqen} \leq z_n \quad , \quad n = 1, 2, \ldots, N \qquad (16)$$

Restrictions (16) state that the total amount of commodities sent from repair centers to charity centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{b=1}^{B} v_t\ x_{tqbn} \le z_n \quad , \quad n = 1,2,\dots,N \tag{17}$$

Restrictions (17) state that the total amount of commodities sent from repair centers to recycling centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{r=1}^{R} v_t\ x_{tqrn} \le z_n \quad , \quad n = 1,2,\dots,N \tag{18}$$

Restrictions (18) state that the total amount of commodities sent from repair centers to disposal centers by vehicle n must be less than or equal to the capacity of vehicle n.

$$\sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{r=1}^{R} v_t\ x_{tbrn} \le z_n \quad , \quad n = 1,2,\dots,N \tag{19}$$

Restrictions (19) state that the total amount of commodities sent from recycling centers to disposal centers by vehicle n must be less than or equal to the capacity of vehicle n.

Now we present the capacity balance constraints of the nodes.

Node k:

$$\sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{n=1}^{N} x_{tmkn} - \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tkjn} = e_k \quad , \quad k = 1,2,\dots,K \tag{20}$$

Node j:

$$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{n=1}^{N} x_{tkjn} - \left(\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tjqn} + \sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tjen} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tjbn} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tjrn} \right) = e_j \quad , \quad j = 1,2,\dots,J \tag{21}$$

Node q:

$$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjqn} + \left(\sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{n} x_{tqbn} + \sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tqen} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tqrn} \right) = e_q \quad , q = 1,2,\dots,Q \tag{22}$$

Node e:

$$\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqen} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjen} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tben} = e_e \quad , \quad e = 1,2,\dots,E \tag{23}$$

Node b:

$$\left(\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjbn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqbn} \right) - \left(\sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tben} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tbrn} \right) = e_b \quad , \quad b = 1,2,\dots,B \tag{24}$$

Node r:

$$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjrn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqrn} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tbrn} = e_r \quad , \quad r = 1,2,\dots,R \tag{25}$$

Node m:

$$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{n=1}^{N} x_{tmkn} = -e_m \quad , \quad m = 1,2,\dots,M \tag{26}$$

2-4) Objective Function

Now, we put: $\boldsymbol{F} = \sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{n=1}^{N} x_{tmkn} + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tkjn} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tjqn} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tjen} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tjbn} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tjrn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tqbn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tqen} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tqrn} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tbrn} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tben}$

Where F is the objective function of the model.

Now, we present the mathematical model of the problem as follows:

$Max\ F$

s.t.

$\sum_{m=1}^{M} x_{tmkn} = \sum_{k=1}^{K} x_{tkjn}$, $t = 1,2,\ldots,T$, $j = 1,2,\ldots,J$, $n = 1,2,\ldots,N$ (27)

$\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{n=1}^{N} x_{tmkn} = s_t$, $t = 1,2,\ldots,T$ (28)

$d_1 \sum_{j=1}^{J} x_{tkjn} \le \sum_{j=1}^{J} x_{tjqn}$, $n = 1,2,\ldots,N$, $t = 1,2,\ldots,T$, $k = 1,2,\ldots,K$, $q = 1,2,\ldots,Q$ (29)

$d_2 \sum_{j=1}^{J} x_{tkjn} \le \sum_{j=1}^{J} x_{tjen}$, $n = 1,2,\ldots,N$, $t = 1,2,\ldots,T$, $k = 1,2,\ldots,K$, $e = 1,2,\ldots,E$ (30)

$d_3 \sum_{j=1}^{J} x_{tkjn} \le \sum_{j=1}^{J} x_{tjbn}$, $n = 1,2,\ldots,N$, $t = 1,2,\ldots,T$, $k = 1,2,\ldots,$, $b = 1,2,\ldots,B$ (31)

$d_4 \sum_{j=1}^{J} x_{tkjn} \le \sum_{j=1}^{J} x_{tjrn}$, $n = 1,2,\ldots,N$, $t = 1,2,\ldots,T$, $k = 1,2,\ldots,K$, $r = 1,2,\ldots,R$ (32)

$\sum_{j=1}^{J} x_{tjqn} \le \sum_{q=1}^{Q} x_{tqen}$, $t = 1,2,\ldots,T$, $n = 1,2,\ldots,N$, $q = 1,2,\ldots,Q$, $e = 1,2,\ldots,E$ (33)

$\sum_{j=1}^{J} x_{tjbn} \le \sum_{b=1}^{B} x_{tben}$, $t = 1,2,\ldots,T$, $n = 1,2,\ldots,N$, $b = 1,2,\ldots,B$, $e = 1,2,\ldots,E$ (34)

$\sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{k=1}^{K} v_t\ x_{tmkn} \le z_n$, $n = 1,2,\ldots,N$ (35)

