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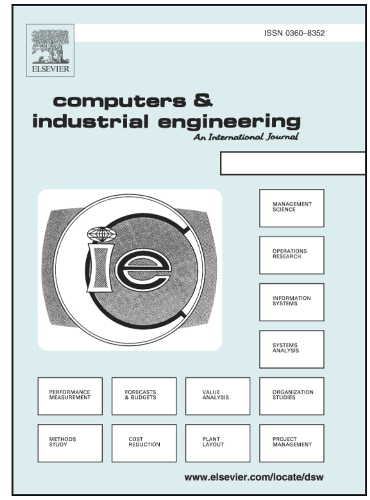

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PII: S0360-8352(19)30698-9
DOI: https://doi.org/10.1016/j.cie.2019.106229
Reference: CAIE 106229

To appear in: *Computers & Industrial Engineering*

Received Date: 29 April 2019
Revised Date: 10 December 2019
Accepted Date: 13 December 2019

Please cite this article as: Alizadeh, M., Makui, A., Mahdi Paydar, M., Forward and reverse supply chain network design for consumer medical supplies considering biological risk, *Computers & Industrial Engineering* (2019), doi: https://doi.org/10.1016/j.cie.2019.106229

Forward and reverse supply chain network design for consumer medical supplies considering biological risk

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Abstract

Medical Supply chain network design is one of the crucial planning problems that if solved efficiently and effectively, can alleviate the dangers arising from the accumulation of wastes. Furthermore, the harmful effects of medical waste, with their infectious nature in the environment, have increased justifies the significance of this research. In this article, forward and reverse supply chain network design for consumer medical products is considered taking into account the biological risks. The proposed model has two objectives: first, maximizing the profit obtained from subtracting the costs from the revenues of the supply chain. Revenues are gained from selling medical supplies to hospitals and medical wastes to recycling centers, as well as getting the permission to use sterilize services from clinics lacking a sterilization center. The costs include activation cost of inventory, sterilization and collection centers, transportation cost, purchasing cost of medical supplies, municipality cost for destruction of medical waste, etc. The second objective is to reduce biological risks. The primary source of infectious medical supplies is from disposable supplies and equipment. Thus, the second objective function is to minimize the distance and travel time between the clinic and the sterilization center. The proposed model is implemented in hospitals in Tehran's 4th municipal district using the Bounded De Novo Programming approach which initially attempts to redesign rare sources of the problem. The issue has two types of resource and policy constraints. The policy constraints of the problem cannot be changed, which is why the bounded De Novo Programming approach is used to solve the problem. Redesigning the capacity of the sterilization center leads to the decrease of biological risks, and in addition to can causes to increasing profitability. Also, by raising the productivity of medical waste in the recycling process, the distribution center can receive more profits.

Keyword: Supply chain network design, Healthcare, Medical waste, Bounded De Novo Programming.

1. Introduction

In the past, producers and consumers were not responsible for the products used. In other words, they were careless of the post consumption process. Many of the consumed and expired products were out of place, regardless of the extent of their return. They saw a fate of including burial, burning, or destruction ahead of them. Each of the above operations would undoubtedly impose destructive effects and damage to the surrounding environment. Now, the point of view of the advancement and development of countries, people, and the government are expecting to pay attention to their funds (Guo et al. 2019). Therefore, the producers plan to reduce the production of their defective goods. Thus, organizations are working to prevent more of the waste by devising an effective and efficient system in distribution network management. In turn, it includes determining the role of existing or potential supply chain resources as well as the interactions between these entities to manage the physical flows related to the recycling of products (Rajendran and Ravindran, 2019).

Today, industrial, government, business, and service organizations have focused on reverse logistics and supply chain processes (Kim et al. 2018). It could contribute to the creation of the actual economic value of goods and services, along with the support of environmental considerations (Mokhtar et al. 2019). Therefore, waste is one of the cases that justify the existence of an efficient logistics network. Waste is a collection of materials that are no longer effective and discarded after consumption or use. Waste has usually divided into five categories of urban waste, industrial waste, hazardous waste, electronic waste and hospital waste. According to the definition of the world healthcare organization, 20 percent of the produced medical waste could include in the category of hazardous waste, including infectious, toxic, and radioactive substances (Birchard, 2002). The amount of waste produced in medical centers is crucial, hence researchers have done much research in this field. The composition of medical waste depends on various factors and also the type of provided health care have a significant effect on the disposal rate of infectious waste (Liberti et al. 1996).

Critical kinds of waste that must fundamentally be considered with safety standards is hospital's waste (Kochan et al. 2018). All infectious waste of hospitals, health care facilities, medical diagnostic labs, and other similar centers are called hospital waste. Hospital wastes have varied according to their origin. For example, the waste from the operating rooms is significantly different from the laboratory or radiology department. In general, there is no specific definition of hospital waste.

The hospital infectious waste is "every solid waste that arises when detecting the disease, securing the human body and animals, and in the investigation of the vaccine, or when producing a vaccine or biological tests." It was according to the United States Environmental Protection Agency (EPA) definition.

2. Literature Review

This section tries to summarize the most relevant and recent literature on the health supply chain. Therefore, the literature review has studied in three parts; general supply chain, environmental impacts on the supply chain, and medical waste supply chain. Finally, by examining the existing conditions, the research gap has been defined.

Recently, researchers investigate some issues in different aspects, simultaneously. In addition to location-allocation, they have examined the inventory and routing problems in the study. It often causes to be class of NP-hard problems (Gharaei et al. 2019). Location-inventory-routing model has been presented in a three-echelon supply chain system: supplier, warehouse, and retailer. A supplier, along with a few warehouses, has to supply a probabilistic demand for some retailers. A normal distribution function follows the demand for a product. They used heuristics to solve the problem. The model is trying to improve in the three phases location, inventory, and routing. The case study of their proposed model applied in the food supply chain system of DKI Jakarta shows that this project can increase availability from 75 to 95 percent (Saragih et al. 2019). Since fifteen years ago, logistics has a special place in hospitals management (Volland et al. 2017). Nowadays, strategic decisions related to logistics in the management of hospitals, such as outsourcing medical goods and sterilization have been considered more and more (Ageron et al. 2018). Therefore, significant results have been observed in reducing the errors and the lead time (Mazzacato et al. 2010). Aydemir-Karadag (2018) presented a mixed-integer mathematical model for location and routing problem of the hospital infectious waste. This model decides the location and number of recycling centers, burning, disinfection, temporary disposal, and how to transfer these wastes. The model with a realistic example investigated, and the results showed that this model can be applied to real problems and provided reasonable solutions. Several articles that have attempted to incorporate different aspect in supply chain (e.g., Gharaei et al. (2019), Ahmadimanesh et al. (2019), Ghadimi et al. (2019), Guo et al. (2019), Sabouhi et al. (2018), Guo et al. (2018), Jabbarzadeh et al. (2018), Moktadir et al. (2018), Özceylan et al. (2017), Govindan et al. (2015) and Privett et al. (2014)).

According to the importance of a sustainable transportation network, researchers in recent years have sought to definition and evaluation criteria for improving existing conditions. Awasthi and Omrani (2019) investigated the design criteria for the selection of sustainable mobility project selection with using fuzzy Delphi technique. Furthermore, Sayyadi and Awasthi (2018) tried to identify the essential factors that related to sustainable transportation planning. They presented a simulation model based on optimization approach to five steps: providing a conceptual system, implementation of a conceptual system, depending on experience (DOE) and analysis of variance (ANOVA), optimization of crucial Factors, sensitivity analyses. They examined the independent Average Kilometers Travelled (AKT), Length of Road Network (LRN), Trip Rate (TRR), Fuel Efficiency (FE) and Emission Factor (EF) factors by the criteria such as congestion, fuel consumption, and emission. As a consequence, they found that the AKT, along with the TRR factor, showed more efficiency in the stable transportation system. For deep reviews, consider the below references. (e.g., Rabbani et al. (2019), Hao et al. (2018), Giri and Masanta (2018), Dubey et al. (2015) and Yin et al. (2016)).

Gharaei et al. (2019) designed the inventory model aimed at reducing the total cost of inventory, maximizing profits, simultaneously. The proposed model has some limits for example purchase cost, screening, disposal, and other items applied in the problem model. Mixed-integer nonlinear programming was formulated and solved in large scale. One of the most critical concerns that researchers are trying to make in their real model is to reduce the danger of environmental impacts (Kazemi et al. 2018). Carbon dioxide gas emissions are one of those that researchers took particular notice (Rabbani et al. 2018). Dangerous carbon dioxide gas produced by industrial plants, transportation, and so on. Therefore, they minimize the danger of environmental impacts in problem objective. Tsao (2015) investigated the supply chain network on trade credits. In the supply chain network, some decisions considered to reduce the total cost of the network, including how to allocate retail stores to the distribution center, cycle time, and replenishment of the distribution center. The algorithm is based on nonlinear optimization to solve it. In this study, the structure of the model consists of three levels; supplier; supplier, distribution center, and retailer. Moving goods in the network is one of the factors of carbon dioxide gas production. Distribution centers are another place of carbon emission. Malmir et al. (2016) investigated the supply chain of medical equipment. In this paper, game theory was used to model the company strategy for the supply of equipment. Taking into account the Markov chain learning process, they simulated the supply chain environment. With the analysis of the simulated environment and earnings calculation, the importance of the reward system and punishment in quality management proved. For more reviews, consider the below articles. (e.g., Hosseini et al. (2019), Duan et al. (2018), Sayyadi and Awasthi (2018), Sarkar and Giri (2018), shah et al. (2018) and Giri and bardhan (2014)).

Pishvaee and Razmi (2012) proposed a multi-objective mathematical model of the environmental supply chain network considering uncertainty in the problem parameters. The proposed model considers the minimization of the traditional cost and also the multiple environmental impacts. They have tried to make a fair balance between the objectives of the problem. Customers receive goods from production center and submit it to the collection center after their consumption. The products will lead to one of the three pathways in the Steel Recycling Center, the Plastic Recycling Center, or the incineration center. They solved the model using the multi-objective fuzzy optimization approach. Due to environmental hazards caused by hospital wastes, the separation of infectious waste from the public is vital.

In most developing countries, these wastes are buried together, which is non-sanitary. Waste production in hospitals requires management and selection of a systematic method to manage hospital wastes is difficult. Hence, Ishtiaq et al. (2018) ranked criteria that were required to choose the best in charges of waste management. They used a hierarchical analysis method for this ranking. The research carried out at the biggest city in Pakistan. The results show the cost of waste management in conjunction with two main criteria for selecting values. They are costs of maintenance and waste management. Some articles that have attempted to environmental impacts on the supply chain (e.g., Ghadimi et al. (2019), Jabbarzadeh et al. (2018), Rahimi and Fazlollahtabar (2018), Gabriel et al. (2018), Kurian (2018), Weraikat et al. (2016) and Sazvar et al. (2014),).

Medical waste management is of supreme importance due to the direct effect on public health of the community. Shi (2009) has tried to take a useful step in medical waste management by providing a reverse logistics mathematical model. The multi-level model included hospitals, collection centers, processing centers, and facilities. Medical waste transferred to the collection centers, then the collection center moved them to the processing centers. In the end, after processing the waste, they are sent to factories to use it again. The model has only one objective that minimized the total cost of the network flow. He has used a numerical example to model the problem model. In most societies, the healthcare industry has grown over time. Studies show that the supply chains of health services have investigated by many researchers (De Vries and Huijsman, 2011) and (Dobrzykowski et al. 2014). Therefore, articles in the field of medical waste management have been subject to the attention of the authors in recent years. However, there are still many research gaps in the area. Today, researchers are aware of the high importance of supply chain networks, and they are trying to take an essential step in this area by offering new approaches. Mato and Kaseva (1999) found that the improper destruction of hospital waste poses threats to public health. Therefore, they studied and researched the city of Dar-Al-Salaam in the country of Tanzania. They suggested upgrading public awareness, enforcement of law and regulation, as well as establishing a place for sanitary burial for hospital waste as critical measures to protect the environment. Lee et al. (2002) investigated the recycling potential of hospital plastic waste. Five hospitals and three veterinary centers located in Massachusetts City studied. The results showed that plastic produced in the laboratory, operating room, and cafeteria. They have a higher rate, which was mainly due to the low contamination of the plastic components, and it was easy to purchase plastic components. They found that the grouping of plastics waste to infectious and non-infectious waste could be a method of facilitating plastic waste recycling in the hospital. Lee et al. (2004) investigated the volume of production, resources, compounds, and methods of removing medical wastes, from which the data used in this study extracted from the Massachusetts municipal municipality. This study attempts to determine waste disposal methods to reduce the cost of treatment and disposal of infectious waste. They focused on cost-effective methods for disposal analysis, medical waste identification, and network flow analysis. While in the previous study, which presented in 2002, it was focused only on the analysis of the recycling potential of medical plastic wastes. First, they obtained information such as low numbers, waste volume, and waste disposal methods. They have indicated the transportation cost in regulated medical wastes transportation to the disposal centers are too expensive. On the other hand, the microwave treatment will not be less costly than treatment and disposal. Finally, the authors of this paper stated that the treatment and disposal approach with microwave technology in the same hospital could be a cost-effective solution. As a result, they found that the cost of waste could reduce by careful removal of non-infectious waste from hospital waste. Hsu et al. (2002) believe that while hospitals reject their medical wastes to observe environmental and individual health, the waste transfer increases potential environmental hazards. Besides, it also imposes many operational costs on the hospital. They tried to solve the problem by defining criteria in the Expert Choice software using the analytical hierarchy process (AHP) method. They have implemented their problem's model in Taiwan's hospitals. According to their research, this method reduces overhead costs and makes hospital waste management possible.

