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Providing an Integrated Multi-Objective Model for Closed-Loop Supply Chain under Fuzzy Conditions with Upgral Approach

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Abstract

This study was conducted aimed at providing a sustainable multi-objective model of supply chain location, inventory, routing under uncertainty with a passive defense approach, in which the Upgral model was first introduced to the world. The Upgral Paradigm is an integrated model for the location-inventory-routing problem in a four-level supply chain where parameters such as demand, facility cost and inventory costs are taken into account uncertain as triangular fuzzy numbers (TFNs). In this study, the characteristics and capabilities of passive defense in the supply chain, such as "logistical flow rate", "backup path security", "the possibility of resource and equipment deployment", and the dispersion principle were considered for location to increase the resilience of supply chain. The model was solved using Whale Optimization Algorithm (WOA) and NSGA-II meta-heuristic algorithm. First, a four-objective mathematical model was proposed for the problem the objectives of which were: 1) minimizing supply chain costs; 2) maximizing social responsibility or social benefits; 3) minimizing environmental impacts; and 4) minimizing risk. Moreover, the experimental sample problems were solved in three small, medium, and large groups using the WOA Algorithm. The

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results of solving this algorithm were compared with the results of NSGA-II one according to the indices including quality, dispersion, uniformity and solution time indices to prove the efficiency of the algorithm. Based on the results, the WOA algorithm had a higher ability to achieve higher quality and near-optimal solutions than NSGA-II algorithm in all cases. The dispersion index values indicated that the WOA Algorithm performed better in exploring and extracting the feasible region. In addition, with respect to the results of the uniformity and the solution time indices, it was found that the NSGA-II Algorithm had a lower solution time than the WOA Algorithm and the answer space more uniformly.

Keywords: closed-loop supply chain, sustainability, passive defense, uncertainty, meta-heuristic algorithm.
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1. Introduction

A supply chain consists of sequential activities including production, lot sizing, distribution and reverse flow of products. Each particular process is often planned and optimized using its anticipated decisions. In later concepts of the supply chain, models such as the closed-loop supply chain and the green supply chain have also been proposed, in which the material flow of can be reverse. A closed-loop supply chain consists of a forward supply chain and a reverse supply chain. The forward supply chain is the set of activities that converts raw materials and semi-finished products into a customer-consumable end product. Reverse supply chain is the process of efficiently and effectively planning, implementing and controlling flow of incoming and storing second-hand goods and information about them in the oppolocation direction of traditional supply chain with the aim of value recovery or proper disposal.

Sustainable supply chain management is defined as materials, information and investment management to create harmony between companies across the supply chain and has been the focus of managers and researchers for two decades [2]. Sustainability in supply chain management and paying attention to environmental factors and social aspects have become important issues in recent years [3] [4]. Environmental and social sustainability are relatively complex issues. However, by adopting technologies, creating a friendly environment and paying attention to environmental factors, they affect the ability of different parts of the supply chain [5].

On the other hand, in order to reduce the vulnerability and increase the tolerance of their supply chain, organizations were forced to spend resources on forecasting demand, supply and internal uncertainties due to increased supply chain uncertainties and factors such as political issues, fluctuations in demand, technological change, financial instability and natural disasters, etc. Paying attention to these uncertainties and risk factors raised the risk management in the supply chain [6]. Risk and failure in supply chain can have a significant effect on short-term performance and a long-term negative effect on financial performance of the organization. The supply chain risk management is so necessary for reduce failures caused by various risks such as uncertain economic cycles, uncertain customer demand, and unpredictable natural and human events, etc. [7]. Risk management involves the identification, assessment and ranking different risks. Risk assessment is one of the key elements of risk management aimed at measuring risk based on various factors such as the degree of impact and the probability of occurrence.

In recent years, the development of models for the closed-loop supply chain and the dimensions of sustainability and risk management in the supply chain have been studied by many researchers. However, despite the importance of passive defense in the sustainable closed-loop supply chain, insufficient attention has been paid to this area. In this regard, this study was conducted aimed at presenting and solving a sustainable closed-loop supply chain model with a passive defense approach. A four-objective mathematical model was presented to achieve the study objective and was solved using the Pareto -based WOA Algorithm. The results of the proposed algorithm were compared with the results of model solving by NSGA-II Algorithm based on indices including quality, uniformity and dispersion to evaluate the performance of the algorithm.

2. Literature review

2.1. Closed-loop supply chain

Many studies have been conducted on the closed-loop supply chain. For example, a multi-product, multi-period model to design closed-loop supply chain network under fuzzy environment was proposed by Vahdani (2015) [8]. In their study, Demirel et al. (2014) proposed a multi-period, multi-segment mixed linear programming model for a closed-loop supply chain network [9]. In a study by Falah Tafti et al. (2014), an integrated supply chain network was designed. The network proposed by this study was a multi-level one comprising assembly, customers, collection, and disposal centers [10]. In their study, Ma et al. (2016) presented a robust two-objective planning model for closed-loop supply chain under uncertainty. They developed a single-objective mathematical model for the closed-loop supply chain problem and solved it using LINGO software. Lingo was not able to solve large-scale problems because of the NP-HARD problem, and they only solved small-scale problems [11]. A multi-objective linear programming model of mushroom production closed-loop supply chain was proposed by Banasik et al. (2017). The model proposed by them in forward logistics included only the manufacturer and the retailer, with no other levels considered. Additionally, in reverse logistics, collection and recovery centers were considered alone [12]. In a study by Hassanzadeh and Baki (2017), a multi-objective facility location model in a closed-loop supply chain under fuzzy conditions was developed. In this study, the location of reverse logistics facilities was modeled [13].

2.2. Sustainable supply chain

There are also studies on sustainable supply chains. Carter and Rogers (2008) presented a comprehensive conceptual framework for sustainable supply chain management. The framework considered four aspects that played a supporting role for the three main concepts of sustainability in addition to economic, environmental, and social aspects [14]. In their study, Titberg and Viet Strach (2010) proposed a systematic approach to sustainable supply chain management. They also proposed a sustainable supply chain home and effectively protected the sustainable supply chain network from environmental and social threats and risks [15].