$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{j=1}^{J} v_t\ x_{tkjn} \le z_n$, $n = 1,2,\ldots,N$ (36)

$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{b=1}^{B} v_t\ x_{tjbn} \le z_n$, $n = 1,2,\ldots,N$ (37)

$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{q=1}^{Q} v_t\ x_{tjqn} \le z_n$, $n = 1,2,\ldots,N$ (38)

$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{e=1}^{E} v_t\ x_{tjen} \le z_n$, $n = 1,2,\ldots,N$ (39)

$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{r=1}^{R} v_t\ x_{tjrn} \le z_n$, $n = 1,2,\ldots,N$ (40)

$\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{e=1}^{E} v_t\ x_{tqen} \le z_n$, $n = 1,2,\ldots,N$ (41)

$\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{b=1}^{B} v_t\ x_{tqbn} \le z_n$, $n = 1,2,\ldots,N$ (42)

$\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{r=1}^{R} v_t\ x_{tqrn} \le z_n$, $n = 1,2,\ldots,N$ (43)

$\sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{r=1}^{R} v_t\ x_{tbrn} \le z_n$, $n = 1,2,\ldots,N$ (44)

$\sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{n=1}^{N} x_{tmkn} - \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tkjn} = e_k$, $k = 1,2,\ldots,K$ (45)

$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{n=1}^{N} x_{tkjn} - (\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tjqn} + \sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tjen} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tjbn} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tjrn}) = e_j$, $j = 1,2,\ldots,J$ (46)

$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjqn} + (\sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{n} x_{tqbn} + \sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tqen} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tqrn}) = e_q$, $q = 1,2,\ldots,Q$ (47)

$\sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqen} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjen} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tben} = e_e$, $e = 1,2,\ldots,E$ (48)

$(\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjbn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqbn}) - (\sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tben} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tbrn}) = e_b$, $b = 1,2,\ldots,B$ (49)

$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjrn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqrn} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tbrn} = e_r$, $r = 1,2,\ldots,R$ (50)

$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{n=1}^{N} x_{tmkn} = -e_m$, $m = 1,2,\ldots,M$ (51)

$0 \le x_{tkjn} \le u_{tkjn}$, $0 \le x_{tj\alpha n} \le u_{tj\alpha n}$ $\alpha = q,e,b,r$,

$0 \leq x_{tq\theta n} \leq u_{tq\theta n} \quad \theta = b, e, r \quad , \quad 0 \leq x_{tb\gamma n} \leq u_{tb\gamma n} \quad \gamma = r, e$

3) Preparing the Problem for Solving

At this stage, in all constraints, we move the terms to the left side of the constraints and, using the slack variables and the additional variables, we subconvert the constraints to the equalities of equal zero.

$$\sum_{m=1}^{M} x_{tmkn} - \sum_{k=1}^{K} x_{tkjn} = 0 = G_{tjn} \quad , \quad t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ n = 1,2,\dots,N \qquad (52)$$

$$\sum_{m=1}^{M} \sum_{k=1}^{K} \sum_{n=1}^{N} x_{tmkn} - s_t = 0 = G_t \quad , \quad t = 1,2,\dots,T \qquad (53)$$

$$d_1 \sum_{j=1}^{J} x_{tjkn} + s_{tkqn} - \sum_{j=1}^{J} x_{tjqn} = 0 = G_{tkqn} \quad , \ n = 1,2,\dots,N \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots,K \ , \ q = 1,2,\dots,Q \qquad (54)$$

$$d_2 \sum_{j=1}^{J} x_{tkjn} + s_{tken} - \sum_{j=1}^{J} x_{tken} = 0 = G_{tken} \ , \ n = 1,2,\dots,N \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots,K \ , \ e = 1,2,\dots,E \qquad (55)$$

$$d_3 \sum_{j=1}^{J} x_{tkjn} + s_{tkbn} - \sum_{j=1}^{J} x_{tkbn} = 0 = G_{tkbn} \ , \ n = 1,2,\dots,N \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots, \ , \ b = 1,2,\dots,B \qquad (56)$$

$$d_4 \sum_{j=1}^{J} x_{tkjn} + s_{tkrn} - \sum_{j=1}^{J} x_{tjrn} = 0 = G_{tkrn} \ , \ n = 1,2,\dots,N \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots,K \ , \ r = 1,2,\dots,R \qquad (57)$$

$$\sum_{j=1}^{J} x_{tjqn} + s_{tqen} - \sum_{q=1}^{Q} x_{tqen} = 0 = G_{tqen} \quad , \quad t = 1,2,\dots,T \ , \ n = 1,2,\dots,N \ , \ q = 1,2,\dots,Q \ , \ e = 1,2,\dots,E \qquad (58)$$

$$\sum_{j=1}^{J} x_{tjbn} + s_{tben} - \sum_{b=1}^{B} x_{tben} = 0 = G_{tben} \quad , \quad t = 1,2,\dots,T \ , \ n = 1,2,\dots,N \ , \ b = 1,2,\dots,B \ , \ e = 1,2,\dots,E \qquad (59)$$

$$\sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{k=1}^{K} v_t \ x_{tmkn} + s_n^1 - z_n = 0 = G_n^1 \ , \quad n = 1,2,\dots,N \qquad (60)$$

$$\sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{j=1}^{J} v_t \ x_{tkjn} + s_n^2 - z_n = 0 = G_n^2 \quad , \quad n = 1,2,\dots,N \qquad (61)$$