Pishvaee et al. (2014) presented a multi-objective contingency model for the medical supply chain network in uncertainty conditions. Based on social and environmental life cycle, the model included in the model for estimating environmental impacts. To overcome the computational complexity, they used an accelerated Benders algorithm, and the obtained computational results are guaranteed to be applicable.

Mantzaras and Voudrias (2017) presented an optimization model with a nonlinear objective function to reduce the cost associated with collection, transport, recycling, and destruction of hospital wastes. In this article, the optimal location of transmission stations, the number of vehicles for selection, an optimal path of transport vehicles, and the minimum cost of hospital waste management system calculated. They solved the proposed model by two separate software, which is first base on the genetic algorithm and the other on the simulation basis to study the performance. The model implemented in eastern Macedonia in the country of Greece. The results showed that the construction of recycling plants caused a high percentage of costs. Due to the recent spread of the Ebola virus in the USA, Le et al. (2018) carried out extensive research on the status of hospital waste shipping facility, medical recycling waste, and also knowledge of personnel. According to the results, few of these facilities were able to accept waste of infectious (Le et al. 2018). Another problem is the illegal disposal of general medical waste in India. The fact that companies that sell medical waste on the black market, and it can negatively influence on medical waste supply chain network (Solberg, 2009).

2.1. Research gap

According to the reviews conducted in the literature, researchers in the supply chain network design have already paid more attention to medical supplies, but it still has been cases that are far away from their eyes. The contributions of this paper are as follows:

- Modeling problem based on the problem defined by industry insiders
- Designing the direct and reverse network of medical disposable supplies with infectious nature
- Considering the risk of biological hazards
- Integrating the direct and reverse flow
- Redesigning the capacity of sterilization centers to increase profitability and reduce the risk of biological hazards
- Developing De Novo Programming is so-called Bounded De Novo Programming approach to remodel rare resources.

Section 3 gives the problem description and mathematical modeling of the supply chain network design. In section 4, Bounded De Novo Programming is considered. In section 5, a case study is conducted. As well, the results obtained by solving the model from the case study are discussed in this section. This section also analyzes the sensitivity of the results. Finally, the conclusions of this study are included.

3. Problem formulation

3.1. Problem description

One of the vital problems in our country is the dangers arising from the accumulation of wastes. An essential part of dangerous waste is produced by medical centers and hospitals. Medical disposable supplies have a very critical role in producing hazardous wastes. So, immediate actions including sterilization, recycling or destruction must be considered in any plans related to medical wastes. We employed the organizational diagnosis method to find the problem and simulate it at hospitals in Tehran province, and after collecting and analyzing data, we modeled it. Therefore, the health and treatment network of District 4 of Tehran was investigated. What is more, it has been considered in the presentation of the proposed model has been solving crucial problems in transferring medical goods to hospitals and reducing the possibility of transmission of disease through medical waste. It has also been a key issue for us to define the issue according to what has caused problems in reality. In this regard, designing a suitable supply chain network beginning from suppliers of disposable medical supplies and ending to destruction and recycling centers is considered in this article. The distribution network of disposable medical supplies includes various issues related to purchasing planning, ordering, warehousing, delivery and, of course, recycling or disposal. Therefore, one of the crucial issues that can have a significant impact on the design of the network is the location problem of the warehouses, recycling centers and the manner of the transportation of medical wastes.

An efficient and effective supply chain can have a significant effect in reducing waste generation as well as reducing the contamination generated by medical wastes. In the proposed model, a distribution center provides medical disposable supplies to medical centers and hospitals. Hospital demands are assumed to be pre-determined and uncertainties are not included in the plans of the distribution center. Since some goods are difficult to supply after delivery, the distribution center will order its suppliers according to this information and the hospital's demand. The distribution center receives orders from suppliers and as a hub, sends them according to the needs of the warehouses. Warehouses have two essential tasks: first, they categorize disposable medicals, and dispose of defective supplies to send them to the collection center. Second, according to the demand, the supplies are transferred to the hospitals. Until now, storage of wastes was the responsibility of hospitals, and this is why those serious problems are raised with medical wastes. Hospitals evince their satisfaction with this procedure because the hospital's mission is to serve patients rather than to the point of storage. Hence the cost of hospital wasting is reduced. Also, hospitals will free up space for their warehouses.

Hospitals should be equipped with the sterilization center, in accordance by the approvals given by the health department to hospitals. Of course, some of the hospitals cannot be equipped with these centers, and clinics also do not have a sterilization center. Thus, we classify hospitals into two groups with and without sterilization center. From now on, we assume that hospitals have a sterilization center and clinics lack this facility.

Hospitals already handle their medical wastes with the aid of the municipality, which handles all types of infectious and non-infectious wastes. Hospitals must pay for this service through a contract with the municipality. Of course, hospitals equipped with a sterilization center would disinfect their medical wastes before being delivered to these centers as far as possible and then be delivered to the municipal disposal facilities. In the presented article, the distribution center has the responsibility for the collection of medical wastes and provides the following conditions:

- Contrary to the previous situation, no hospital fees are collected for the collection and transfer of medical wastes.
- The entire process of sterilization of infectious wastes from clinics is done at the center.
- The distribution center is required to establish a sterilization center or use hospitals' facilities for sterilization in accordance with the contract for the sterilization of medical infectious waste.

- When ordering supplies, clinics pay for the right to service due to the sterilization of wastes.
- Hospitals only prepare their medical infectious wastes for transportation.

In this regard, finding the best location of the sterilization center is also considered in the model. Of course, in accordance with the contracts between the distribution centers and hospitals, we assume that as far as possible, the sterilization units of hospitals can be used for the sterilization of infectious medical wastes at the clinics. Hospitals are considering the following restrictions, which will trigger activation of new locations for the sterilization center:

- Some hospitals will not sign contracts due to infectious diseases caused by medical infectious wastes.
- Due to the limited capacity of hospitals, they will not be able to cover all infectious waste in clinics.

The distance between the receipt of infectious wastes from the clinics and its delivery to the sterilization center is the most essential cause of biologically hazardous. In this section, all areas where the carriage of wastes passes through, are contaminated and causes many dangers.

After sterilization, medical wastes that are no longer infectious are transported to the collection centers. Therefore, the location finding of the establishment of the collection center is also considered in our model. This center focuses on the separation of medical wastes and separates them into recycled and non-recyclable ones. The recycling centers buy recyclable medical wastes. Irrecoverable wastes will also be transferred to the municipality at a cost to the destruction.

In this research, the subsequent objective of the distribution center is to take responsibility for warehousing the wastes from the hospital over time. The hospital's storage causes a large volume of medical supplies with an expired date no longer usable. In the same way, the distribution center is trying to set up its warehouses near the hospitals. It should be noted that hospital demands are assumed to be known.

In this article, maximizing the profit for the distribution center and minimizing the biological risks are considered as objective functions. Inthe end, the general structure of the direct and reverse distribution system is shown in Figure1.

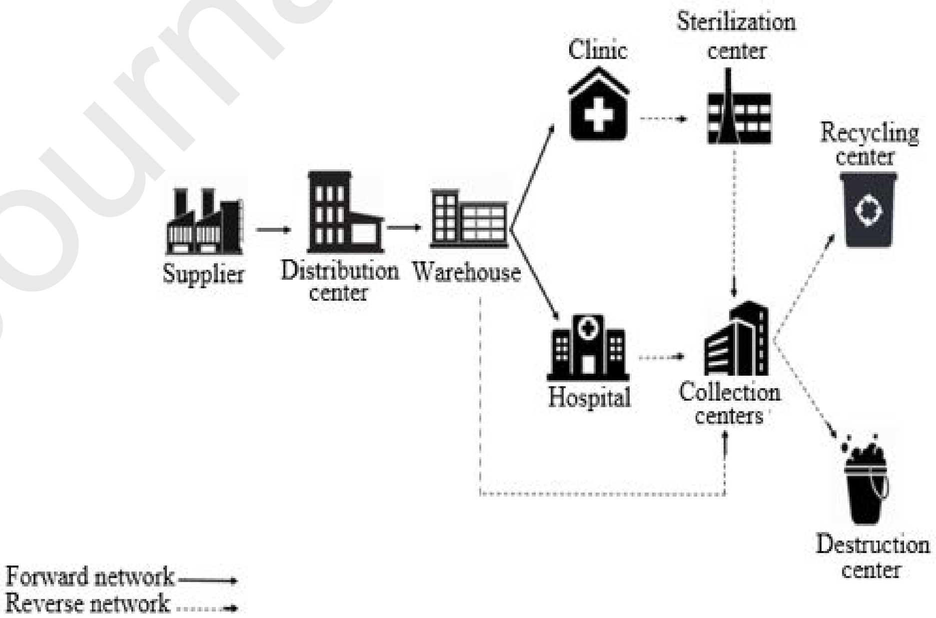

Fig1. The proposed supply chain network

Since the proposed model is based on a case study, it is necessary to consider the conditions that occur in reality. Therefore, the following factors are related to the proposed model:

1. One-period mode.
2. All demands by hospitals and clinics are deterministic and within one period of time.
3. Hospitals and clinics receive medical supplies only from the distribution center.
4. A special means of transport is used for the distribution network in the direct and reverse direction. Of course, the cost will be different.
5. The mathematical model tries to locate the warehouse, the sterilization center and the collection center.
6. Due to the importance of medical supplies, there is no shortage.
7. The hospital's sterilization center capacity is limited. Also, some hospitals are not allowed to carry out this operation due to contamination caused by the transfer of medical wastes from the clinic to the hospital, but they have enough capacity to do so.
8. The distribution center is responsible for the cost of the contract for the transfer of medical wastes from the clinic to the hospital's sterilization center.
9. Medical wastes are divided into two categories: sharp and non-sharp.

Medical waste is one of the essential factors in transferring biological hazards that the problem model has tried to sterile the medical waste and then send it to the recycling centers according to conditions. So far, all of the medical waste destroyed, while the supply chain network of medical goods and waste, in addition to profitability, can play a crucial role in the return of consumer goods. Briefly, the medical waste produced at the clinic must sent to sterilization center. Sterilization centers can be established separately or medical waste send into hospitals under a contract. An essential factor in this transfer is the reduction of biological risks. Furthermore, storage tasks are removed from hospitals, and the model tries to stablish the warehouses at a minimum distance with hospitals so that hospitals focus only on serving patients.

3.2. Mathematical model

The following notations are used to formulate the model.