Using a multi-objective planning model, Pishvaee et al. (2014) designed a pharma supply chain network. The model proposed in this study was a sustainable one consisting of three economic, environmental (green) and social objectives. The economic objective included minimizing fixed, operating and shipping costs, the environmental objective included minimizing the environmental impacts of shipping and operational activities, and the social objective included maximizing job creation, local development, and minimizing customer risk, and damages to the workers. The model was solved using the accelerated Bender decomposition algorithm [16]. A sustainable closed-loop supply chain network was designed by Duika et al. (2014). For this problem, they proposed a multi-objective mathematical model, taking environmental, economic and social dimensions into account and solved it using imperialist competitive and variable neighborhood search (VNS) meta-heuristic algorithms [17]. In a study by Aravandan and Panerselvan (2014), a multi-level, multi-product model for a closed-loop supply chain was developed. For the network under investigation involving all levels of forward and reverse logistics, they developed a mathematical model with the aim of minimizing costs, taking into account facility capacity constraints and solved it using LINGO software and a heuristic approach. In their model, the intended objective function included social and environmental costs [18]. Taking into account the value of jobs and business (as a measure of sustainability), Kopius et al. (2014) examined the closed-loop supply chain. In this study, a rule-based information system was developed to investigate the social values of employees and customers. In this system, customers and employees are evaluated based on evaluation indices and available information [19].

In a study by Bhattajarai and Cruz (2015), the problem of economic sustainability in the closed-loop supply chain was investigated. The researchers designed a decision-making system for assessing the economic validity that made optimal decisions based on the product and customer life cycle. The system operates in forward and reverse logistics and creates integration at the supply chain level investigated [20].

Taking the location, routing, and inventory considerations into account under uncertainty, Jalehcian et al. (2016) modeled the sustainable closed-loop supply chain. They first presented a three-objective mathematical model based on economic, social, and environmental dimensions, and then solved the model in the Gaussian software environment using a heuristic algorithm [21]. In their study, Batini et al (2016) examined the problem of sustainable closed-loop supply chain in humanitarian operations. Taking into account the sustainability dimensions, they designed this supply chain for humanitarian aid and developed a scenario-based mathematical model considering the facilities and vehicles capacity constraints [22]. Rezaei and Kheirkhah (2017) investigated the problem of sustainable closed-loop supply chain and presented a three-objective mathematical model with economic, social and environmental objectives. They solved the model using the cuckoo search algorithm [23]. In a study by Das (2018), lean systems in sustainable supply chain design were reviewed with the aim of integrating lean systems applications into model design and planning of a supply chain to improve overall business sustainability performance. In this study, suppliers of sustainable supply chain materials were identified based on the literature [24].

2.3. Passive defense in supply chain

Numerous studies have examined passive defense in general in the supply chain. In some studies, supply chain risk management literature has been reviewed [7]. Taking into account the risk of facility disruptions such as commodity node disruption, Peng et al. (2011) investigated the problem of supply chain network design including supply, transmission and demand nodes (two-level supply chain) [25]. In their study, Jonakis and Lewis (2011) presented a framework to design a multifactorial decision support system in order to manage the risks in the manufacturing supply chain. Graph theory was proposed by Wanger and Nashat as a way to initialize and reduce supply chain vulnerability [26]. Isarone et al. (2008) conducted a study aimed at presenting a multi-objective stochastic programming approach for supply chain design under uncertainty [27]. In another approach proposed by Go et al. (2007), an algorithm was proposed for dealing with the issue of multi-stage global supply networks with the aim of maximizing profit and minimizing risk, in which risks such as supply, demand, exchange rate and failure risks were investigated [28]. Considering passive defense risk, Aghaei and Ebadi (2013) designed a supply chain management network. They developed a mathematical model for this problem and used a heuristic algorithm to solve the model. In the proposed model, facilities were located based on passive defense measures. First, potential locations were prioritized for facilities using the AHP method and then, the calculated weight was applied to the mathematical model [29]. In their study, Zhou et al. (2013) presented a three-stage planning model based on the CVAR approach to risk management in a three-level supply chain [30]. Using the Conditional Value at Risk (CVAR), Soleimani and Guindan (2014) designed and planned a reverse logistic network [31].

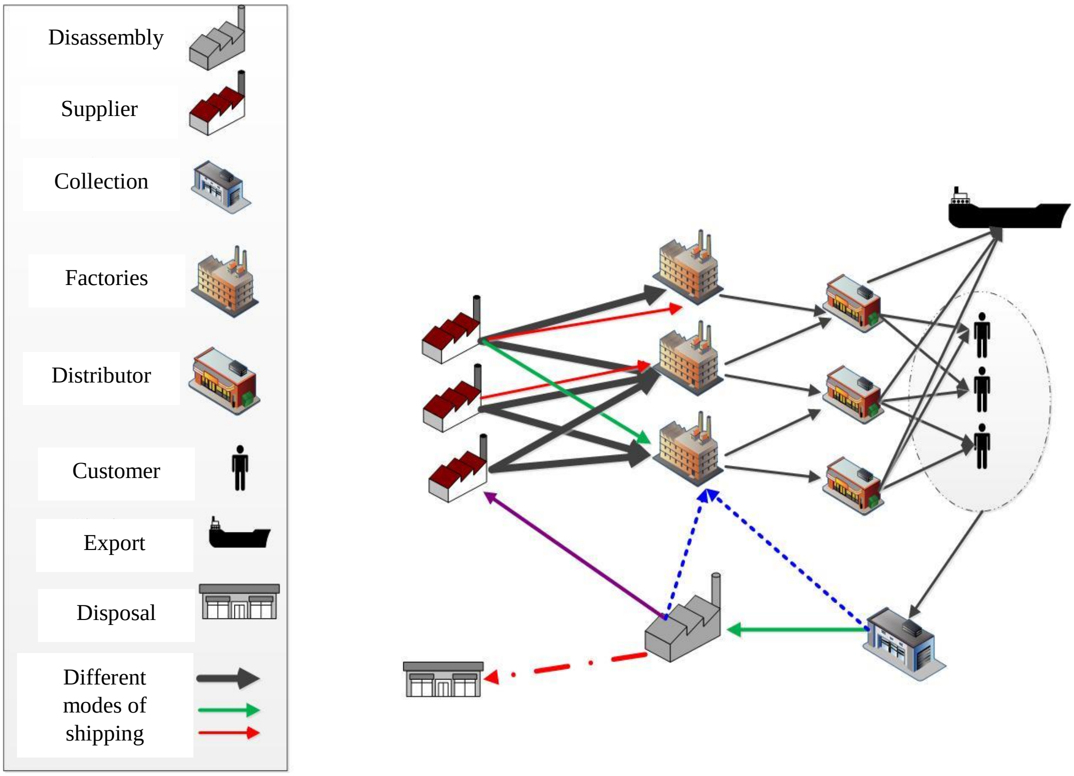

Figure 1: Supply chain investigated

Jamali Firouzabadi and Golshenas Rad (2014) developed a decision support system to locate the refinery location. They first prioritized and weighted potential locations based on factors such as manufacturing cost, passive defense measures, etc. using the AHP method and then presented and solved a mathematical model for locating based on defined priorities [32]. Taking into account retail risks, Golpira et al. (2017) studied green chain management [33].