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{b=1}^{B} v_t \ x_{tjbn} + s_n^3 - z_n = 0 = G_n^3 \quad , \quad n = 1,2,\dots,N \qquad (62)$$

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{q=1}^{Q} v_t \ x_{tjqn} + s_n^4 - z_n = 0 = G_n^4 \quad , \quad n = 1,2,\dots,N \qquad (63)$$

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{e=1}^{E} v_t \ x_{tjen} + s_n^5 - z_n = 0 = G_n^5 \quad , \quad n = 1,2,\dots,N \qquad (64)$$

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{r=1}^{R} v_t \ x_{tjrn} + s_n^6 - z_n = 0 = G_n^6 \quad , \quad n = 1,2,\dots,N \qquad (65)$$

$$\sum_{t=1}^{T} \sum_{q=1}^{Q} \sum_{e=1}^{E} v_t \ x_{tqen} + s_n^7 - z_n = 0 = G_n^7 \quad , \quad n = 1,2,\dots,N \qquad (66)$$

$$\sum_{t=1}^{T} \sum_{q=1}^{Q} \sum_{b=1}^{B} v_t \ x_{tqbn} + s_n^8 - z_n = 0 = G_n^8 \quad , \quad n = 1,2,\dots,N \qquad (67)$$

$$\sum_{t=1}^{T} \sum_{q=1}^{Q} \sum_{r=1}^{R} v_t \ x_{tqrn} + s_n^9 - z_n = 0 = G_n^9 \quad , \quad n = 1,2,\dots,N \qquad (68)$$

$$\sum_{t=1}^{T} \sum_{b=1}^{B} \sum_{r=1}^{R} v_t \ x_{tbrn} + s_n^{10} - z_n = 0 = G_n^{10} \quad , \quad n = 1,2,\dots,N \qquad (69)$$

$$\sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{n=1}^{N} x_{tmkn} - \sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{n=1}^{N} x_{tkjn} - e_k = 0 = G_k \quad , \quad k = 1,2,\dots,K \qquad (70)$$

$$\sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{n=1}^{N} x_{tkjn} - \left(\sum_{t=1}^{T} \sum_{q=1}^{Q} \sum_{n=1}^{N} x_{tjqn} + \sum_{t=1}^{T} \sum_{e=1}^{E} \sum_{n=1}^{N} x_{tjen} + \sum_{t=1}^{T} \sum_{b=1}^{B} \sum_{n=1}^{N} x_{tjbn} + \sum_{t=1}^{T} \sum_{r=1}^{R} \sum_{n=1}^{N} x_{tjrn} \right) - e_j = 0 = G_j \quad , \quad j = 1,2,\dots,J \qquad (71)$$

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{n=1}^{N} x_{tjqn} + \left(\sum_{t=1}^{T} \sum_{b=1}^{B} \sum_{n=1}^{n} x_{tqbn} + \sum_{t=1}^{T} \sum_{e=1}^{E} \sum_{n=1}^{N} x_{tqen} + \sum_{t=1}^{T} \sum_{r=1}^{R} \sum_{n=1}^{N} x_{tqrn} \right) - e_q = 0 = G_q \quad , q = 1,2,\dots,Q \qquad (72)$$

$$\sum_{t=1}^{T} \sum_{q=1}^{Q} \sum_{n=1}^{N} x_{tqen} + \sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{n=1}^{N} x_{tjen} + \sum_{t=1}^{T} \sum_{b=1}^{B} \sum_{n=1}^{N} x_{tben} - e_e = 0 = G_e \quad , \quad e = 1,2,\dots,E \qquad (73)$$

$(\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjbn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqbn}) - (\sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{n=1}^{N} x_{tben} + \sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{n=1}^{N} x_{tbrn}) - e_b = 0 = G_b \quad , \quad b = 1, 2, \dots, B$ (74)

$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N} x_{tjrn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{n=1}^{N} x_{tqrn} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{n=1}^{N} x_{tbrn} - e_r = 0 = G_r \quad , \quad r = 1, 2, \dots, R$ (75)

$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{n=1}^{N} x_{tmkn} + e_m = 0 = G_m \quad , \quad m = 1, 2, \dots, M$ (76)