Indices:

i	supplier
w	warehouse
h	hospital
e	sterilization center
c	collection center
r	recycling center
m	destruction center
p	product

Parameters:

FW_w	The fixed cost of using the warehouse in the place *w*, taking into account the annual discount rate
FE_e	The fixed cost of using the sterilization center in place *e*, taking into account the annual discount rate
FC_c	The fixed cost of using the collection center in place *c*, taking into account the annual discount rate
FLE_e	Contract cost per waste transmitted from clinic to sterilization center *e*
RI_{pi}	Transportation cost of product *p* from supplier *i* to collection center *c*

R_{pw}	Transportation cost of product p from distribution center to warehouse in place w
RW_{pwh}	Transportation cost of product p from warehouse in place w to hospital h
RHE_{phe}	Transportation cost of product p from hospital h to sterilization center in place e
RHC_{phc}	Transportation cost of the product p from hospital h to collection center in place c
RWC_{pwc}	Transportation cost of the product p from warehouse w to collection center in place c
RE_{pec}	Transportation cost of the product p from sterilization center e to collection center in place c
RC_{pcr}	Transportation cost of product p from collection center c to recycling center r
OH_{ph}	Operational cost of the medical waste product p at hospital h
OE_{pe}	Operational cost of the medical waste product p at sterilization center e
OC_{pc}	Operational cost of the medical waste product p at collection center c
C_{pcm}	Delivery cost of the medical waste product p from collection center c to destruction center m
SH_{ph}	Revenue of the medical waste product p sold to hospital h
S_{ph}	Revenue of the sterilization service of the medical waste p for hospital h
SR_{pr}	Revenue of the medical waste product p sold to recycling center r
B_{pi}	Purchase cost of product p from supplier i
D_{ph}	Demand of product p at hospital h
P_h	1, if the hospital h has sterilization center; otherwise 0
F_p	1, if the product p is sharp tip; otherwise 0
DWH_{wh}	Distance between warehouse w to hospital h
DHE_{he}	Distance between hospital h to sterilization center e
OW	Maximum coverage radius between the warehouse to the hospital
OE	Maximum coverage radius between the hospital to the sterilization center
k	Vehicle displacement capacity
α	The percentage of the sharp rip wastage which are recyclable
β	The percentage of the non-sharp rip wastage which are recyclable
γ_p	The percentage of the defective medical product p
CA_w	Warehouse w capacity
CA'_e	Sterilization center e capacity
CA''_c	Collection center c capacity

Decisions variables:

QI_{pi}	The amount of product p transmitted from supplier i to the distribution center

Q_{pw}	The amount of product p transmitted from the distribution center to warehouse w
QW_{pwh}	The amount of product p transmitted from warehouse w to hospital h
QHE_{phe}	The amount of medical waste p transmitted from hospital h to the sterilization center to place e
QHC_{phc}	The amount of medical waste p transmitted from hospital h to the collection center to place c
QWC_{pwc}	The amount of product p transmitted from warehouse w to the collection center in the place c
QE_{pec}	The amount of medical waste p transmitted from sterilization center e to the collection center in the place c
QC_{pcr}	The amount of medical waste p transmitted from collection center c to destruction center m
X_w	1, if warehouse w activate; otherwise 0
Y_e	1, if sterilization center e activate; otherwise 0
Z_c	1, if collection center c activate; otherwise 0
LE_{he}	Frequency of vehicle movement

3.2.2. Objective functions

The first objective function in equation (1) is to maximize the profitability of the distribution center through revenues from the sale of medical products for hospitals, revenues from services received from clinics and the sale of recycled wastes to recycling centers. Also, the cost reduction for warehouse activation, the sterilization center and the collection center, and the product purchase costs from the supplier, transportation costs, operating costs and, of course, contracts between the distribution center and the hospital for the sterilization of medical wastes at the clinics have been taken on this objective.

In equation (2), the objective function reduces the biological risks. Since the highest level of contamination of medical wastes is after the consumption of medical supplies until it is transferred to the sterilization center, the minimization of the number of times of displacement from the clinic to the sterilization center is defined in this equation.

$$\begin{aligned} Max z1 = & \sum_p\sum_w\sum_h SH_{ph}QW_{pwh} + \sum_p\sum_w\sum_h S_{ph}QW_{pwh}\left(1-p_h\right) \\ & + \sum_p\sum_w\sum_h SR_{pr}QCR_{pcr} - \left(\sum_w FW_W X_w + \sum_w FE_e Y_e + \sum_w FC_c Z_c\right) \\ & - \left(\sum_p\sum_i B_{pi}QI_{pi}\right) - \left(\sum_p\sum_h\sum_e QHE_{phe}(1-p_h)FLE_e\right) \\ & - \left(\begin{array}{l} \sum_p\sum_i RI_{pi}QI_{pi} + \sum_p\sum_w R_{pw}Q_{pw} + \sum_p\sum_w\sum_h RW_{pwh}QW_{pwh} + \\ \sum_p\sum_h\sum_e RHE_{phe}QHE_{phe} + \sum_p\sum_h\sum_e RHE_{phc}QHE_{phe} + \sum_p\sum_w\sum_c RWC_{pwc}QWC_{pwc} \\ + \sum_p\sum_e\sum_c RE_{pec}QE_{pec} + \sum_p\sum_c\sum_r RC_{pcr}QC_{pcr} + \sum_p\sum_c\sum_m C_{pcm}QCM_{pcm} \end{array}\right) \\ & - \left(\begin{array}{l} \sum_p\sum_w\sum_h OH_{ph}QW_{pwh}(1-p_h) + \sum_p\sum_h\sum_e OE_{pe}QHE_{phe} + \\ \sum_p\sum_w\sum_h\sum_e\sum_c OC_{pc}(QWC_{pwc} + QHE_{phc} + QE_{pec}) \end{array}\right) \end{aligned} \quad (1)$$

$$Min z2 = \sum_h\sum_e LE_{he}DHE_{he} \quad (2)$$

3.2.3. Constraints

$$\sum_i QI_{pi} = \sum_w Q_{pw} \qquad \forall p \qquad (3)$$

$$\sum_p Q_{pw} \le X_w CA_w \qquad \forall w \qquad (4)$$

$$Q_{pw} = \sum_h QW_{pwh} + \sum_c QWC_{pwc} \qquad \forall p, w \qquad (5)$$

$$\sum_w QW_{pwh} = D_{ph} \qquad \forall p, h \qquad (6)$$

$$\sum_w QW_{pwh}(1-p_h) = \sum_e QHE_{phe} \qquad \forall p, h \qquad (7)$$

$$\sum_p \sum_h QHE_{phe} \le Y_e CA_e \qquad \forall e \qquad (8)$$

$$\sum_h QHE_{phe} = \sum_c QE_{pec} \qquad \forall p, e \qquad (9)$$

$$\sum_p \sum_e QE_{pec} + \sum_p \sum_h QHC_{phc} + \sum_p \sum_w QWC_{pwc} \le Z_c CA''_c \qquad \forall c \qquad (10)$$

$$\alpha\left(\left(\sum_h QHC_{phc} F_p\right) + \left(\sum_e QE_{pec} F_p\right) + \left(\sum_w QWC_{pwc} F_p\right)\right) + \beta\left(\begin{array}{l}\left(\sum_h QHC_{phc}\left(1-F_p\right)\right) + \left(\sum_e QE_{pec}\left(1-F_p\right)\right) + \\ \left(\sum_w QWC_{pwc}\left(1-F_p\right)\right)\end{array}\right) = \sum_r QC_{pcr} \qquad \forall p, c \qquad (11)$$

$$\left(1-\alpha\right)\left(\left(\sum_h QHC_{phc} F_p\right) + \left(\sum_e QE_{pec} F_p\right) + \left(\sum_w QWC_{pwc} F_p\right)\right) + \left(1-\beta\right)\left(\begin{array}{l}\left(\sum_h QHC_{phc}\left(1-F_p\right)\right) + \left(\sum_e QE_{pec}\left(1-F_p\right)\right) \\ + \left(\sum_w QWC_{pwc}\left(1-F_p\right)\right)\end{array}\right) = \sum_m QCM_{pcm} \qquad \forall p, c \qquad (12)$$

$$\sum_c QHC_{phc} P_h = \sum_w QW_{pwh} P_h \qquad \forall h, p \qquad (13)$$

$$Q_{pw} \gamma_p = \sum_c QWC_{pwc} \qquad \forall p, w \qquad (14)$$

$$DWH_{wh} X_w \le OW \qquad \forall w, h \qquad (15)$$

$$DHE_{he}(1-P_h) Y_e \le OE \qquad \forall h, e \qquad (16)$$

$$L_{he} = \left\lceil \frac{\sum_{p} QHE_{phe}}{K} \right\rceil \qquad \forall h,e \qquad (17)$$

$$QI_{pi}, Q_{pw}, QW_{pwh}, QHE_{phe}, QHC_{phc},$$
$$QE_{pec}, QC_{pcr}, FA_{he} \in \text{INT} \qquad (18)$$
$$X_w, Y_e, Z_c \in \text{Binary}$$

Constraint (3) shows the balance of the medical supplies received from the supplier and the transfer to the warehouse**.** Constraint (4) ensures that consumer medical supplies are transferred to the warehouse if enough storage capacity is available. Constraint (5) indicates that the medical supplies available in the warehouse are either transmitted to the hospitals in accordance with the request or transmitted directly to the collection center for reasons of corruption or defective goods. Constraint (6), it is clear that the balance between the goods shipped from the warehouse to the hospital is shown in accordance with the demand. Constraint (7) states that if the hospital has no sterilization center, it sends its medical waste to the sterilization center, and limitation (8) also indicates that medical waste can be sent when the sterilization center was activated **.** Constraint (9) shows the balance between waste of the hospital that transferred to the sterilization center and that to the collection center**.** Constraint (10) indicates the allocation of the collection center, if its capacity can cover the waste shipped. Constraint (11) indicates the amount of medical waste transferred from the collection center to the recycling center. The collection center receives the medical waste from the warehouse, the hospital and the sterilization center. Equation (12) shows the amount of residual waste sent to the destruction center. Equation (13) ensures the balance between products sent from the warehouse to the hospital with the medical waste transferred to the collection center. Constraint (14) shows the amount of defective medicine received from the supplier and transferred to the collection center. Constraints (15 and 16) specify the maximum coverage radius. Constraint (17) also shows the number of times a vehicle is moving. Constraint (18) also shows the state of the decision variables.

Constraint (17) is also considered as the upper limit for the number of shipments. Hence, the above equation can be converted into three constraints:

$$L_{he} = FA_{he} \qquad \forall h,e \qquad (19)$$

$$FA_{he} \geq \frac{\sum_{p} QHE_{phe}}{K} \qquad \forall h,e \qquad (20)$$

$$FA_{he} \leq \left(\frac{\sum_{p} QHE_{phe}}{K}\right) + 1 - \xi \qquad \forall h,e \qquad (21)$$

Therefore, the direct and reverse distribution network of consumer medical products was presented with consideration of the biological risks. In the following, the method of solving this model will be investigated due to the multipurpose nature of the model.

4. Solving method

Today, in the real world, decision-makers are struggling to achieve more than one goal, and in most cases, the goals of the problem have a conflicting nature and so the solution will be a Pareto optimal solution. In this article, the Bounded De Novo programming is used to solve the model based on the De Novo programming introduced by Zeleny (1986).

4.1. De Novo Programming

The general model and the performance steps of De Novo Programming are as follows:

A) To form the linear programming model.

$$\begin{aligned} &Maxz = CX \\ &st: \\ &AX \leq b \\ &X \geq 0 \end{aligned} \tag{30}$$

B) A constrained B budget is available for all limited resources, while the P vector is the cost vector of the resources.

$$\begin{aligned} &Maxz = CX \\ &st: \\ &AX - b \leq 0 \\ &p.b \leq B \end{aligned} \tag{31}$$

C) A right side of the constraints b is assumed to be dependent on the need for redesign.

Model solving (31) means finding the optimal allocation of B for portfolio b, so that at the same time maximizes all values of $Z = CX$. Then:

$$\begin{aligned} &Maxz = Cx \\ &st: \\ &PAx \leq Pb \leq B \end{aligned} \tag{32}$$

PA as vector V. So that:

$$\begin{aligned} &Maxz = Cx \\ &st: \\ &Vx \leq B \\ &x \geq 0 \end{aligned} \tag{33}$$

$$\begin{aligned} &Z = (z_1, z_2, ..., z_k) \in R^k \\ &V = (v_1, v_2, ..., v_n) = P.A \in R^n \end{aligned} \tag{34}$$

Now, suppose that there is a multi-objective problem $(z_1, z_2, ..., z_k)$, where k is the objective function, the above model is solved independently of each other for every objective function.

$$\begin{aligned} &Maxz_1 = C_1 x \\ &st: \\ &Vx \leq B \\ &x \geq 0 \\ &. \\ &. \\ &. \\ &Maxz_k = C_k x \\ &st: \\ &Vx \leq B \\ &x \geq 0 \end{aligned} \tag{35}$$

The optimal values for each objective function are obtained according to the above model. There will be vector Z^*.

$$Z^* = (z_1^*, z_2^*, ..., z_k^*) \in R^k \quad (36)$$

The ideal solution is in terms of B.

D) Now, the Meta optimum problem can be considered as follows:

$$\begin{aligned} &MinD = VX \\ &st: \\ &CX \geq Z^* \\ &x \geq 0 \end{aligned} \quad (37)$$

Therefore, we will have a multi-objective model:

$$\begin{aligned} &MinD = VX \\ &st: \\ &C_1X \geq Z_1^* \\ &C_2X \geq Z_2^* \\ &. \\ &. \\ &. \\ &C_kX \geq Z_k^* \\ &x \geq 0 \end{aligned} \quad (38)$$

By optimal solving model (38), the value of X^* is obtained. By using X^* we can calculate $B^* = VX^*$. Also we have $b^* = AX^*$.