3. Mathematical modeling

In this study, a sustainable closed-loop supply chain with the features described below was presented. This proposed sustainable supply chain network consisted of four levels in the forward path (including suppliers, factories, distribution centers, and customers) and four levels in the reverse path (including collection, disassemble, reproduction, and disposal centers) (Figure 1). The model was a multi-product, multi-period one. Moreover, the facility was reversible. In this study, it was possible that customer demand could not be satisfied and the model determined the optimal amount of product delivery to market based on the market situation and related scenarios.

In the proposed supply chain, in the forward path, suppliers and collection centers are responsible for providing components and raw materials to production equipment (supplier role). The solution is provided to the extent that the rate of return products allows for the demand for components by collection centers that are the source of supply through improved components delivery. In the event of any shortage in supply of improved components, factories can purchase the required components from suppliers. New products from factories are delivered to customers through distribution centers to meet their demand, and the reverse supply chain process begins with customer returns. The returned goods are then disassembled according to their quality, high quality parts are sent to production centers, reproducible parts are sent to the reproducible centers and unusable parts to disposable

centers. The quality of returned goods plays a decisive role in their flow. In this problem, the quality of returned goods is considered uncertain. In this study, in production centers and product recovery centers, according to the demand for different products and according to the quality requested by the customer, the production centers produced the products.
In the model under study, risk management was used as one of the passive defense capabilities in supply chain to increase supply chain resilience. As one of the passive defense measures is dispersion, the dispersion principle was also used to locate the facilities in supply chain. On the other hand, in order to use the passive defense approach, the supply chain agility and flexibility were also considered, which were applied in mathematical modeling as relevant constraints, and also were considered as risk minimization, delay costs and non-compliance with minimum flexibility levels in objective functions. In this study, three dimensions of supply chain sustainability were considered, including economic, social and environmental. Each of these dimensions was considered based on different criteria and constraints in the model. The impact of the supply chain on the use of non-renewable energies such as fossil fuels, waste from the supply chain, recycling rates, etc. was considered to investigate the environmental dimension. Moreover, the impact of the supply chain on investment, market share, and income from recycling was considered to examine the economic dimension, and the impact of the supply chain on social sustainability, social justice, the number of jobs created and labor force damage in production centers to examine the social dimension.
In the following, the designed mathematical model and the ts components are described based on the problem description.

3.1. Model indices and parameters

A) Indices
I: Fixed point set index for supply centers
J: Fixed point set index for production centers
L: Fixed point set index for customers
M: It contains points with coordinates (c_m, d_m) and the set of actual points for the recovery centers (m = 1,2, ..., M)
N: It contains points with coordinates (a_n, b_n) and the set of actual points for the disposal centers (n = 1,2, ..., N)
K: It contains the points with coordinates (x_k, y_k) and the set of potential points for the distribution centers (k = 1,2,. . . , K)
P: It contains points with coordinates $({x'}_p, {y'}_p)$ and the set of potential points for the recycling centers (p = 1,2,. . . , P)
S: Set product index
T: Period index
B) Parameters
QS: Returned product quality levels (qs = 1,2,. . . , QS)
Senenario: Set of scenarios (sen = 1,2, .., scenario)
$r^{st}_{l,qs,sen}$: Return rate of product s with quality level qs from customer center I in period t.
$d^{st}_{l,sen}$: Customer demand for product s in period t.
Prices $_{s,sen}$: The price of good s delivered to the customer in the forward path (from distributor to customer).
$price^{max}_{s,qs,sen}$: Upper limit of the price of the returned product s with quality level qs paid to customer (at time of collection).
$price^{min}_{s,qs,sen}$: Lower limit of the price of the returned product s with quality level qs paid to customer (at time of collection).

$costp_{s,sen}$: The cost of producing a unit of product s.
$costp_{s,sen}$: The cost of recycling a unit of product s.
$costn_{s,sen}$: The cost of desposing a unit of product s.
$value_{s,sen}$: Value added to the system after recycling a unit of product s.
Bj^{st} : Return rate of product s from recovery center m to production center j in period t.
Bn^{st}: Return rate of product s from recovery center m to disposal center n in period t.
Bk^{st}: Return rate of product s from recover center m to distribution center k in period t.
Bp^{st}: Return rate of product s from recovery center m to recycling center p in period t.
f_k: Fixed cost of construction a distribution center at location k.
f_m: Cost of construction of recovery center at location m.
f_p: Cost of construction of recycling center at location p.
f_n: Cost of construction of disposal center at location n.
$c^s_{ij,sen}$: All costs of shipping product s from supply center i to production center j.
$c^s_{jk,sen}$: All costs of shipping product s from supply center i to distribution center k.
$c^s_{kl,sen}$: All costs of shipping product s from distribution center k to customer center I.
$c^s_{lm,sen}$: All shipping costs per unit of returned product from customer I to recovery center m.
$c^s_{mp,sen}$: All shipping costs per unit of returned product from recovery center m to recycling center p.
$c^s_{mn,sen}$: All shipping costs per unit of returned product from recovery center m to disposal center n.
$c^s_{mk,sen}$: All shipping costs per unit of returned product from recovery center m to distribution center k.
$c^s_{mj,sen}$: All shipping costs per unit of returned product from recovery center m to distributor center j.
$c^s_{pj,sen}$: All shipping costs per unit of returned product from recycling center p to production center j.
$c^s_{pi,sen}$: All shipping costs per unit of returned product from recycling center p to supply center i.
$cq^s_{jj,sen}$: All costs of shipping product s from production center to its own warehouse.
$cq^s_{jk,sen}$: All costs of shipping product s from producer's warehouse to distribution center k.
ca_i: Capacity of supply center at location i.
ca_j : Capacity of production center at location j.
ca_{jj}: Capacity of producer's warehouse at location j.
cr_j: Capacity for reproduction of products in production center at location j.
ca_k: Capacity of distribution center at location k.
cr_k : Capacity for distribution of second-hand products at distribution center k.
cr_i: Capacity for the production of raw materials from second-hand products in supply center at location i.
ca_m: Capacity of recovery center at location m.
ca_p: Capacity of recycling center at location p.
ca_n: Capacity of disposal center at location n.
$h^s_{j,sen}$: Cost of maintaining each unit of product s in producer's warehouse at location j.
$\alpha_{k,sen}$: Number of job opportunities created in distribution center k.
$\alpha_{inv,sen}$: Number of job opportunities created in reverse logistics centers.
dl_j: Average working days lost due to workplace injury in production center j per unit of each product production.
θ_l: Workplace injury weight factor.
sp_{js}: Average waste generated at in production center j to produce each unit of product s.
dp_{js}: Average hazardous materials used in production center j to produce each unit of product s.
θ_w: Waste generated weight factor (weight of waste generated in the objective function).