$x_{tkjn} + s_{tkjn} - u_{tkjn} = 0 = G_{tkjn} \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots,k \ , \ j = 1,2,\dots,J \ , \ n = 1,2,\dots,N$ (77)

$x_{tjqn} + s_{tjqn} - u_{tjqn} = 0 = G_{tjqn} \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,j \ , \ q = 1,2,\dots,Q \ , \ n = 1,2,\dots,N$ (78)

$x_{tjen} + s_{tjen} - u_{tjen} = 0 = G_{tjen} \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ e = 1,2,\dots,E \ , \ n = 1,2,\dots,N$ (79)

$x_{tjbn} + s_{tjbn} - u_{tjbn} = 0 = G_{tjbn} \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ b = 1,2,\dots,B \ , \ n = 1,2,\dots,N$ (80)

$x_{tjrn} + s_{tjrn} - u_{tjrn} = 0 = G_{tjrn} \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ r = 1,2,\dots,R \ , \ n = 1,2,\dots,N$ (81)

$x_{tqbn} + s_{tqbn} - u_{tqbn} = 0 = G_{tqbn} \ , \ t = 1,2,\dots,T \ , \ q = 1,2,\dots,Q \ , \ b = 1,2,\dots,B \ , \ n = 1,2,\dots,N$ (82)

$x_{tqen} + s_{tqen} - u_{tqen} = 0 = G_{tqen} \ , \ t = 1,2,\dots,T \ , \ q = 1,2,\dots,Q \ , \ e = 1,2,\dots,E \ , \ n = 1,2,\dots,N$ (83)

$x_{tqrn} + s_{tqrn} - u_{tqrn} = 0 = G_{tqrn} \ , \ t = 1,2,\dots,T \ , \ q = 1,2,\dots,Q \ , \ r = 1,2,\dots,R \ , \ n = 1,2,\dots,N$ (84)

$x_{tbrn} + s_{tbrn} - u_{tbrn} = 0 = G_{tbrn} \ , \ t = 1,2,\dots,T \ , \ b = 1,2,\dots,B \ , \ r = 1,2,\dots,R \ \ n = 1,2,\dots,N$ (85)

$x_{tben} + s_{tben} - u_{tben} = 0 = G_{tben} \ , \ t = 1,2,\dots,T \ , \ b = 1,2,\dots,B \ , \ e = 1,2,\dots,E \ , \ n = 1,2,\dots,N$ (86)

$x_{tkjn} \geq 0 \ , \ t = 1,2,\dots,T \ , \ k = 1,2,\dots,K \ , \ j = 1,2,\dots,J \ , \ n = 1,2,\dots,N$

$x_{tjqn} \geq 0 \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ q = 1,2,\dots,Q \ , \ n = 1,2,\dots,N$

$x_{tjen} \geq 0 \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ e = 1,2,\dots,E \ , \ n = 1,2,\dots,N$

$x_{tjbn} \geq 0 \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ b = 1,2,\dots,B \ , \ n = 1,2,\dots,N$

$x_{tjrn} \geq 0 \ , \ t = 1,2,\dots,T \ , \ j = 1,2,\dots,J \ , \ r = 1,2,\dots,R \ , \ n = 1,2,\dots,N$

$x_{tqbn} \geq 0 \ , \ t = 1,2,\dots,T \ , \ q = 1,2,\dots,Q \ , \ b = 1,2,\dots,B \ , \ n = 1,2,\dots,N$

$x_{tqen} \geq 0 \ , \ t = 1,2,\dots,T \ , \ q = 1,2,\dots,Q \ , \ e = 1,2,\dots,E \ , \ n = 1,2,\dots,N$

$x_{tqrn} \geq 0 \ , \ t = 1,2,\dots,T \ , \ q = 1,2,\dots,Q \ , \ r = 1,2,\dots,R \ , \ n = 1,2,\dots,N$

$x_{tbrn} \geq 0 \ , \ t = 1,2,\dots,T \ , \ b = 1,2,\dots,B \ , \ r = 1,2,\dots,R \ , \ n = 1,2,\dots,N$

$x_{tben} \geq 0 \ , \ t = 1,2,\dots,T \ , \ b = 1,2,\dots,B \ , \ e = 1,2,\dots,E \ , \ n = 1,2,\dots,N$

Given the above notation, to simplify, the problem can be written as follows:

Max F

s.t.