The value of B^* shows the minimum amount of funds for access to Z^* which achieves through X^* and b^*. As $B^* \geq B$, the optimal path to achieve the ideal performance of Z^* for a given budget B is $r = \frac{B}{B^*}$

and the design of the optimal system (X, b, Z) in which $X = r^*.X^*$, $b = r^*b^*$, $Z = r^*Z^*$, and r^* is a suitable tool for redesigning the system.

4.2. Bounded De Novo Programming

As stated, the above solution procedure for the state of a linear programming model is that all of its variables are involved with the expected resources and there is no equilibrium constraint, or in other words, there is no policy in it. The main purpose of this study is to note that the main constraints of the model are divided into two categories.

- Policy constraints: The constraints such as balance equations, coverage radius and other.
- Resource constraints: Restrictions include the capacity of centers.

De Novo Programming method does not have political performance constraints and only limits on rare resources. The problem model includes limitations of storage capacity, sterilization center, and collection center. In this regard, there is no problem for storage capacity and collection center, and the majority of restrictions are on the capacity of sterilization centers. For this purpose, this restriction is considered to be subject to constraint (8) for the capacity of the sterilization center.

What was presented in the De Novo Programming method by Zeleny (1986) was in a linear model with no policy constraints and it was constant. Similarly, the achieved amount of $r = \frac{B}{B^*}$ is in the range of (0-1). The essential point in the application of Bounded De Novo Programming in this study is that there are policy constraints that can cause the allocated budget to be effective only to a certain extent and is greater than that of the surplus. There are, of course, the policy constraints of any issue that determines it. In other words, the policy constraint of problem, one of which is a set of constraints of supply chain balancing network, is a deterrent to further improvements. These items were not observed in the De novo method described by Zeleny (1986) as the solution of all the variables involved in the problem-solving procedure but now presented with respect to the policy constraints of the De novo method. Therefore, the capacity of the sterilization center can be effective only to a certain extent and the allocation of additional funds will be a surplus that will not be followed by improvements in the objective function. Therefore, the problem model will be as follows:

$$\begin{aligned} & Max z = CX \\ & st: \\ & VX \le B \\ & GX \le g \\ & X \ge 0 \end{aligned} \tag{39}$$

As mentioned earlier $V = PA$. This means that the vector V is calculated only for those constraints that are to be decided on their right-hand resources b. Therefore, this constraint is considered for the capacity of the sterilization center. In the following, the second step is to be performed as described below:

$$\begin{aligned} & Min D = VX \\ & st: \\ & C_1 X \ge Z_1^* \\ & C_2 X \ge Z_2^* \\ & . \\ & . \\ & . \\ & C_k X \ge Z_k^* \\ & GX \le g \\ & x \ge 0 \end{aligned} \tag{40}$$

It should be noted that $Min D = VX$ shows the optimal budget amount for allocating the capacity of the sterilization center (B^*). Then, we have to obtain the value $r = \frac{B}{B^*}$ to determine the amount of changes in the sterilization centers. After calculating it and applying the increase/ reduction of the capacity of the sterilization center, according to the multi-objective model solving procedure, the problem is solved by considering changes. Finally, the optimal amount of objective functions will be presented.

Therefore, in the first step the model will be as follows:

$$\begin{aligned}
&Max z1 = \sum_p \sum_w \sum_h SH_{ph} QW_{pwh} + \sum_p \sum_w \sum_h S_{ph} QW_{pwh} \left(1-p_h\right) + \\
&\sum_p \sum_w \sum_h SR_{pr} QCR_{pcr} - \left(\sum_w FW_W X_w + \sum_w FE_e Y_e + \sum_w FC_c Z_c\right) \\
&-\left(\sum_p \sum_i B_{pi} QI_{pi}\right) - \left(\sum_p \sum_h \sum_e QHE_{phe} (1-p_h) FLE_e\right) \\
&-\left(\begin{aligned}&\sum_p \sum_i RI_{pi} QI_{pi} + \sum_p \sum_w R_{pw} Q_{pw} + \\ &\sum_p \sum_w \sum_h RW_{pwh} QW_{pwh} + \sum_p \sum_h \sum_e RHE_{phe} QHE_{phe} \\ &+\sum_p \sum_h \sum_e RHE_{phc} QHE_{phe} + \sum_p \sum_w \sum_c RWC_{pwc} QWC_{pwc} + \\ &\sum_p \sum_e \sum_c RE_{pec} QE_{pec} + \sum_p \sum_c \sum_r RC_{pcr} QC_{pcr} + \sum_p \sum_c \sum_m C_{pcm} QCM_{pcm}\end{aligned}\right) \\
&-\left(\begin{aligned}&\sum_p \sum_w \sum_h OH_{ph} QW_{pwh} (1-p_h) + \sum_p \sum_h \sum_e OE_{pe} QHE_{phe} + \\ &\sum_p \sum_w \sum_h \sum_e \sum_c OC_{pc} (QWC_{pwc} + QHE_{phc} + QE_{pec})\end{aligned}\right)
\end{aligned} \quad (41)$$

$$Min z2 = \sum_h \sum_e LE_{he} DHE_{he} \quad (42)$$

$$\sum_i QI_{pi} = \sum_w Q_{pw} \qquad \forall p \quad (43)$$

$$\sum_p Q_{pw} \le X_w CA_w \qquad \forall w \quad (44)$$

$$Q_{pw} = \sum_h QW_{pwh} + \sum_c QWC_{pwc} \qquad \forall p,w \quad (45)$$

$$\sum_w QW_{pwh} = D_{ph} \qquad \forall p,h \quad (46)$$

$$\sum_w QW_{pwh} (1-p_h) = \sum_e QHE_{phe} \qquad \forall p,h \quad (47)$$

$$\sum_p \sum_h QHE_{phe} \le Y_e BIGM \qquad \forall e \quad (48)$$

$$\sum_h QHE_{phe} = \sum_c QE_{pec} \qquad \forall p,e \quad (49)$$

$$\sum_p \sum_e QE_{pec} + \sum_p \sum_h QHC_{phc} + \sum_p \sum_w QWC_{pwc} \le Z_c CA''_c \qquad \forall c \quad (50)$$

$$\begin{aligned}
&\alpha\left(\left(\sum_h QHC_{phc} F_p\right) + \left(\sum_e QE_{pec} F_p\right) + \left(\sum_w QWC_{pwc} F_p\right)\right) + \\
&\beta\left(\begin{aligned}&\left(\sum_h QHC_{phc}\left(1-F_p\right)\right) + \left(\sum_e QE_{pec}\left(1-F_p\right)\right) + \\ &\left(\sum_w QWC_{pwc}\left(1-F_p\right)\right)\end{aligned}\right) \\
&= \sum_r QC_{pcr}
\end{aligned} \qquad \forall p,c \quad (51)$$

$$(1-\alpha)\left(\left(\sum_h QHC_{phc}F_p\right)+\left(\sum_e QE_{pec}F_p\right)+\left(\sum_w QWC_{pwc}F_p\right)\right)+$$
$$(1-\beta)\left(\left(\sum_h QHC_{phc}\left(1-F_p\right)\right)+\left(\sum_e QE_{pec}\left(1-F_p\right)\right)+\left(\sum_w QWC_{pwc}\left(1-F_p\right)\right)\right) \quad \forall p,c \quad (52)$$
$$=\sum_m QCM_{pcm}$$

$$\sum_c QHC_{phc}P_h=\sum_w QW_{pwh}P_h \quad \forall h,p \quad (53)$$

$$Q_{pw}\gamma_p=\sum_c QWC_{pwc} \quad \forall p,w \quad (54)$$

$$DWH_{wh}X_w \le OW \quad \forall w,h \quad (55)$$

$$DHE_{he}(1-P_h)Y_e \le OE \quad \forall h,e \quad (56)$$

$$L_{he}=FA_{he} \quad \forall h,e \quad (57)$$

$$FA_{he} \ge \frac{\sum_p QHE_{phe}}{K} \quad \forall h,e \quad (58)$$

$$FA_{he} \le \left(\frac{\sum_p QHE_{phe}}{K}\right)+1-\xi \quad \forall h,e \quad (59)$$

$$\sum_p\sum_h\sum_e V.QHE_{phe} \le B \quad (60)$$

$$QI_{pi}, Q_{pw}, QW_{pwh}, QHE_{phe}, QHC_{phc},$$
$$QWC_{pwc}, QE_{pec}, QC_{pcr} \in \text{INT} \quad (61)$$
$$X_w, Y_e, Z_c \in \text{Binary}$$

Constraints (57-59) is written for non-linear limitation (17). Constraints (57-59) has been used to calculate the upper limit. Limit (60) is also for the De Novo programming. This limitation shows how much funding can be spent on resource redesign. In the second step, we need to form the model by considering the amount of objective functions and policy constraints. In this regard, the model description is as follows:

$$MinZ3=\sum_p\sum_h\sum_e V.QHE_{phe} \quad (62)$$

$$
\begin{aligned}
&(\sum_p\sum_w\sum_h SH_{ph}QW_{pwh} + \sum_p\sum_w\sum_h S_{ph}QW_{pwh}\left(1-p_h\right) + \\
&\sum_p\sum_w\sum_h SR_{pr}QCR_{pcr} - \left(\sum_w FW_W X_w + \sum_w FE_e Y_e + \sum_w FC_c Z_c\right) \\
&-\left(\sum_p\sum_i B_{pi}QI_{pi}\right) - \left(\sum_p\sum_h\sum_e QHE_{phe}(1-p_h)FLE_e\right) \\
&-\left(\begin{array}{l}
\sum_p\sum_i RI_{pi}QI_{pi} + \sum_p\sum_w R_{pw}Q_{pw} + \\
\sum_p\sum_w\sum_h RW_{pwh}QW_{pwh} + \sum_p\sum_h\sum_e RHE_{phe}QHE_{phe} \\
+\sum_p\sum_h\sum_e RHE_{phc}QHE_{phe} + \sum_p\sum_w\sum_c RWC_{pwc}QWC_{pwc} + \\
\sum_p\sum_e\sum_c RE_{pec}QE_{pec} + \sum_p\sum_c\sum_r RC_{pcr}QC_{pcr} + \\
\sum_p\sum_c\sum_m C_{pcm}QCM_{pcm}
\end{array}\right) \\
&-\left(\begin{array}{l}
\sum_p\sum_w\sum_h OH_{ph}QW_{pwh}(1-p_h) + \sum_p\sum_h\sum_e OE_{pe}QHE_{phe} + \\
\sum_p\sum_w\sum_h\sum_e\sum_c OC_{pc}(QWC_{pwc} + QHE_{phc} + QE_{pec})
\end{array}\right) \geq Z_1^*
\end{aligned} \qquad (63)
$$

$$\sum_h\sum_e LE_{he}DHE_{he} \leq Z_2^* \qquad (64)$$

$$\sum_i QI_{pi} = \sum_w Q_{pw} \qquad \forall p \qquad (65)$$

$$\sum_p Q_{pw} \leq X_w CA_w \qquad \forall w \qquad (66)$$

$$Q_{pw} = \sum_h QW_{pwh} + \sum_c QWC_{pwc} \qquad \forall p, w \qquad (67)$$

$$\sum_w QW_{pwh} = D_{ph} \qquad \forall p, h \qquad (68)$$

$$\sum_w QW_{pwh}(1-p_h) = \sum_e QHE_{phe} \qquad \forall p, h \qquad (69)$$

$$\sum_p\sum_h QHE_{phe} \leq Y_e BIGM \qquad \forall e \qquad (70)$$

$$\sum_h QHE_{phe} = \sum_c QE_{pec} \qquad \forall p, e \qquad (71)$$

$$\sum_p\sum_e QE_{pec} + \sum_p\sum_h QHC_{phc} + \sum_p\sum_w QWC_{pwc} \leq Z_c CA_c'' \qquad \forall c \qquad (72)$$

$$\alpha\left(\left(\sum_h QHC_{phc}F_p\right)+\left(\sum_e QE_{pec}F_p\right)+\left(\sum_w QWC_{pwc}F_p\right)\right)+ \beta\left(\begin{array}{l}\left(\sum_h QHC_{phc}\left(1-F_p\right)\right)+\left(\sum_e QE_{pec}\left(1-F_p\right)\right)+\\ \left(\sum_w QWC_{pwc}\left(1-F_p\right)\right)\end{array}\right) = \sum_r QC_{pcr} \quad \forall p,c \tag{73}$$