θ_h: Hazardous materials weight factor (weight of hazardous materials in the objective function).
$VARD^{sen}{}_{ist}$: Rate of delay risk for the delivery of parts of product s by supplier i in period t.
$VARD_{kst}$: Rate of delay risk for the delivery of product s by distributor k in period t.
$VARQ_{ist}$: The risk associated with defective product s received from supplier i in period t.
$VARQ_{Kst}$: The risk associated with the defective product s received from the distributor k in period t.
$VARND_{it}$: The risk of natural disasters for supplier i in period t.
$VARF^{sen}{}_{it}$: Liquidity risk of supplier i in period t.
$dk_{kk'}$: The distance of distributor k to distributor k' which is calculated as the Euclidean distance.
$dn_{nn'}$: The distance of destruction center n to destruction center n' which is calculated as the Euclidean distance.
$dm_{mm'}$: The distance of collection center m to collection center m' which is calculated as the Euclidean distance.
$dp_{pp'}$: The distance of recycling center p to recycling center p' which is calculated as the Euclidean distance.
DK: Minimum distance between established distribution centers
DM: Minimum distance between established collection centers
DN: Minimum distance between established disposal centers
DP: Minimum distance between established recycling centers
LDC_{ist}: Delay cost of supplier i to supply product s in period t
O_{ist}: Cost of ordering product s to supplier i in period t
$F0$: Flexibility intended by the factory or organization
F_{ist}: Flexibility of supplier i to supply product s in period t
R_{ist}: Percentage of returned product s from supplier i in period t
$R0$: Maximum percentage acceptable for returned product during the planning horizon

3.2. Model variables

$fp^{sen}{}_{s,qs}$: The optimal price per unit of returned product s with quality qs.
y_k: If the distribution center is established at location k, its value is 1, otherwise 0.
y_m: If the collection center is established at location m, its value is 1, otherwise 0.
y_p: If the recovery center is established at location p, its value is 1, otherwise 0.
y_n: If the disposal center is established at location n, its value is 1, otherwise 0.
$x^{st}_{ij,sen}$: The flow rate of product s from supply center i to production center j in period t.$x^{st}_{jk,sen}$: The flow rate of product s from production center j to distribution center k in period t.$Q^{st}_{jj,sen}$: The flow rate of product s from production center j to its warehouse in period t.
$x^{st}_{kl,sen}$: The flow rate of product s from distribution center k to customer l in period t.
$Q^{st}_{jk,sen}$: The flow rate of product s from producer j's warehouse to distribution center k in period t.
$x^{st}_{lm,qs,sen}$: The flow rate of returned product s with quality qs from customer I to recovery center m in period t.
$x^{st}_{mk,sen}$: The flow rate of returned product s from recovery center m to distribution center k in period t.
$x^{st}_{mp,sen}$: The flow rate of returned product s from recovery center m to recycling center p in period t.
$x^{st}_{mn,sen}$: The flow rate of returned product s from recovery center m to disposal center n in period t.
$x^{st}_{mj,sen}$: The flow rate of returned product s from recovery center m to production center j in period t.
$x^{st}_{pj,sen}$: The flow rate of reused product s from recycling center p to production center j in period t.

$x^{st}_{pi,sen}$: The flow rate of reused product s from recycling center p to supply center i in period t.
$U^{st}_{j,sen}$: The amount of product s remained in producer j's warehouse in period t.
$q^{st}_{l,sen}$: Customer I unmet demand for product s in period t.

3.3. The main structure of the mathematical model

The first objective function

The components of the first objective function are:

- Facility costs

$$\sum_{k\in K} f_k y_k + \sum_{m\in M} f_m y_m + \sum_{n\in N} f_n y_n + \sum_{p\in P} f_p y_p$$

- Shipping costs

$$\begin{array}{l}\sum_{t\in T}\sum_{sen}(\sum_{s\in S}\sum_{i\in I}\sum_{j\in J} c^s_{ij,sen}x^{st}_{ij,sen} + \sum_{s\in S}\sum_{j\in J}\sum_{k\in K} c^s_{jk,sen}x^{st}_{jk,sen}\\ +\sum_{s\in S}\sum_{k\in K}\sum_{l\in L} c^s_{kl,sen}x^{st}_{kl,sen} + \sum_{s\in S}\sum_{l\in L}\sum_{m\in M} c^s_{lm,sen}x^{st}_{lm,sen}\\ +\sum_{s\in S}\sum_{m\in M}\sum_{p\in P} c^s_{mp,sen}x^{st}_{mp,sen} + \sum_{s\in S}\sum_{m\in M}\sum_{n\in N} c^s_{mn,sen}x^{st}_{mn,sen}\\ +\sum_{s\in S}\sum_{m\in M}\sum_{j\in J} c^s_{mj,sen}x^{st}_{mj,sen} + \sum_{s\in S}\sum_{m\in M}\sum_{k\in K} c^s_{mk,sen}x^{st}_{mk,sen}\\ +\sum_{s\in S}\sum_{p\in P}\sum_{j\in J} c^s_{pj,sen}x^{st}_{pj,sen} + \sum_{s\in S}\sum_{p\in P}\sum_{i\in I} c^s_{pi,sen}x^{st}_{pi,sen}))\end{array}$$

- Warehouse costs

$$\sum_{t\in T}\sum_{sen}(\sum_{s\in S}\sum_{j\in J} cq^s_{jj,sen}Q^{st}_{jj,sen} + \sum_{s\in S}\sum_{ij\in J}\sum_{k\in K} cq^s_{jk,sen}Q^{st}_{jk,sen})$$

- Maintenance costs

$$\sum_{t\in T}(\sum_{sen}(\sum_{s\in S}\sum_{j\in J} h^s_{j,sen}U^s_{j,sen}))$$

- Costs paid to customer for returned products

$$\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{qs=1}^{QS} x^{st}_{lm,qs}fp_{s,qs}$$

- Production costs per unit of product in production centers

$$\sum_{t\in T}\sum_{sen}(\sum_{j\in J}\sum_{s\in S}(cost_{s,sen}(Q^{st}_{jj,sen} + \sum_{k\in K} x^{st}_{jk,sen})\ ))$$

- Costs of recycling of returned products

$$\sum_{t=1}^{T}\sum_{sen}(\sum_{m=1}^{M}\sum_{p=1}^{P}\sum_{s=1}^{S} x^{st}_{mp,sen}\cos tp_{s,sen})$$