$G_{tjn}=0$, t=1,2,...,n j=1,2,...,J , n=1,2,...,N (87)

$G_t=0$, t=1,2,...,T (88)

$G_{tkqn}=0$, t=1,2,...,n , k=1,2,...,K , q=1,2,...,Q , n=1,2,...,N (89)

$G_{tken}=0$, $t=1,2,...,T$, $k=1,2,...,K$, $e=1,2,...,E$, $n=1,2,...,N$ (90)
$G_{tkbn}=0$, $t=1,2,\dots,T$, $k=1,2,\dots,K$, $b=1,2,\dots,B$, $n=1,2,\dots,N$ (91)
$G_{tkrn}=0$, $t=1,2,\dots,T$, $k=1,2,\dots,K$, $r=1,2,\dots,R$, $n=1,2,\dots,N$ (92)
$G_{tqen}=0$, $t=1,2,\dots,T$, $q=1,2,\dots,Q$, $e=1,2,\dots,E$, $n=1,2,\dots,N$ (93)
$G_{tben}=0$, $t=1,2,\dots,T$, $b=1,2,\dots,B$, $e=1,2,\dots,E$, $n=1,2,\dots,N$ (94)
$G_n^1=0$, $n=1,2,\dots,N$ (95)
$G_n^2=0$, $n=1,2,\dots,N$ (96)
$G_n^3=0$, $n=1,2,\dots,N$ (97)
$G_n^4=0$, $n=1,2,\dots,N$ (98)
$G_n^5=0$, $n=1,2,\dots,N$ (99)
$G_n^6=0$, $n=1,2,\dots,N$ (100)
$G_n^7=0$, $n=1,2,\dots,N$ (101)
$G_n^8=0$, $n=1,2,\dots,N$ (102)
$G_n^9=0$, $n=1,2,\dots,N$ (103)
$G_n^{10}=0$, $n=1,2,\dots,N$ (104)
$G_k=0$, $k=1,2,\dots,K$ (105)
$G_j=0$, $j=1,2,\dots,J$ (106)
$G_q=0$, $q=1,2,\dots,Q$ (107)
$G_e=0$, $e=1,2,\dots,E$ (108)
$G_b=0$, $b=1,2,\dots,B$ (109)
$G_r=0$, $r=1,2,\dots,R$ (110)
$G_m=0$, $m=1,2,\dots,M$ (111)
$G_{tkjn}=0$, $t=1,2,\dots,T$, $k=1,2,\dots,K$, $j=1,2,\dots,J$, $n=1,2,\dots,N$ (112)
$G_{tjqn}=0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $q=1,2,\dots,Q$, $n=1,2,\dots,N$ (113)
$G_{tjen}=0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $e=1,2,\dots,E$, $n=1,2,\dots,N$ (114)
$G_{tjbn}=0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $b=1,2,\dots,B$, $n=1,2,\dots,N$ (115)
$G_{tjrn}=0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $r=1,2,\dots,R$, $n=1,2,\dots,N$ (116)
$G_{tqbn}=0$, $t=1,2,\dots,T$, $q=1,2,\dots,Q$, $b=1,2,\dots,B$, $n=1,2,\dots,N$ (117)
$G_{tqen}=0$, $t=1,2,\dots,T$, $q=1,2,\dots,Q$, $e=1,2,\dots,E$, $n=1,2,\dots,N$ (118)
$G_{tqrn}=0$, $t=1,2,\dots,T$, $q=1,2,\dots,Q$, $r=1,2,\dots,R$, $n=1,2,\dots,N$ (119)
$G_{tbrn}=0$, $t=1,2,\dots,T$, $b=1,2,\dots,B$, $r=1,2,\dots,R$, $n=1,2,\dots,N$ (120)
$G_{tben}=0$, $t=1,2,\dots,T$, $b=1,2,\dots,B$, $e=1,2,\dots,E$, $n=1,2,\dots,N$ (121)
$x_{tkjn}\geq 0$, $t=1,2,\dots,T$, $k=1,2,\dots,K$, $j=1,2,\dots,J$, $n=1,2,\dots,N$
$x_{tjqn}\geq 0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $q=1,2,\dots,Q$, $n=1,2,\dots,N$
$x_{tjen}\geq 0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $e=1,2,\dots,E$, $n=1,2,\dots,N$
$x_{tjbn}\geq 0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $b=1,2,\dots,B$, $n=1,2,\dots,N$
$x_{tjrn}\geq 0$, $t=1,2,\dots,T$, $j=1,2,\dots,J$, $r=1,2,\dots,R$, $n=1,2,\dots,N$
$x_{tqbn}\geq 0$, $t=1,2,\dots,T$, $q=1,2,\dots,Q$, $b=1,2,\dots,B$, $n=1,2,\dots,N$
$x_{tqen}\geq 0$, $t=1,2,\dots,T$, $q=1,2,\dots,Q$, $e=1,2,\dots,E$, $n=1,2,\dots,N$
$x_{tqrn}\geq 0$, $t=1,2,\dots,T$, $q=1,2,\dots,Q$, $r=1,2,\dots,R$, $n=1,2,\dots,N$

$x_{tbrn} \geq 0 \quad , \quad t = 1,2,\ldots,T \quad , \quad b = 1,2,\ldots,B \quad , \quad r = 1,2,\ldots,R \quad , \quad n = 1,2,\ldots,N$