$$\left(1-\alpha\right)\left(\left(\sum_h QHC_{phc}F_p\right)+\left(\sum_e QE_{pec}F_p\right)+\left(\sum_w QWC_{pwc}F_p\right)\right)+ \left(1-\beta\right)\left(\begin{array}{l}\left(\sum_h QHC_{phc}\left(1-F_p\right)\right)+\left(\sum_e QE_{pec}\left(1-F_p\right)\right)+\\ \left(\sum_w QWC_{pwc}\left(1-F_p\right)\right)\end{array}\right) = \sum_m QCM_{pcm} \quad \forall p,c \tag{74}$$

$$\sum_c QHC_{phc}P_h = \sum_w QW_{pwh}P_h \quad \forall h,p \tag{75}$$

$$Q_{pw}\gamma_p = \sum_c QWC_{pwc} \quad \forall p,w \tag{76}$$

$$DWH_{wh}X_w \le OW \quad \forall w,h \tag{77}$$

$$DHE_{he}(1-P_h)Y_e \le OE \quad \forall h,e \tag{78}$$

$$L_{he} = FA_{he} \quad \forall h,e \tag{79}$$

$$FA_{he} \ge \frac{\sum_p QHE_{phe}}{K} \quad \forall h,e \tag{80}$$

$$FA_{he} \le \left(\frac{\sum_p QHE_{phe}}{K}\right)+1-\xi \quad \forall h,e \tag{81}$$

$$QI_{pi}, Q_{pw}, QW_{pwh}, QHE_{phe}, QHC_{phc}, QWC_{pwc}, QE_{pec}, QC_{pcr} \in \text{INT} \tag{82}$$

$$X_w, Y_e, Z_c \in \text{Binary}$$

As is clear, the objective function of the problem is based on the second De Novo step. Constraints are included policy ones and primary objective functions. The amount of target functions should be better than the obtained value, otherwise equal. The problem will be solved by calculating r. It affects the capacity of the sterilization center only and has no effect on other variables and the objective function. As mentioned above, other variables of the problem cannot be tackled according to policy constraints. Therefore, with the sterilization center changes, the problem can be solved once again using multi-objective approaches and the final answer to the problem will be achieved.

In this section, first by definition of the assumptions and the general description of the problem, a schematic of the distribution network is displayed. The supply chain network of medical supplies is one of the crucial distribution networks and distribution of consumer supplies. The reverse network of this chain is undoubtedly more important. Nowadays, the wastes crisis is one of the essential concerns of the state. The high volume of medical wastes and, of course, its high contamination, caused the Ministry of Health to pay special attention to it and is trying to make a chance of this threat. Therefore, the design of the supply chain network of medical supplies can be a factor in order to make this happen.

5. Model Implementation and Numerical Results

5.1. Case study

The main purpose of this article is to design a chain of direct and reverse supply of consumer medical supplies of an infectious nature in order to minimize the risk of biological hazards caused by medical wastes at the lowest possible cost. Also, recycling of medical wastes will help to strengthen and, of course, improve the natural cycle of human life. According to the census of 1395, the population of Tehran is 8,693,706, and its area is about 574 square kilometers; Tehran is the 25th most populous city in the world. In District 4 of Tehran, a total of 5 hospitals and 12 clinics are considered. Hospitals of Lavasani, Al-Ghadir, Obstetrics and Gynecar Arash, Tehran pars and Ghamar Bani Hashem are equipped with the center of sterilization, and clinics of Imam Reza, Iran, Al-Mohammad, Musavi, 14 Ma'soom, Nabovvat, Isar, Shahed, Narmak, Shaghayegh, Vafadar and Shemiranno are lack of sterilization center.

In this study, three medical supplies that are infectious after consumption are studied. Dressing set, peripheral venous catheter (pvc), and latex gloves are the products that have been evaluated in this model. The suppliers of these supplies, which are contracting with the distribution center, are located in Tehran. The proposed warehouses for construction in District 4 of Tehran are located in Narmak, al-Ghadir Square.

As stated, the distribution center has the responsibility to sterilize the medical supplies consumed by the clinics, which can be implemented by contract with the hospital sterilization center or through the construction of the sterilization center. To this end, there are three proposed sites for its activation, Hakimiyeh, the first square of Tehran pars and al-Ghadir square. In the case of collecting centers, the location of the construction site should also be considered. Therefore, the places of Al-Ghadir square and the second square of Tehran Pars are considered. As stated in the model, there are also centers for recycling and destruction in this area.

A brief description of the warehouses, the sterilization center, the hospital, the collection center, the recycling and disposal center is given in Figure 2. As previously mentioned, this research has been conducted in District 4 of Tehran.

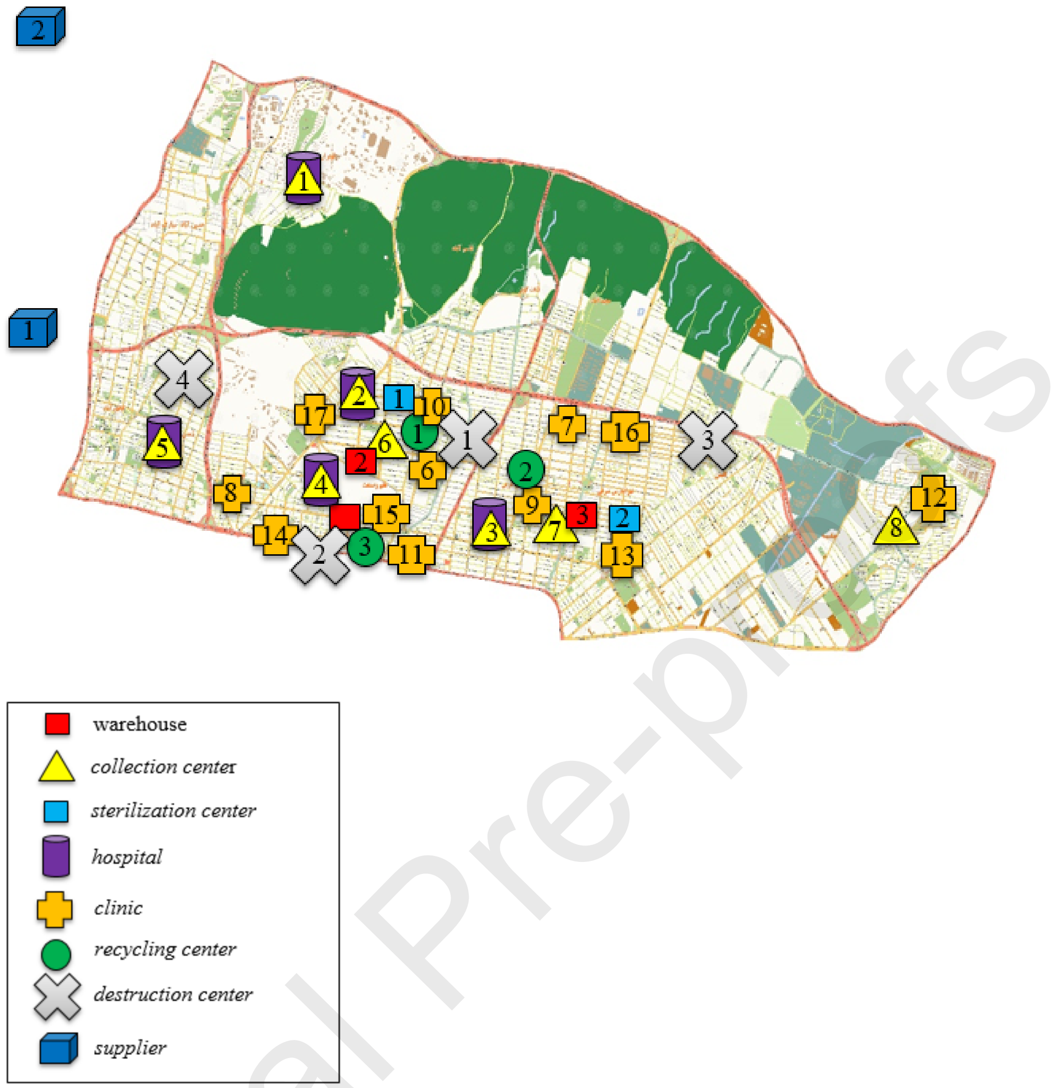

Fig 2. A schematic view of the facilities in the case study

It should be noted that in addition to potential sterilization centers, the hospital sterilization center with a sterilization center can also be contracted. According to the explanation, a number of candidate points for the construction of the warehouse, the center of sterilization and the collection center, from different districts of the 4th district of Tehran, because of the closest approach to hospitals and, of course, the conditions for the construction of these centers, are selected for potential points. Candidate points for the construction of centers of warehouses, sterilization and collections are described in the table below. (Table 1-3)

As mentioned above, in addition to the above-mentioned sterilization centers that are potentially considered by the distribution center, five hospitals with a sterilization center are also considered as sterilization centers for other clinics lacking this center. The suppliers of this distribution center are located in Tehran, but they are not present in District 4 of Tehran, therefore, they were shown in the outer part of the map of 4th district. One of the warehouse tasks is to classify products and prepare packages. Each 20 sets of dressing, 30 latex gloves and every 200 syringes are individually packed. The vehicle can accommodate up to 20 packages. The input parameters of the problem are referred to below.

Table 1. Capacity and activation cost of warehouses

	Warehouse 1	Warehouse 2	Warehouse 3
Capacity	2000	2000	3000
Activation cost	130	190	206

Table 2. Capacity and activation cost of sterilization centers

sterilization center name	Center number	Capacity	Contract cost per each medical waste	Activation cost
Lavasani hospital	1	100	0.5	0
Al-Ghadir hospital	2	700	0.5	0
Arash hospital	3	500	0.5	0
Tehranpars hospital	4	500	0.5	0
Ghamar bani hospital	5	100	0.5	0
Al-Ghadir	6	500	0	4860
Tehranpars	7	500	0	3600
Hakimieh	8	500	0	3500

Table 3. Capacity and activation cost of collecting centers

collection center	Capacity	Activation cost
collection center 1	3000	300
collection center 2	2000	200

The distribution center should pay its initial costs to setup the warehouse, the sterilization center and the collection center. What costs are involved in activating them is not just for the same single period that the model is planning. For this purpose, all initial costs of the above mentioned centers, which include land purchase, equipment, licensing, etc., are converted into a one-month period using the equal payment Series. Its relation is as follows:
A=P(A/P, i ,n)

The capacity of the simple and special transportation car is 20 cartons. As previously stated, the dimensions of each carton are constant, and in each carton can be 20 sets of dressing, 30 packets of latex gloves and 200 syringe packages individually. According to the opinion of the decision maker, 70% of the sharp medical wastes and 60% of non-sharp medical waste can be sent to the recycling center. Also, 1% of all three types of medical products in the warehouse are sent directly to collection centers for defective or corrupted reasons. The cost of transporting the means of transport in the chain of supply is further discussed.

5.2. Computational results

In this chapter, the deterministic model of the supply chain network of medical supplies is presented, considering the effective parameters of the problem and solved by one of the problem solving methods in GAMS software. Although each objective function was performed separately in the GAMS software, but due to the multi-objective nature of the problem, in order to simultaneously investigate all objective functions, this was achieved by one of the techniques of research in the operation. This is achieved by using LP methods and Bounded De Novo Programming methods. Furthermore, the effective performance of the model has been studied by explaining the details of the case study.