- Costs of disposal of returned products

$$\sum_{t=1}^{T}\sum_{sen}(\sum_{n=1}^{N}\sum_{p=1}^{P}\sum_{s=1}^{S} x^{st}_{mn,sen}\cos tn_{s,sen})$$

- Profits added to the system after recycling

$$\sum_{t=1}^{T}\sum_{sen}(\sum_{m=1}^{M}\sum_{p=1}^{P}\sum_{s=1}^{S} x_{mp,sen}^{st} value_{s,sen})$$

- Income from sales of products to customers in forward logistics (from distributor to customer)

$$\sum_{t=1}^{T}\sum_{sen}(\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{s=1}^{S} x_{kl,sen}^{st} price_{s,sen})$$

- Ordering and delay costs

$$\sum_{i\in I}\sum_{t\in T}\sum_{j\in J}\sum_{s}(O_{ist}+LDC_{ist})\sum_{sen} x_{ij,sen}^{st}$$

The cost components above were expressed separately, and the first objective function, which was the same supply chain profit, was obtained from subtracting the total cost from income, as follows:

$$\begin{aligned} maxz1 = &\sum_{t=1}^{T}\sum_{sen}(\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{s=1}^{S} x_{kl,sen}^{st} price_{s,sen}) + \sum_{t\in T}\sum_{sen}(\sum_{m\in M}\sum_{p\in P}\sum_{s\in S} x_{mp,sen}^{st} value_{s,sen}) \\ &-(\sum_{k\in K} f_k y_k + \sum_{m\in M} f_m y_m + \sum_{p\in P} f_p y_p + \sum_{n} f_n y_n) + \sum_{t}\sum_{sen}(\sum_{s\in S}\sum_{i\in I}\sum_{j\in J} c_{ij,sen}^{s} x_{ij,sen}^{st}) \\ &+\sum_{s\in S}\sum_{j\in J} cq_{jj,sen}^{s} Q_{jj,sen}^{st} + \sum_{s\in S}\sum_{j\in J}\sum_{k\in K} c_{jk,sen}^{s} x_{jk,sen}^{st} + \sum_{s\in S}\sum_{ij\in J}\sum_{k\in K} cq_{jk,sen}^{s} Q_{jk,sen}^{st} \\ &+\sum_{s\in S}\sum_{k\in K}\sum_{l\in L} c_{kl,sen}^{s} x_{kl,sen}^{st} + \sum_{s\in S}\sum_{l\in L}\sum_{m\in M} c_{lm,sen}^{s} x_{lm,sen}^{st} + \sum_{s\in S}\sum_{m\in M}\sum_{p\in P} c_{mp,sen}^{s} x_{mp,sen}^{st} \\ &+\sum_{s\in S}\sum_{m\in M}\sum_{n\in N} c_{mn,sen}^{s} x_{mn,sen}^{st} + \sum_{s\in S}\sum_{m\in M}\sum_{j\in J} c_{mj,sen}^{s} x_{mj,sen}^{st} + \sum_{s\in S}\sum_{m\in M}\sum_{k\in K} c_{mk,sen}^{s} x_{mk,sen}^{st} \\ &+\sum_{s\in S}\sum_{p\in P}\sum_{j\in J} c_{pj,sen}^{s} x_{pj,sen}^{st} + \sum_{s\in S}\sum_{p\in P}\sum_{i\in I} c_{pi,sen}^{s} x_{pi,sen}^{st} + \sum_{s\in S}\sum_{j\in J} h_{j,sen}^{s} U_{j,sen}^{st}) \\ &+\sum_{t=1}^{T}\sum_{sen}(\sum_{l=1}^{L}\sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{qs=1}^{QS} x_{lm,qs,sen}^{st} fp^{sen}{}_{s,qs}) + \sum_{t\in T}\sum_{sen}(\sum_{m\in M}\sum_{p\in P}\sum_{s\in S} x_{mp,sen}^{st} \cos tp_{s,sen}) \\ &+\sum_{t\in T}\sum_{sen}(\sum_{m\in M}\sum_{n\in N}\sum_{s\in S} x_{mn,sen}^{st} \cos tn_{s,sen}) + \sum_{t\in T}\sum_{sen\in senario}\sum_{s\in S}\sum_{j\in J}(\cos t_{s,sen}(Q_{jj,sen}^{st} \\ &+\sum_{k\in K} x_{jk,sen}^{st}) + \sum_{i}(\sum_{s}\sum_{t}(O_{ist}+LDC_{ist})\sum_{sen}\sum_{j} x_{ij,sen}^{st}) \end{aligned} \tag{3.1}$$

The second objective function: The objective was to maximize social responsibility or social benefits.

$$\max z2 = \sum_{t\in T}\sum_{sen}(\sum_{k\in K}\alpha_{k,sen}y_k + \sum_{m\in M}\alpha_{inv,sen}y_m + \sum_{p\in P}\alpha_{inv,sen}y_p + \sum_{n\in N}\alpha_{inv,sen}y_n) \tag{3.2}$$

$$-\theta_l \sum_{t\in T}\sum_{sen}(\sum_{j\in J}\sum_{s\in S}(dl_j(Q^{st}_{jj,sen}+\sum_{k\in K}x^{st}_{jk,sen})))$$

The third objective function: the objective was to reduce environmental impacts.

$$\min z3=\theta_w\sum_{t\in T}\sum_{sen}(\sum_{j\in J}\sum_{s\in S}(sp_{js}(Q^{st}_{jj,sen}+\sum_{k\in K}x^{st}_{jk,sen})))+\theta_k\sum_{t\in T}\sum_{sen}(\sum_{j\in J}\sum_{s\in S}(dp_{js}(Q^{st}_{jj,sen}+\sum_{k\in K}x^{st}_{jk,sen}))) \tag{3.3}$$

The fourth objective function: risk minimization

$$minz4=\sum_{sen}(\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{i=1}^{I}VARD^{sen}{}_{ist}(\sum_{j=1}^{J}x^{st}{}_{ij,sen})+\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{k=1}^{K}VARD_{kst}(\sum_{l=1}^{L}x^{st}{}_{kl,sen}) \tag{3.4}$$

$$+\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{i=1}^{I}VARQ_{ist}(\sum_{j=1}^{J}x^{st}{}_{ij,sen})+\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{k=1}^{K}VARQ_{kst}(\sum_{l=1}^{L}x^{st}{}_{kl,sen})$$

$$+\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{i=1}^{I}VARND_{it}(\sum_{j=1}^{J}x^{st}{}_{ij,sen})+\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{i=1}^{I}VARF^{sen}{}_{it}(\sum_{j=1}^{J}x^{st}{}_{ij,sen}))$$