$x_{tben} \geq 0 \quad , \quad t = 1,2,\ldots,T \quad , \quad b = 1,2,\ldots,B \quad , \quad e = 1,2,\ldots,E \quad , \quad n = 1,2,\ldots,N$

The above problem is a constrained optimization problem. Using the Lagrangian operator, we transform it into an unconstrained optimization problem as follows:

$$L = F + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{n=1}^{N}\rho_{tjn}\, G_{tjn} + \sum_{t=1}^{T}\rho_t\, G_t + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{q=1}^{Q}\sum_{n=1}^{N}\rho_{tkqn}\, G_{tkqn} + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{e=1}^{E}\sum_{n=1}^{N}\rho_{tken}\, G_{tken} + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{b=1}^{B}\sum_{n=1}^{N}\rho_{tkbn}\, G_{tkbn} + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{n=1}^{N}\rho_{tkrn}\, G_{tkrn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{e=1}^{E}\sum_{n=1}^{N}\rho_{tqen}\, G_{tqen} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{e=1}^{E}\sum_{n=1}^{N}\rho_{tben}\, G_{tben} + \sum_{n=1}^{N}\rho_n^1\, G_n^1 + \sum_{n=1}^{N}\rho_n^1\, G_n^2 + \sum_{n=1}^{N}\rho_n^3\, G_n^3 + \sum_{n=1}^{N}\rho_n^4\, G_n^4 + \sum_{n=1}^{N}\rho_n^5\, G_n^5 + \sum_{k=1}^{K}\rho_k\, G_k + \sum_{j=1}^{J}\rho_j\, G_j + \sum_{q=1}^{Q}\rho_q\, G_q + \sum_{e=1}^{E}\rho_e\, G_e + \sum_{b=1}^{B}\rho_b\, G_b + \sum_{r=1}^{R}\rho_r\, G_r + \sum_{m=1}^{M}\rho_m\, G_m + \sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{n=1}^{N}\rho_{tkjn}\, G_{tkjn} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{q=1}^{Q}\sum_{n=1}^{N}\rho_{tjqn}\, G_{tjqn} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{e=1}^{E}\sum_{n=1}^{N}\rho_{tjen}\, G_{tjen} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{b=1}^{B}\sum_{n=1}^{N}\rho_{tjbn}\, G_{tjbn} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{n=1}^{N}\rho_{tjrn}\, G_{tjrn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{b=1}^{B}\sum_{n=1}^{N}\rho_{tqbn}\, G_{tqbn} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{e=1}^{E}\sum_{n=1}^{N}\rho_{tqen}\, G_{tqen} + \sum_{t=1}^{T}\sum_{q=1}^{Q}\sum_{r=1}^{R}\sum_{n=1}^{N}\rho_{tqrn}\, G_{tqrn} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{r=1}^{R}\sum_{n=1}^{N}\rho_{tbrn}\, G_{tbrn} + \sum_{t=1}^{T}\sum_{b=1}^{B}\sum_{e=1}^{E}\sum_{n=1}^{N}\rho_{tben}\, G_{tben} \qquad (122)$$

Where ρ_{tjn}, ρ_t, ρ_{tkqn}, ρ_{tken}, ρ_{tkbn}, …,ρ_{tbrn} and ρ_{tben} are the Lagrangian coefficients.

According to Lagrange's method, the optimal solution is obtained by solving the following system.

$$\frac{\partial L}{\partial X} = 0 \qquad (123)$$

Where X is a vector consisting of all the variables and Lagrange coefficients. Since system (123) is a large and difficult one, we solve it using the genetic algorithm (GA) method. Now, assuming $H(X) = \frac{\partial L}{\partial X}$, we design a genetic algorithm to solve system $H(X) = 0$.

To design the genetic algorithm, without loss of generality, we assume that vector X has n components. So we can write:

$$X^T = (x_1, x_2, \ldots, x_n)$$

Now, we write the steps of the designed genetic algorithm.

4) Algorithm Genetics

Step 1) Giving initial values to the following parameters:

$$X_i = \begin{bmatrix} x_1^i \\ \vdots \\ x_n^i \end{bmatrix} \quad , \quad i = 1,2,\ldots,\lambda$$

$\prod = \{X_1, X_2, \ldots, X_\lambda\}$

And ϵ , λ

The value of ϵ corresponds to the accuracy of the answer, and the initial components of X_i are the first generation chromosomes, whose values are chosen from non-negative rational numbers.

Step 2) If there is a t ($t = 1,2,\ldots,\lambda$) and we have $H(X_t) \leq \epsilon$, then go to step 14 (X_t is an ϵ −approximate answer). Otherwise, go to step 3.

Step 3) $I = 1$

Step 4) We choose two random numbers from the set of $\{1,2,\ldots,\lambda\}$. Suppose the two numbers chosen are α and β. We obtain a vector as follows:

$$X_{\alpha\beta} = \frac{X_\alpha + X_\beta}{2}$$

Step 5) $X_{\lambda+I} = X_{\alpha\beta}$

Step 6) Put $\prod = \prod \cup \{X_{\lambda+I}\}$ and go to the next step.