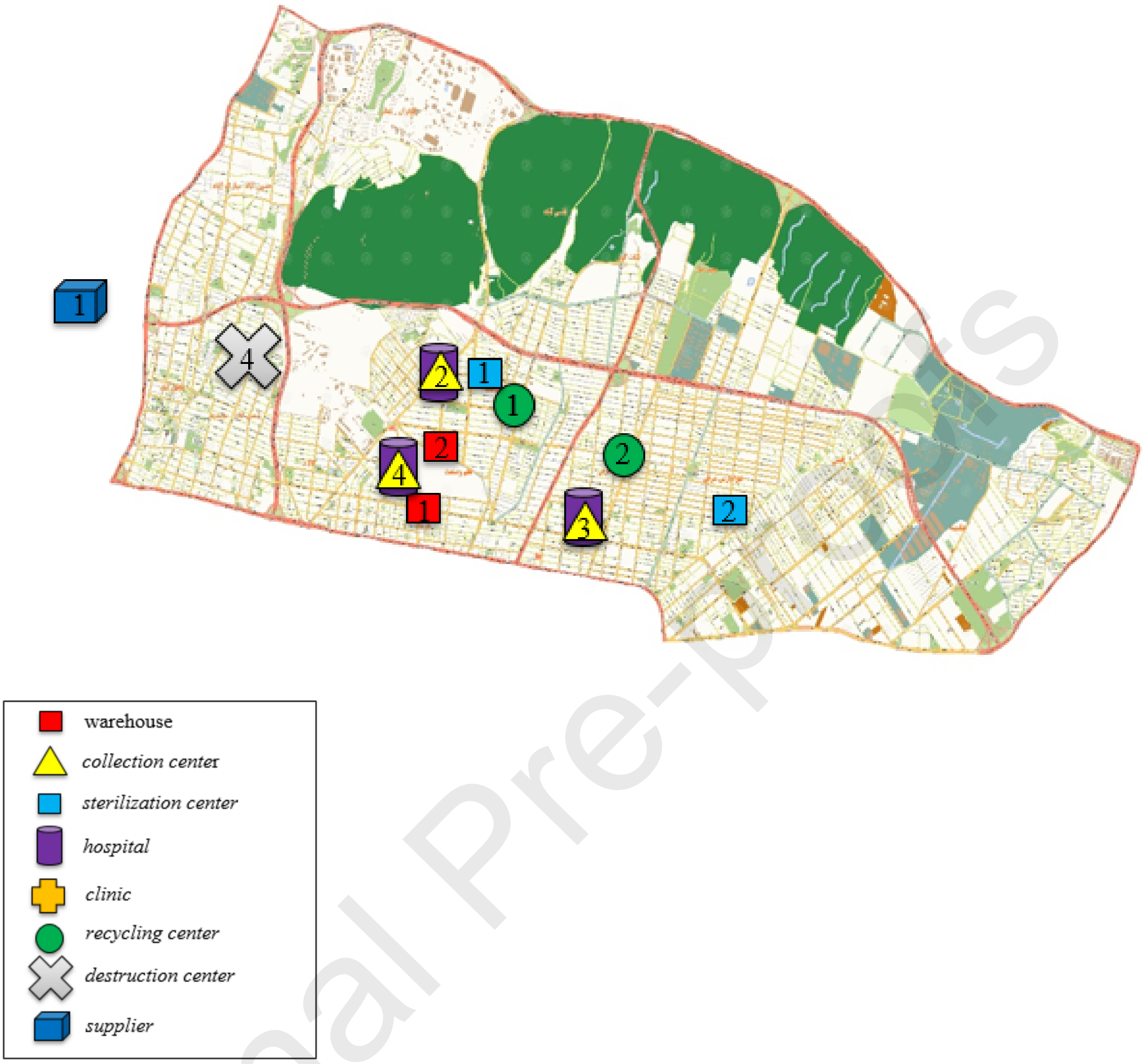

Fig3. A general view of the result of solving problem

As outlined in Figure 3, from the three candidates for the warehouse only two of them have been activated. These warehouses are in Al-Ghadir and Tehran pars. In the case of the sterilization centers, three hospital sterilization centers, Al-Ghadir, Arash and Tehran pares have been activated, and there is no need to activate the candidate's sterilization centers by the distribution center. It is noteworthy that the activated hospital sterilization centers, meaning that hospitals have a capacity for the medical waste of other clinics lacking a sterilization center that can use it for the purpose of sterilizing medical waste at the cost of a contract with the distribution center. Among the centers for collecting candidates, both centers have been activated for service delivery. These centers are also located in Al-Ghadir and Tehran pars Square. It is clear that hospitals and clinics in district 4 are stable, and in the above figure, only activated potential centers are demonstrated. The results of the variables are presented in the following tables. Table 4-12 show the results of the amount of transmission on the supply chain network.

Table 4. Frequency of moving vehicles from the hospital to the sterilization center

Supplier / product	1	2	3	4	5	6	7	8
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	9	0	0	0	0	0	0
7	0	0	0	8	0	0	0	0
8	0	8	0	0	0	0	0	0
9	0	0	5	3	0	0	0	0
10	0	8	0	0	0	0	0	0
11	0	0	0	8	0	0	0	0
12	0	0	0	8	0	0	0	0
13	0	0	9	0	0	0	0	0
14	0	9	0	0	0	0	0	0
15	0	0	8	0	0	0	0	0
16	0	0	0	8	0	0	0	0
17	0	8	0	0	0	0	0	0

Table 5. The amount of goods received from each supplier

Supplier / product	1	2
1	1487	0
2	1387	0
3	300	0

Table 6. The amount of transfer of each product to the warehouse

Warehouse / product	1	2	3
1	898	589	0
2	1387	0	0
3	275	25	0

Table 7. The amount of transfer of medical products from warehouse to hospital

Hospital	product	1	2	3	1	2	3	1	2	3
	Warehouse	1			2			3		
1		0	0	15	71	60	0	0	0	0
2		0	0	0	200	217	24	0	0	0
3		0	0	15	125	104	0	0	0	0
4		0	0	14	150	134	0	0	0	0
5		39	0	16	37	67	0	0	0	0
6		75	0	18	0	70	0	0	0	0
7		73	0	18	0	64	0	0	0	0
8		77	0	17	0	64	0	0	0	0
9		71	0	19	0	63	0	0	0	0
10		72	0	17	0	69	0	0	0	0
11		65	0	16	0	68	0	0	0	0
12		69	0	16	0	61	0	0	0	0
13		78	0	18	0	69	0	0	0	0
14		80	0	17	0	69	0	0	0	0
15		62	0	18	0	64	0	0	0	0
16		68	0	19	0	67	0	0	0	0
17		60	0	20	0	63	0	0	0	0

Table 8. The amount of medical products transported from the warehouse to the collection center

collection		1	2
product	**warehouse**		
1	**1**	9	0
2		0	0
3		2	0
1	**2**	6	0
2		14	0
3		1	0
1	**3**	0	0
2		0	0
3		0	0

Table 9. The amount of medical waste transferred from hospital to sterilization center

sterilization		1	2	3	4	5	6	7	8
waste	**Hospital**								
1	**6**	0	75	0	0	0	0	0	0
2		0	70	0	0	0	0	0	0
3		0	18	0	0	0	0	0	0
1	**7**	0	0	0	73	0	0	0	0
2		0	0	0	64	0	0	0	0
3		0	0	0	18	0	0	0	0
1	**8**	0	77	0	0	0	0	0	0
2		0	64	0	0	0	0	0	0
3		0	17	0	0	0	0	0	0
1	**9**	0	0	71	0	0	0	0	0
2		0	0	3	60	0	0	0	0
3		0	0	19	0	0	0	0	0
1	**10**	0	72	0	0	0	0	0	0
2		0	69	0	0	0	0	0	0
3		0	17	0	0	0	0	0	0
1	**11**	0	0	0	65	0	0	0	0
2		0	0	0	68	0	0	0	0
3		0	0	0	16	0	0	0	0
1	**12**	0	0	0	69	0	0	0	0
2		0	0	0	61	0	0	0	0
3		0	0	0	16	0	0	0	0
1	**13**	0	0	78	0	0	0	0	0
2		0	0	69	0	0	0	0	0
3		0	0	18	0	0	0	0	0
1	**14**	0	80	0	0	0	0	0	0
2		0	69	0	0	0	0	0	0
3		0	17	0	0	0	0	0	0
1	**15**	0	0	62	0	0	0	0	0
2		0	0	64	0	0	0	0	0
3		0	0	18	0	0	0	0	0
1	**16**	0	0	0	68	0	0	0	0
2		0	0	0	67	0	0	0	0
3		0	0	0	19	0	0	0	0
1	**17**	0	60	0	0	0	0	0	0
2		0	63	0	0	0	0	0	0
3		0	20	0	0	0	0	0	0

Table 10. The amount of medical waste transferred from the sterilization to the collection center

collection		1	2
waste	**sterilization**		
1	1	0	0
2		0	0
3		0	0
1	2	364	0
2		335	0
3		89	0
1	3	0	211
2		136	0
3		0	55
1	4	0	275
2		320	0
3		0	69
1	5	0	0
2		0	0
3		0	0
1	6	0	0
2		0	0
3		0	0
1	7	0	0
2		0	0
3		0	0
1	8	0	0
2		0	0
3		0	0

Table 11. The amount of medical waste transferred from the collection to the recycling center

recycling		1	2	3
product	**collection**			
1	1	393	0	0
2		380	0	0
3		93	0	0
1	2	0	500	0
2		0	453	0
3		0	118	0

Table 12. The amount of medical waste transferred from the collection to the destruction center

recycling		1	2	3	4
product	**collection**				
1	1	0	0	0	262
2		0	0	0	254
3		0	0	0	40
1	2	0	0	0	333
2		0	0	0	302
3		0	0	0	51

After the implementation of the model, using the De Novo method, the optimal allocation of funds to increase the capacity of the sterilization center was 3708 units ($B^* = 3708$). This means that the allocation of more than 3708 units is a surplus charge for the distribution center and will not have any effect on the improvement of the target functions. On the other hand, due to the equation $r = \frac{B}{B^*}$ the amount of changes in capacity, it is calculated. (r = 1.8878)

In De Novo programming, the current capacity of the sterilization centers that were activated should increase by a factor of r. In the solution of the problem with this method, the sterilization centers of 2, 3, 4, 6, 7 were activated. In other words, three centers of sterilization from hospitals and two centers of sterilization were nominated by the distribution center were activated. Therefore, the capacity of these centers will be multiplied by r. After changing the capacity and taking into account the cost of B^* in the target function in order to implement this capacity change, the problem will again be solved by the LP-metric method. The optimal values of target functions are also given in Table 13.

Table 13. The optimal values of target functions

Objective	Goal	LP metric Optimum	Bounded De Novo Optimum
First	32414.76	30577.47	32045.3
Second	222.1	235.4	225.6

It can be seen in Table 13 that, by increasing the budget of 3708 units to equip the sterilization centers, how much the profitability of the distribution center will increase. This amount is obtained through the De Novo programming.

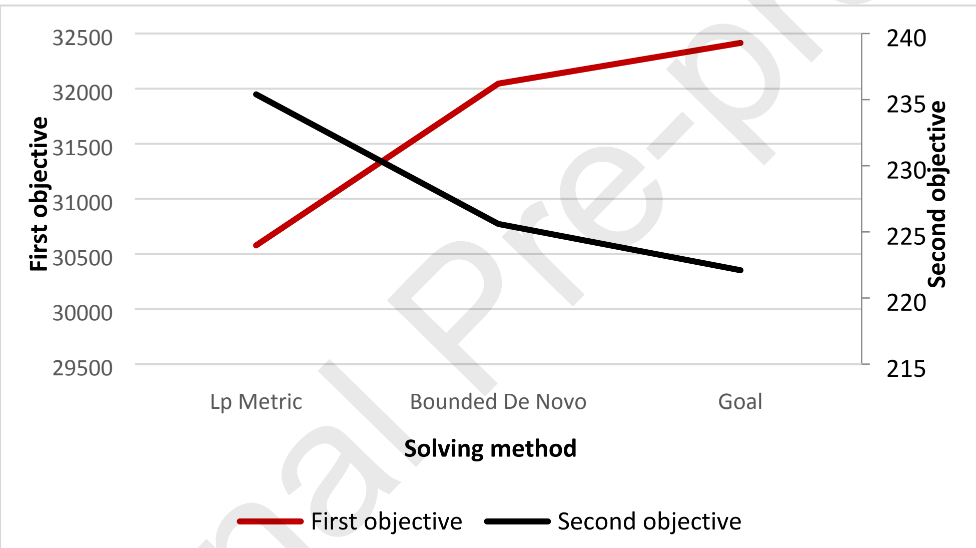

Fig4. The amount of the first objective function using solving methods

As shown in Figure 4, in the first objective function that the maximization of profit, the De Novo programming approach has a very close response to the goal. On the other hand, the second objective function, which tries to reduce biological risks, De Novo programming is so better than the LP metric.

5.3. Sensitivity analyses

In this section, we review and analyze the solutions that have been produced for the proposed model. First, Figure 5 shows the conflict between the objectives of the problem. Thus, by increasing the first objective function, the second objective function, which is minimization, is increasing. Also by reducing the second objective function, the first objective function is reduced.

As stated in the issue, the alpha and beta coefficients are determined by the decision maker. Figure 6 shows that increasing or decreasing the coefficients, how much profit or loss can be transferred to the company. Figure 7 also shows the effect of the gamma value. The lower the defective products sent from the warehouse to the collection center, the profitability of the distribution center increases.