Constraints

$$\sum_{k\in K}x^{st}_{kl,sen}+q^{st}_{l,sen}=d^{st}_{l,sen}\forall l\in L,\forall s\in S,t\in T,sen\in senario \tag{3.5}$$

$$\sum_{m\in M}x^{s}_{lm,qs,sen}=r^{s}_{l,qs,sen}\forall l\in L,\forall s\in S,allquality-level,sen\in senario \tag{3.6}$$

Terms (3.5) and (3.6) ensured that in the direct path, all customer demand could not be satisfied and in the reverse path, all returned goods might be collected from customer centers.

$$\sum_{k\in K}x^{st}_{mk,sen}=Bk^{st}\sum_{qs}(\sum_{l\in L}x^{st}_{lm,qs,sen})\forall m\in M,\forall s\in S,t\in T \tag{3.7}$$

$$\sum_{j\in J}x^{st}_{mj}=Bj^{st}\sum_{l\in L}x^{st}_{lm}\forall m\in M,\forall s\in S,t\in T \tag{3.8}$$

$$\sum_{i\in I}x^{st}_{mp,sen}=Bp^{st}\sum_{qs}(\sum_{l\in L}x^{st}_{lm,qs,sen})\forall m\in M,\forall s\in S,t\in T \tag{3.9}$$

$$\sum_{n\in N}x^{st}_{mn,sen}=Bn^{st}\sum_{qs}(\sum_{l\in L}x^{st}_{lm,qs,sen})\forall m\in M,\forall s\in S,t\in T \tag{3.10}$$

$$\sum_{j\in J}(x^{st}_{jk,sen}+Q^{st}_{jk,sen})=\sum_{l\in L}x^{st}_{kl,sen}-\sum_{m\in M}x^{st}_{mk,sen}\forall k\in K,\forall s\in S,t\in T \tag{3.11}$$

$$\sum_{i\in I}x^{st}_{ij,sen}+\sum_{m\in M}x^{st}_{mj,sen}+\sum_{p\in P}x^{st}_{pj,sen}=\sum_{k\in K}x^{st}_{jk,sen}+Q^{st}_{jj,sen}\forall j\in J,\forall s\in S,t\in T \tag{3.12}$$

$$U^{st}_{j,sen}=Q^{st}_{jj,sen}-\sum_{k\in K}Q^{st}_{jk,sen}\forall j\in J,\forall s\in S,t\in T \tag{3.13}$$

Constraints (3.7) to (3.13) were related to flow balance constraints in nodes.

$$\sum_{k\in K} Q^{st}_{jk,sen} \leq Q^{s}_{jj,sen} \forall j \in J, \forall s \in S, t \in T \tag{3.14}$$

Term (3.14) ensured that the output flow from the producers 'warehouse was less than the total input flow to the producers' warehouse.

$$\sum_{s\in S}\sum_{j\in J} x^{st}_{ij,sen} \leq ca_i \forall i \in I, t \in T \tag{3.15}$$

$$\sum_{s\in S}\sum_{k\in K} x^{st}_{jk,sen} + \sum_{s\in S} Q^{st}_{jj,sen} \leq ca_j \forall j \in J, t \in T \tag{3.16}$$

$$\sum_{s\in S}\sum_{l\in L} x^{st}_{kl,sen} \leq ca_k y_k \forall k \in K, t \in T \tag{3.17}$$

$$\sum_{s\in S}\sum_{k\in K} x^{st}_{mk,sen} + \sum_{s\in S}\sum_{j\in J} x^{st}_{mj,sen} + \sum_{s\in S}\sum_{n\in N} x^{st}_{mn,sen} + \sum_{s\in S}\sum_{p\in P} x^{st}_{mp,sen} \leq ca_m y_m \forall m \in M, t \in T \tag{3.18}$$

$$\sum_{s\in S}\sum_{m\in M} x^{st}_{mk,sen} \leq cr_k y_k \forall k \in K, t \in T \tag{3.19}$$

$$\sum_{s\in S}(\sum_{m\in M} x^{st}_{mj,sen} + \sum_{p\in P} x^{st}_{pj,sen}) \leq cr_j \forall j \in J, t \in T \tag{3.20}$$

$$\sum_{s\in S}\sum_{p\in P} x^{st}_{pi,sen} \leq cr_i \forall i \in I, t \in T \tag{3.21}$$

$$\sum_{s\in S}\sum_{m\in M} x^{st}_{mn,sen} \leq ca_n y_n \forall n \in N, t \in T \tag{3.22}$$

$$\sum_{s\in S}\sum_{m\in M} x^{st}_{mp,sen} \leq ca_p y_p \forall p \in P, t \in T \tag{3.23}$$

$$\sum_{s\in S} U^{st}_{j,sen} \leq ca_{jj} \forall j \in J, t \in T \tag{3.24}$$

Terms (3.15) to (3.24) ensured that the flow was only between points where facilities were established and that the total flow in each facility did not exceed its capacity.

$$\sum_{k\in K} y_k \geq 1 \tag{3.25}$$

$$\sum_{m\in M} y_m \geq 1 \tag{3.26}$$

$$\sum_{p\in P} y_p \geq 1 \tag{3.27}$$

$$\sum_{n\in N} y_n \geq 1 \tag{3.28}$$

Terms (3.25) to (3.28) ensured that at least one of the potential centers was active.

$$Bk^{st} + Bj^{st} + Bp^{st} + Bn^{st} = 1 \forall s \in S, t \in T \tag{3.29}$$

Term (3.29) ensured that the sum of the coefficients of the return products was 1.

$$fp^{sen}{}_{s,qs} = price^{\min}_{s,qs,sen} + (price^{\max}_{s,qs,sen} - price^{\min}_{s,qs,sen}) \times CR_{s,qs,sen} \sum_{qs} x^{st}_{lm,qs,sen} \tag{3.30}$$

In Equation (3.30), the price level chosen was determined by the return rate of product at each quality level where $C_{s,qs,sen}$ was the return rate of product s with the quality qs. The customer presented its goods with a specified quality level to collection centers if their proposed price was greater than or equal to the expected price. Accordingly, the probability of return of product s with the quality qs was calculated using Equation (3.31) (it is worth noting that the product price and the return rate at each quality level followed a uniform probability distribution):

$$C_{s,qs,sen} = p(price_{s,qs} - fp^{sen}_{s,qs} \geq 0) = \min\{1, \frac{\max(0, price_{s,qs} - price^{\min}_{s,qs,sen})}{price^{\max}_{s,qs,sen} - price^{\min}_{s,qs,sen}}\} \tag{3.31}$$

$$dk_{kk'} \geq DK \tag{3.32}$$

$$dn_{nn'} \geq DN \tag{3.33}$$

$$dm_{mm'} \geq DM \tag{3.34}$$

$$dp_{pp'} \geq DP \tag{3.35}$$

$$\sum_{t\in T} \sum_{i\in I} R_{ist} \sum_{sen} \sum_{i\in I} x^{st}_{ij,sen} \leq R_0 \sum_{t\in T} \sum_{l\in L} d^t_{ls} \qquad \forall s \tag{3.36}$$

$$F_{ist} \sum_{sen} \sum_{j\in J} x^{st}_{ij,sen} \geq F_0 \qquad \forall i, s, t \tag{3.37}$$