Step 7) If $I = \lambda$, go to step 8. Otherwise, put $I = I + 1$ and go to step 4.

Step 8) Put $J = 1$ and go to the next step.

Step 9) Calculate: $H_J = H\,(X_J)$

Step 10) If $J = 2\lambda$, go to Step 12. Otherwise, go to the next step.

Step 11) Put $J = J+1$ and go to step 9.

Step 12) Put $K = \prod$ and go to step 13.

Step 13) Put $\prod = \phi$ and go to the next step.

Step 14) We select λ of the Vectors X_J (from K) that have the lowest value of H_J and place them in $\prod$. Then, go to step 2.

Step 15) Stop.

4-1) Explaining the Steps of the Designed Genetic Algorithm

In step one, we determine the values of the initial chromosomes as desired. The second step actually guarantees the stopping condition of the algorithm. That is, if the generated chromosome satisfies the stopping condition, then the desired approximate solution has been obtained and the algorithm terminates. Otherwise, the method continues until the stopping condition is met. The third step starts the first execution of the algorithm. In the fourth step, a new chromosome is generated. That is, in this step, two chromosomes are randomly selected, their average is calculated, and the average value is determined as a new chromosome. In the fifth step, the new chromosome generated in the fourth step is indexed. This newly indexed chromosome is added to the chromosome set in the sixth step. In the seventh step, it is checked whether the chromosomes space is filled or not. If the chromosomes space is not filled, then it goes to a step that produces a new chromosome and adds it to the chromosomes set. Otherwise, it goes to a step that selects the required number of better chromosomes by performing mutation operation and removes the other chromosomes. Step eight announces the start of the mutation operation. In the ninth step, the value of the evaluator function is calculated for each chromosome. In the tenth step, it is checked whether the value of the evaluator function has been calculated for all chromosomes or not. If the value of the evaluator function has been calculated for all chromosomes, then it goes to a step that moves the chromosomes to a new space. Otherwise, it goes to a step that calculates the value of the evaluator function (for the chromosomes for which the value of the evaluator function has not been calculated). In the eleventh step, the new index of the evaluator function value is determined. In the twelfth step, the chromosomes are moved to the new space. In the thirteenth step, it is determined that the previous space of chromosomes is empty. In the fourteenth step, the required number of chromosomes, with the smallest value of the evaluator function, are selected and transferred to the previously empty space of chromosomes, and the algorithm cycle is repeated. In fact, steps 8 to 14 perform the mutation operations. The algorithm terminates at the fifteenth step.

5) Implementing Algorithms and Solving Numerical Examples

Now we solve the following example using the designed genetic algorithm. We use MATLAB software to implement the algorithm.

Example: We implement the method on the following supply chain network.