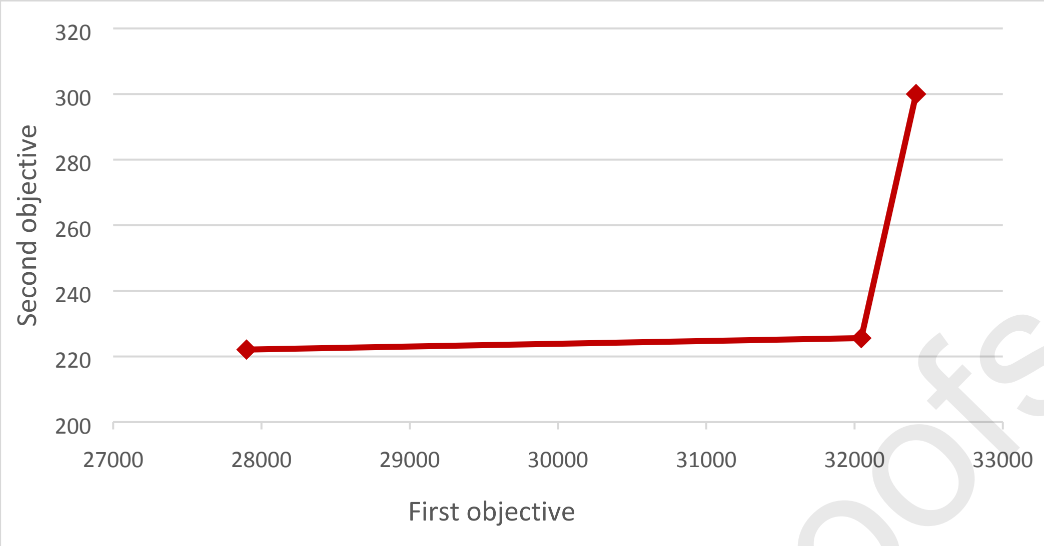

Fig 5. Pareto optimal answer

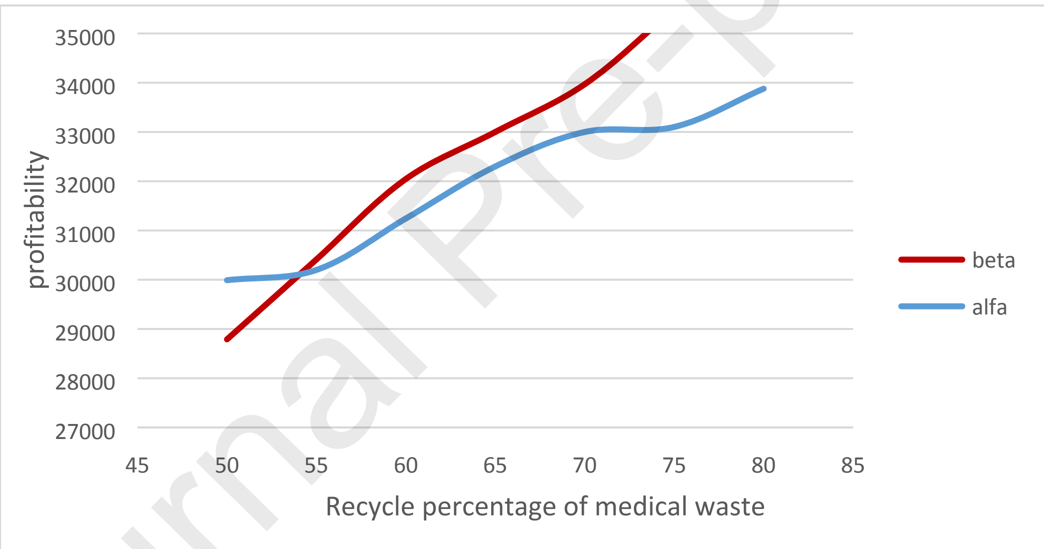

Fig6. The effect of the Alfa and Beta value on profit

Fig7. The effect of the gamma value on profit

Earlier, the amount of the second objective function, which reduces biological hazards, is 225.6 km. From the final model's solution, it has been observed that sterilization centers were developed in 3 hospitals from distribution center to serve. In this regard, if one of the above centers is unable to serve the predetermined causes, the second objective function will suffer the changes that are shown in Figure 8. In other words, Figure 8 indicates that the second objective function will change if the sterilization center does not receive the risk of medical waste from the beginning because risk of pollution does not reject the risk of medical wastes. Of course, if any of the two sterilization centers become disable at the same time, the solution is infeasible.

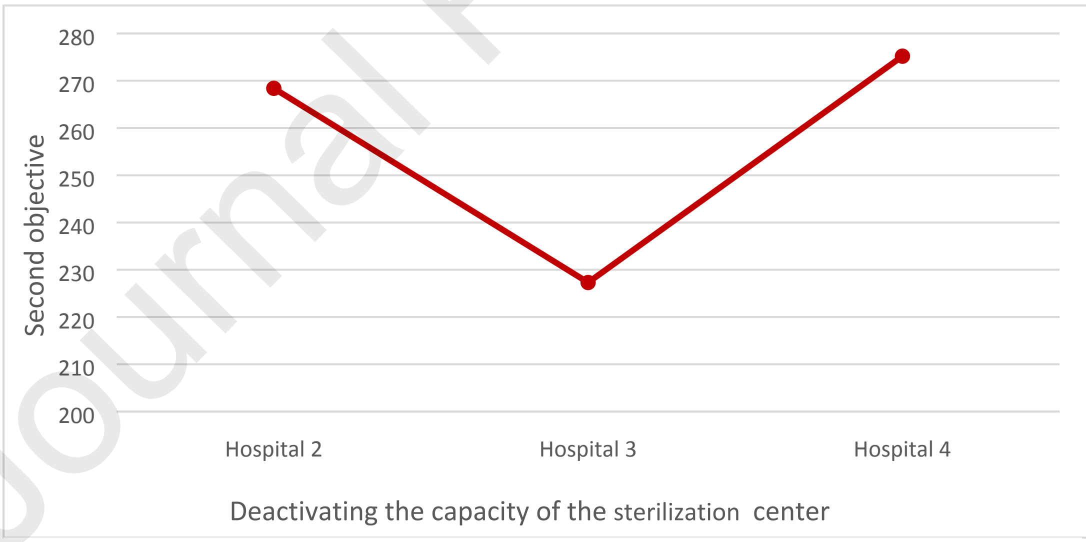

Fig 8. Variations of the second objective function in the deactivated capacity of the sterilization centers

According to the sensitivity analyses section, cases such as the percentage of medical waste that send to the recycling center, the rate of defective goods produced from suppliers, and the capacity of sterilization from hospitals could have a significant effect on the model. In this chapter, we have seen how close the solution, Bounded De Novo programming, is close to the goals.

5.4. Managerial implications

There are many reasons for not entering investors in the industry of developing countries today. The risk of investments in projects that have not been implemented so far is much more than the actual extent itself. The health industry is one of the most efficient industries that use a lot of people daily. The present study, based on a case study in district 4 of Tehran, shows that the supply chain network, in addition to profitability, improves health performance. According to information obtained from hospitals in Tehran, a substantial number of people receive disease through hospital waste, and sometimes it is irrecoverable. Therefore, the supply chain network, in addition to the economic dimension coverage, is trying to minimize the biological risks caused by medical waste. On the other hand, what makes this network more attractive is the recycling of medical waste, which has already destroyed directly.

Managerial implications section can cause to increase managers desirous for reading papers. Managers want to know about the details of the problem without reading mathematical models in order to make the best decision for their company. As is evident, the noticeable numbers of goods in the warehouse defected. It can cause raising the total cost of the first objective. In other words, if the rate of defective supplies decreases from 3 to 1 percent, the profitability increasing by about 3.4 percent. Moreover, as the results have shown, if the quantity of sharp medical waste that sends to the recycling center increase from 70% to 80%, the profitability will raise approximately 2.6%, and if decrease from 70% to 60%, the first objective will diminish about 5.6%. Furthermore, increasing 70 percent to 80 percent rate of non-sharp medical waste that transfers to the recycling center can cause to increasing 8.9% of the profitability. On the other hand, if the rate of that decreasing from 70% to 60%, the profitability decreasing 6 percent. As shown in the sensitivity analyses section, when hospitals do not wish to receive medical waste from clinics, the biological risk will increase. Thus, the establishment of a sterilization center necessarily cannot improve the goals, and in order to minimize risks, it is better to use the best situations.

6. Conclusion

Supply chain network design is one of the essential problems in industries that require long-term and short-term decisions such as location, allocation, transportation, and inventory. In this article, forward and reverse network modeling of medical consumption supplies has been presented concerning biological risks. It is a multi-echelon problem in the forward network including warehouse, distributor, hospital and clinic. The reverse network involves sterilization, collection, recycling and destruction center. The proposed model is defined based on the problem of the Tehran health network. The proposed model is multi-objective; the first objective is to maximize profit. In other words, it tries to reduce the total cost of distribution, transportation, operation, and so on. The second objective is to minimize biological risks. The transfer of medical wastes from the clinic to the sterilization center is the highest base of biological hazards. Thus, the distance between the receipt of infectious wastes from the clinics and its delivery to the sterilization center is assumed the most serious cause of biological hazards. The contracts that the distribution center has established with hospitals have reduced the biological risk transmission of infectious waste. Medical wastes are divided into two categories: sharp and non-sharp. In the present era, it needs to be improved before it needs improvement. Hence, De Novo Programming is to redesign the resources. In this research, there are two constraints: resources and policy. Thus, De Novo programming cannot be used in this problem. The De Novo Programming method does not have political performance constraints and is limited only to rare resources. The problem model includes limitations of storage capacity, sterilization center and collection center. In this regard, there is no problem for storage capacity and collection center, and the majority of restrictions are on the capacity of sterilization centers. Therefore, Bounded De Novo programming has been taken from De Novo that Zeleny presented in 1986. In this approach, the rare sources of the problem have been redesigned. The optimal problem response from the De Novo programming is very close to the ideal answer. Owing to policy constraints, the optimal answer cannot be close to the ideal answer more than the bounded De Novo answer. The allocation of budget to the resources for redesign leads to the best possible solution. Rates reduction of defective goods and raising the quantity of medical waste that transferred to recycling centers can affect profitability. A decrease or increase of sterilization capacity for hospitals can affect the second goal in addition to the first objective function. This study showed that, according to the Bounded De Novo programming approach, paying 3708 units can increase the capacity of sterilization centers from hospitals in order to the answers closer to goals. The health network of District 4 in Tehran is studied in this research.

One of the study suggestions is to investigate the strategic and tactical decisions of the supply chain network in addition to decisions related to biological risk. The scheduling of vehicles from the clinic to the sterilization center is highly critical. In the multi-period case, the transfer of medical waste plays a crucial role. Therefore, the duration of medical wastes in the hospital is a factor of biological risks. The present study aimed to develop a model to design and improve the supply chain with short-term planning. However, concerning the significant instability of various factors in the real world, it is advisable to study market status and competitors, improve the market situation and its performance, such as using updated technology and enhancing production and recycling products.

References

Ageron, B., Benzidia, S., & Bourlakis, M. (2018). Healthcare logistics and supply chain–issues and future challenges. In Supply Chain Forum: An International Journal (Vol. 19, No. 1, pp. 1-3). Taylor & Francis.

Ahmadimanesh, F., Paydar, M. M., & Asadi-Gangraj, E. (2019). Designing a mathematical model for dental tourism supply chain. Tourism Management, 75, 404-417.

Awasthi, A., & Omrani, H. (2019). A goal-oriented approach based on fuzzy axiomatic design for sustainable mobility project selection. International Journal of Systems Science: Operations & Logistics, 6(1), 86-98.

Aydemir-Karadag, A. (2018). A profit-oriented mathematical model for hazardous waste locating-routing problem. Journal of Cleaner Production, 202, 213-225.

Birchard, K. (2002). Out of sight, out of mind… the medical waste problem. The lancet, 359(9300), 56.

De Vries, J., & Huijsman, R. (2011). Supply chain management in health services: an overview. Supply Chain Management: An International Journal, 16(3), 159-165.

Dobrzykowski, D., Deilami, V. S., Hong, P., & Kim, S. C. (2014). A structured analysis of operations and supply chain management research in healthcare (1982–2011). International Journal of Production Economics, 147, 514-530.

Duan, C., Deng, C., Gharaei, A., Wu, J., & Wang, B. (2018). Selective maintenance scheduling under stochastic maintenance quality with multiple maintenance actions. International Journal of Production Research, 56(23), 7160-7178.

Dubey, R., Gunasekaran, A., Sushil, & Singh, T. (2015). Building theory of sustainable manufacturing using total interpretive structural modelling. International Journal of Systems Science: Operations & Logistics, 2(4), 231-247.