Constraints (3.36) ensured that the total returned goods does not exceed the maximum permissible level.
The Constraints (3.37) was related to the level of supplier flexibility that had to be greater than the level set by the organization or factory.

$$y_m, y_k, y_p, y_n \in \{0,1\} \forall m \in M, \forall k \in K, \forall p \in P, \forall n \in N, t \in T \tag{3.38}$$

$$\begin{array}{l} x^{st}_{ij}, x^{st}_{jk}, Q^{st}_{jj}, U^{st}_{j}, x^{st}_{kl}, Q^{st}_{jk}, x^{st}_{lm}, x^{st}_{mj}, x^{st}_{mk}, x^{st}_{mp}, x^{st}_{mn}, f_{ps,qs} \geq 0 \\ \forall i \in I, \forall j \in J, \forall k \in K, \forall l \in L, \forall m \in M, \forall n \in N, \forall p \in P, t \in T \end{array} \tag{3.39}$$

Constraints (3.38) and (3.39) were logical and obvious constraints on the decision variables of the problem.
VAR method was used to determine the risks. In this regard, the following parameters were defined:
D_{ist}: Distribution function of delay in delivering parts of product s by supplier i in period t.
D_{kst}: Distribution function of delay in delivering product s by distributor k in period t.
Q_{ist}: Distribution function of defective product s received from supplier i in period t.
Q_{Kst}: Distribution function of defective product s received from distributor k in period t.
ND_i: The number of natural disasters that impaired the activity of supplier i.
F_{it}: Fixed purchase cost from supplier i in period t.
VF_{ist}: Variable cost of purchasing product s from supplier i in period t.
Various methods have been developed for estimating VAR, one of which is the Extreme value theory introduced by Longin et al in the 90s. Radpour et al argue that, assuming that risk managers tend

to focus on the extreme values of the distribution of future losses and in general the heavy losses, the greatest concern should be in accurately estimating the type of losses distribution sequence. The extreme value theory so can be a useful and valuable method for estimating VAR. Despite the low probability of occurrence of extreme events, they are associated with large effects.
The general form of the generalized distribution for the extreme value is shown with the following equation:

$$f_{\gamma,\delta,k}\left(x\right)=\begin{cases}\exp\left(-\left[1-k\left(\frac{x-\gamma}{\delta}\right)\right]^{\frac{1}{k}}\right) & 1-k\left(\frac{x-\gamma}{\delta}\right)\geq 0, k\neq 0\\ \exp\left(-exp\left(\frac{x-\gamma}{\delta}\right)\right) & -\infty\leq x\leq\infty,\ k=0\end{cases}\tag{3.40}$$

Where $f_{\gamma,\delta,k}\left(x\right)$ is the cumulative distribution function of the maximum variable (extreme values), γ is the position of distribution; δ is the distribution parameter and k is to the sequence index and denotes the shape or density of the sequence of distribution.

4. Solution method

Most of the logistic network design models, such as the problem discussed in this study, are difficult problems. These problems can be reduced to the problem of locating facilities with limited capacity. The problem of locating facilities with limited capacity falls into the category Np-Complete [34]. As a result, the problem of designing the logistic network investigated in this study belonged to the category Np-Hard. Accurate methods cannot be used to solve alrge-sized problems because of their high time complexity. So in this study, Pareto-based WOA Algorithm was used to solve the studied problem the results of which were compared with those of NSGA-II Algorithm.

4.1. Whale Optimization Algorithm (WOA)

The WOA algorithm starts with a set of random solutions. At each iteration, search agents update their positions with respect to either a randomly chosen search agent or the best solution obtained so far. The a parameter is decreased from 2 to 0 in order to provide exploration and exploitation, respectively. A random search agent is chosen when $|A| > 1$, while the best solution is selected when $|A| < 1$ for updating the position of the search agents. Depending on the value of p, WOA is able to switch between spiral or circular movements. Finally, the WOA algorithm is terminated by the satisfaction of a termination criterion. In the following, the pseudo code of the algorithm is given.
The general structure of the WOA can be seen in Figure 2. In this study, this algorithm was designed in conjunction with an optimization process that was based on the variable neighborhood search (VNS) structure. The proposed structure of the algorithm was as in Figure 3.

4.1.1. How to represent the solution

In this study, the matrix was used to represent each solution. Each solution consisted of several matrices designed according to the model outputs. For the variable zm, for example, a row matrix (one-dimensional) was defined with the number of entries equal to m (m was the number of collection centers), for the variable row matrix, a one-dimensional matrix, and for the variable$x_{ij,sen}^{st}$, a 5-dimensional matrix was defined with the dimensions I * J * sen * S * T. Similarly, the matrix was defined for the other outputs.