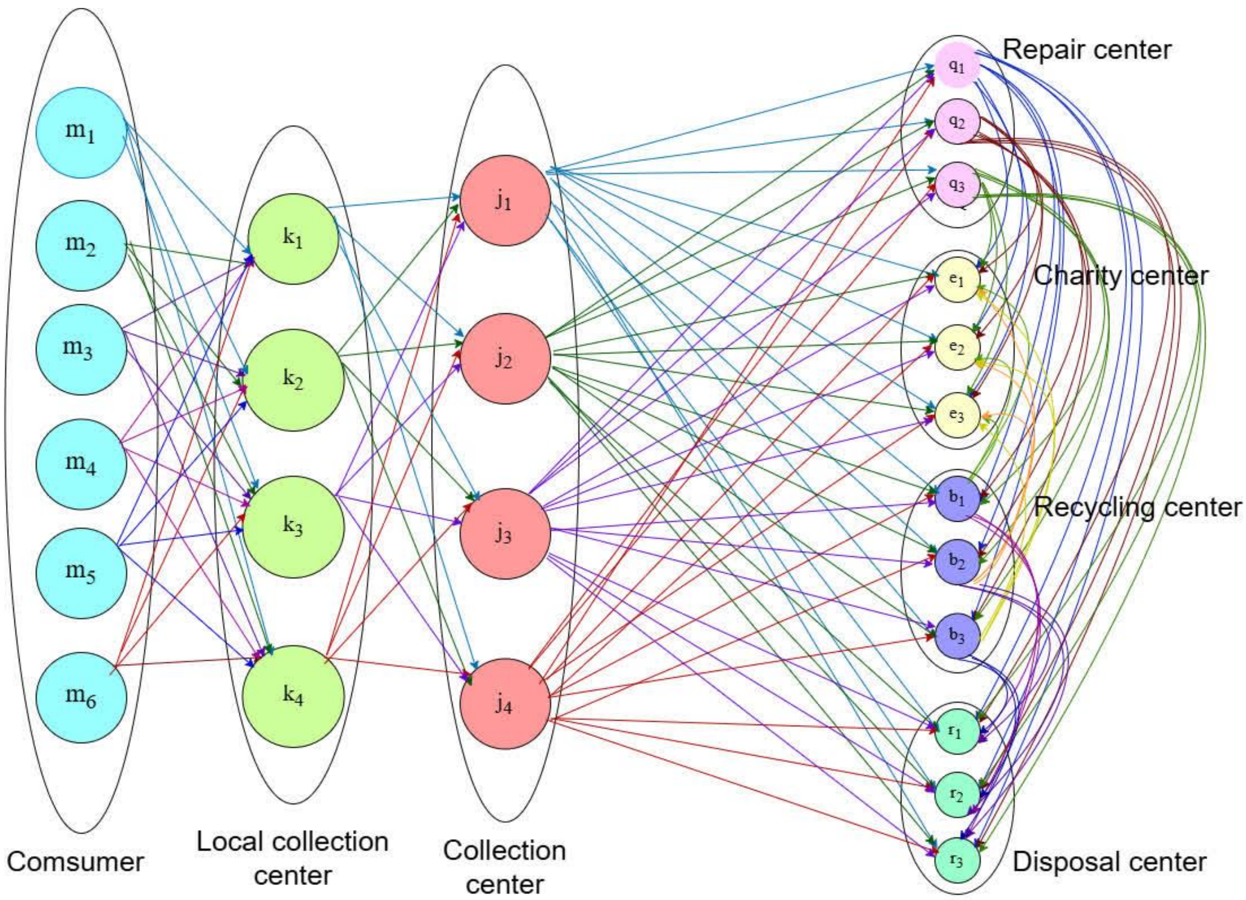

Figure 3. A Sample of Seven-Partite Supply Chain Network

First, we present the example data. To simplify and to keep the article short, we will keep the amount of data small.

$M = 6, K = 4, I = 4, J = 4, Q = 3, E = 3, B = 3, R = 3, T = 5, N = 5, \epsilon = 1, \lambda = 20.$

t	1	2	3	4	5
s_t	7	5	6	4	5

τ	m	k	j	q	e	b	r
e_τ	6	3	6	4	5	2	3

i	1	2	3	4
d_i	8	5	7	5

t	**1**	**2**	**3**	**4**	**5**
v_t	**7**	**5**	**3**	**5**	**4**

n	**1**	**2**	**3**	**4**	**5**
z_n	**4**	**8**	**3**	**5**	**6**

Values of z_{tk}:

t , k	1	2	3	4
1	4	4	2	3
2	3	4	3	2
3	2	3	3	4

4	3	5	3	3
5	5	2	2	4

Values of z_{ti}^{j}:

t , i	1	2	3	4
1	3	4	2	3
2	3	3	3	6
3	6	4	5	5
4	5	2	3	2
5	2	3	7	3

Values of z_{ti}^{q}:

t , i	1	2	3	4
1	2	4	2	4
2	5	4	3	2
3	6	3	5	3
4	5	2	3	2
5	3	3	4	6

Values of z_{ti}^{e}:

t , i	1	2	3	4
1	4	3	2	4
2	5	4	6	2
3	3	3	5	3
4	6	2	3	2
5	4	3	3	2

Values of z_{ti}^{b}:

t , i	1	2	3	4
1	3	3	2	4
2	2	3	3	2
3	4	3	5	3
4	3	6	3	2
5	5	3	3	5

Values of z_{ti}^{r}:

t , i	1	2	3	4
1	6	2	3	3
2	5	4	3	2
3	3	3	5	3
4	4	5	3	2
5	3	2	3	6

By running the algorithm, the values of the decision variables are obtained. Since the number of decision variables is highly large, even in this small size, in order not to make the article too long, we will only provide a few of their values as follows:

Values of $\boldsymbol{x_{tkjn}\ for\ t = n = 4}$:

k , j	1	2	3	4
1	3.22	3.25	4.11	3.27
2	5.06	5.33	3.99	2.65
3	5.02	2.87	3.22	1.28
4	3.94	4.60	4.33	0.58

When the decision variables have the condition of being integer, we must round the decimal part of the answers.

Conclusions and Future Research

This article addresses recycling used goods using a reverse supply chain network. Since the problem is complex and difficult in the defined state, we have solved it using an appropriate meta-heuristic method. The experimental implementation of the designed algorithm shows that the use of genetic algorithms is appropriate for solving the problem and the approximate solutions obtained are important from an application point of view. The authors believe that the method used in this paper can be redesigned and employed for other supply chain problems. If we change the conditions of the problem, then we must conduct a new study. For example, if at least one of the parameters or decision variables is stochastic, fuzzy, uncertain, or interval, the problem changes and requires a new study, all of which we propose for future research.

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