Gabriel, C. A., Bortsie-Aryee, N. A., Apparicio-Farrell, N., & Farrell, E. (2018). How supply chain choices affect the life cycle impacts of medical products. Journal of cleaner production, 182, 1095-1106.

Ghadimi, P., Wang, C., & Lim, M. K. (2019). Sustainable supply chain modeling and analysis: Past debate, present problems and future challenges. Resources, Conservation and Recycling, 140, 72-84.

Ghadimi, P., Wang, C., Azadnia, A. H., Lim, M. K., & Sutherland, J. W. (2019). Life cycle-based environmental performance indicator for the coal-to-energy supply chain: A Chinese case application. Resources, Conservation and Recycling, 147, 28-38.

Gharaei, A., Hoseini Shekarabi, S. A., & Karimi, M. (2019). Modelling and optimal lot-sizing of the replenishments in constrained, multi-product and bi-objective EPQ models with defective products: Generalised Cross Decomposition. International Journal of Systems Science: Operations & Logistics, 1-13.

Gharaei, A., Karimi, M., & Hoseini Shekarabi, S. A. (2019). Joint economic lot-sizing in multi-product multi-level integrated supply chains: generalized benders decomposition. International Journal of Systems Science: Operations & Logistics, 1-17.

Gharaei, A., Karimi, M., & Shekarabi, S. A. H. (2019). An integrated multi-product, multi-buyer supply chain under penalty, green, and quality control polices and a vendor managed inventory with consignment stock agreement: The outer approximation with equality relaxation and augmented penalty algorithm. Applied Mathematical Modelling, 69, 223-254.

Giri, B. C., & Bardhan, S. (2014). Coordinating a supply chain with backup supplier through buyback contract under supply disruption and uncertain demand. International Journal of Systems Science: Operations & Logistics, 1(4), 193-204.

Giri, B. C., & Masanta, M. (2018). Developing a closed-loop supply chain model with price and quality dependent demand and learning in production in a stochastic environment. International Journal of Systems Science: Operations & Logistics, 1-17.

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. European Journal of Operational Research, 240(3), 603-626.

Guo, H., Li, C., Zhang, Y., Zhang, C., & Lu, M. (2018). A location-inventory problem in a closed-loop supply chain with secondary market consideration. Sustainability, 10(6), 1891.

Guo, J., He, L., & Gen, M. (2019). Optimal strategies for the closed-loop supply chain with the consideration of supply disruption and subsidy policy. Computers & Industrial Engineering, 128, 886-893.

Hao, Y., Helo, P., & Shamsuzzoha, A. (2018). Virtual factory system design and implementation: integrated sustainable manufacturing. International Journal of Systems Science: Operations & Logistics, 5(2), 116-132.

Hoseini Shekarabi, S. A., Gharaei, A., & Karimi, M. (2019). Modelling and optimal lot-sizing of integrated multi-level multi-wholesaler supply chains under the shortage and limited warehouse space: generalised outer approximation. International Journal of Systems Science: Operations & Logistics, 6(3), 237-257.

Hsu, P. F., Wu, C. R., & Li, Y. T. (2008). Selection of infectious medical waste disposal firms by using the analytic hierarchy process and sensitivity analysis. Waste Management, 28(8), 1386-1394.

Ishtiaq, P., Khan, S. A., & Haq, M. U. (2018). A multi-criteria decision-making approach to rank supplier selection criteria for hospital waste management: A case from Pakistan. Waste Management & Research, 36(4), 386-394.

Jabbarzadeh, A., Haughton, M., & Khosrojerdi, A. (2018). Closed-loop supply chain network design under disruption risks: A robust approach with real world application. Computers & Industrial Engineering, 116, 178-191.

Jabbarzadeh, A., Fahimnia, B., & Sabouhi, F. (2018). Resilient and sustainable supply chain design: sustainability analysis under disruption risks. International Journal of Production Research, 56(17), 5945-5968.

Kazemi, N., Abdul-Rashid, S. H., Ghazilla, R. A. R., Shekarian, E., & Zanoni, S. (2018). Economic order quantity models for items with imperfect quality and emission considerations. International Journal of Systems Science: Operations & Logistics, 5(2), 99-115.

Kim, J., Do Chung, B., Kang, Y., & Jeong, B. (2018). Robust optimization model for closed-loop supply chain planning under reverse logistics flow and demand uncertainty. Journal of Cleaner Production

Kochan, C. G., Nowicki, D. R., Sauser, B., & Randall, W. S. (2018). Impact of cloud-based information sharing on hospital supply chain performance: A system dynamics framework. International Journal of Production Economics, 195, 168-185.

Kurian, J. (2018). A Study on the Green Supply Chain Management Practices and Their Influence in the Environmental Performance of the Firm: With Reference to Indian Pharmaceutical Industry. OIDA International Journal of Sustainable Development, 11(11), 59-78.

Le, A. B., Hoboy, S., Germain, A., Miller, H., Thompson, R., Herstein, J. J., ... & Lowe, J. J. (2018). A pilot survey of the US medical waste industry to determine training needs for safely handling highly infectious waste. American journal of infection control, 46(2), 133-138.

Le, A. B., Buehler, S. A., Maniscalco, P. M., Lane, P., Rupp, L. E., Ernest, E., ... & Beam, E. L. (2018). Determining training and education needs pertaining to highly infectious disease preparedness and response: A gap analysis survey of US emergency medical services practitioners. American journal of infection control, 46(3), 246-252.

Lee, B. K., Ellenbecker, M. J., & Moure-Eraso, R. (2002). Analyses of the recycling potential of medical plastic wastes. Waste management, 22(5), 461-470.

Lee, B. K., Ellenbecker, M. J., & Moure-Ersaso, R. (2004). Alternatives for treatment and disposal cost reduction of regulated medical wastes. Waste management, 24(2), 143-151.

Liberti, L., Tursi, A., Costantino, N., Ferrara, L., & Nuzzo, G. (1996). Optimization of infectious hospital waste management in Italy: Part II. Waste characterization by origin. Waste management & research, 14(5), 417-431.

Makui, A., Ghousi, R., & Zhalefruzan, S. (2018). A multi objective model for maximizing immunogenicity level of vaccination while minimizing cost and extra-immunization. Journal of Mathematical Modeling, 6(2), 1-16.

Malmir, B., Dehghani, S., Jahantigh, F. F., & Najjartabar, M. (2016, June). A new model for supply chain quality management of hospital medical equipment through game theory. In Proceedings

of the 6th International Conference on Information Systems, Logistics and Supply Chain, ILS 2016.
Mantzaras, G., & Voudrias, E. A. (2017). An optimization model for collection, haul, transfer, treatment and disposal of infectious medical waste: Application to a Greek region. Waste Management, 69, 518-534.
Mato, R. R. A. M., & Kaseva, M. E. (1999). Critical review of industrial and medical waste practices in Dar es Salaam City. Resources, Conservation and Recycling, 25(3-4), 271-287.
Mazzocato, P., Savage, C., Brommels, M., Aronsson, H., & Thor, J. (2010). Lean thinking in healthcare: a realist review of the literature. BMJ Quality & Safety, 19(5), 376-382.
Mokhtar, A. R. M., Genovese, A., Brint, A., & Kumar, N. (2019). Improving reverse supply chain performance: The role of supply chain leadership and governance mechanisms. Journal of Cleaner Production.
Moktadir, M. A., Ali, S. M., Mangla, S. K., Sharmy, T. A., Luthra, S., Mishra, N., & Garza-Reyes, J. A. (2018). Decision modeling of risks in pharmaceutical supply chains. Industrial Management & Data Systems, 118(7), 1388-1412.
Özceylan, E., Demirel, N., Çetinkaya, C., & Demirel, E. (2017). A closed-loop supply chain network design for automotive industry in Turkey. Computers & industrial engineering, 113, 727-745.
Pishvaee, M. S., & Razmi, J. (2012). Environmental supply chain network design using multi-objective fuzzy mathematical programming. Applied Mathematical Modelling, 36(8), 3433-3446.
Pishvaee, M. S., Razmi, J., & Torabi, S. A. (2014). An accelerated Benders decomposition algorithm for sustainable supply chain network design under uncertainty: A case study of medical needle and syringe supply chain. Transportation Research Part E: Logistics and Transportation Review, 67, 14-38.
Privett, N., & Gonsalvez, D. (2014). The top ten global health supply chain issues: perspectives from the field. Operations Research for Health Care, 3(4), 226-230.
Rabbani, M., Hosseini-Mokhallesun, S. A. A., Ordibazar, A. H., & Farrokhi-Asl, H. (2018). A hybrid robust possibilistic approach for a sustainable supply chain location-allocation network design. International Journal of Systems Science: Operations & Logistics, 1-16.
Rabbani, M., Foroozesh, N., Mousavi, S. M., & Farrokhi-Asl, H. (2019). Sustainable supplier selection by a new decision model based on interval-valued fuzzy sets and possibilistic statistical reference point systems under uncertainty. International Journal of Systems Science: Operations & Logistics, 6(2), 162-178.
Rahimi, M., & Fazlollahtabar, H. (2018). Optimization of a Closed Loop Green Supply Chain using Particle Swarm and Genetic Algorithms. Jordan Journal of Mechanical & Industrial Engineering, 12(2).
Rajendran, S., & Ravindran, A. R. (2019). Inventory Management of Platelets along Blood Supply Chain to Minimize Wastage and Shortage. Computers & Industrial Engineering.
Sabouhi, F., Pishvaee, M. S., & Jabalameli, M. S. (2018). Resilient supply chain design under operational and disruption risks considering quantity discount: A case study of pharmaceutical supply chain. Computers & Industrial Engineering, 126, 657-672
Saragih, N. I., Bahagia, N., & Syabri, I. (2019). A heuristic method for location-inventory-routing problem in a three-echelon supply chain system. Computers & Industrial Engineering, 127, 875-886.
Sarkar, S., & Giri, B. C. (2018). Stochastic supply chain model with imperfect production and controllable defective rate. International Journal of Systems Science: Operations & Logistics, 1-14.
Sayyadi, R., & Awasthi, A. (2018). A simulation-based optimisation approach for identifying key determinants for sustainable transportation planning. International Journal of Systems Science: Operations & Logistics, 5(2), 161-174.
Sayyadi, R., & Awasthi, A. (2018). An integrated approach based on system dynamics and ANP for evaluating sustainable transportation policies. International Journal of Systems Science: Operations & Logistics, 1-10.

Sazvar, Z., Mirzapour Al-e-Hashem, S. M. J., Baboli, A., & Jokar, M. A. (2014). A bi-objective stochastic programming model for a centralized green supply chain with deteriorating products. International Journal of Production Economics, 150, 140-154.
Shah, N. H., Chaudhari, U., & Cárdenas-Barrón, L. E. (2018). Integrating credit and replenishment policies for deteriorating items under quadratic demand in a three echelon supply chain. International Journal of Systems Science: Operations & Logistics, 1-12.
Shi, L. H. (2009, September). A mixed integer linear programming for medical waste reverse logistics network design. In 2009 International Conference on Management Science and Engineering (pp. 1971-1975). IEEE.
Solberg, K. E. (2009). Trade in medical waste causes deaths in India. The Lancet, 373(9669), 1067.
Tsao, Y. C. (2015). Design of a carbon-efficient supply-chain network under trade credits. International Journal of Systems Science: Operations & Logistics, 2(3), 177-186.
Volland, J., Fügener, A., Schoenfelder, J., & Brunner, J. O. (2017). Material logistics in hospitals: a literature review. Omega, 69, 82-101.
Yin, S., Nishi, T., & Zhang, G. (2016). A game theoretic model for coordination of single manufacturer and multiple suppliers with quality variations under uncertain demands. International Journal of Systems Science: Operations & Logistics, 3(2), 79-91.
Weraikat, D., Zanjani, M. K., & Lehoux, N. (2016). Coordinating a green reverse supply chain in pharmaceutical sector by negotiation. Computers & Industrial Engineering, 93, 67-77.
Zeleny, M. (1986). Optimal system design with multiple criteria: De Novo programming approach. Engineering costs and production economics, 10(1), 89-94.

Highlights

Forward and reverse supply chain network design for consumer medical supplies considering biological risk

1) Considering the biological risks in designing medical supply chain network
2) Biological hazardous is generated between the clinics and sterilization centers
3) The mathematical model locates the warehouse, sterilization, and collection center
4) Modifying the De Novo programming method to the Bounded De Novo Programming

Forward and reverse supply chain network design for consumer medical supplies considering biological risk

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