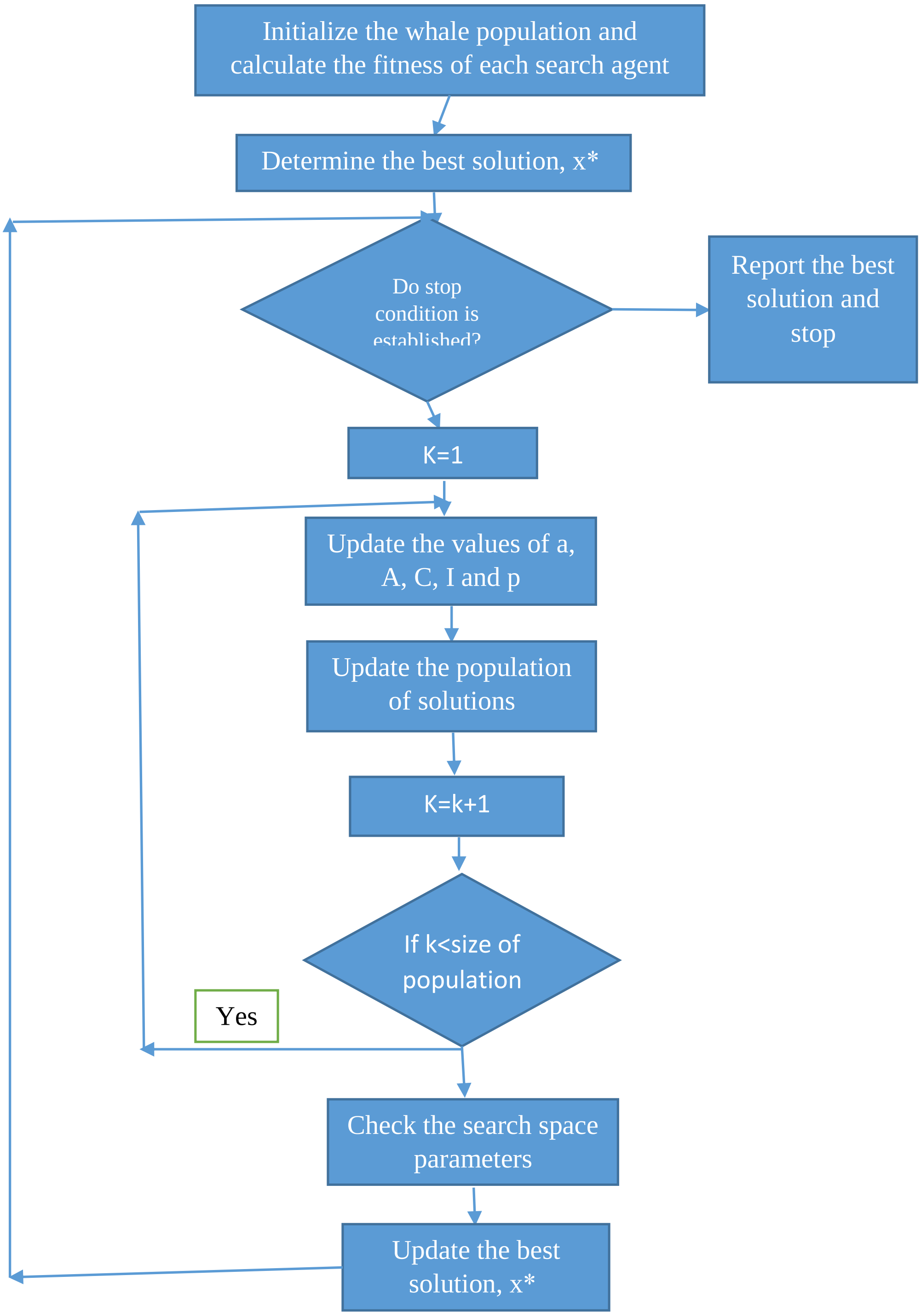

Figure 2: The general structure of the WOA

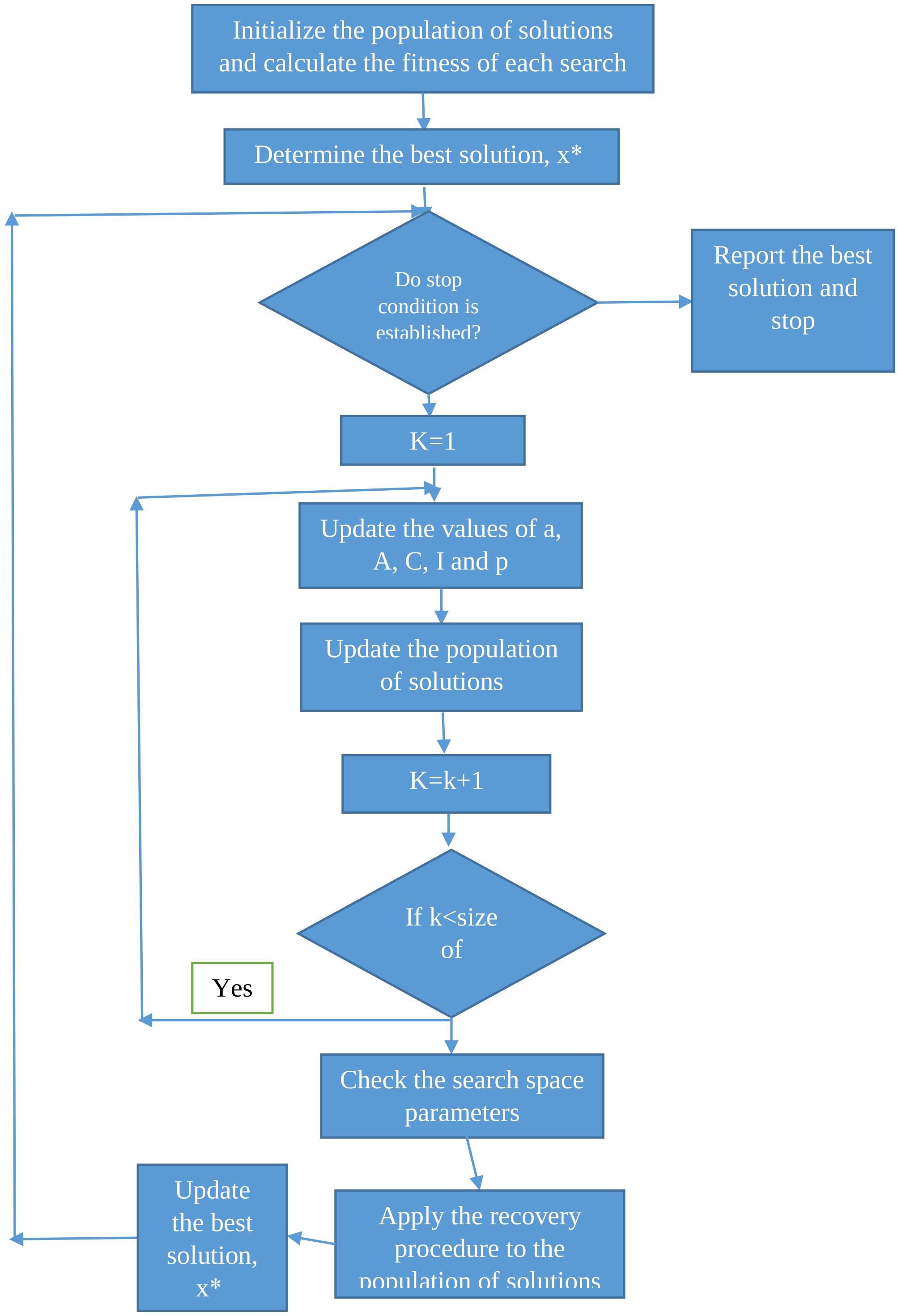

Figure 3: The proposed structure of the WOA

4.1.2. How to generate initial solutions

In this study, initial solutions were generated using a random approach. In order to generate the initial solutions, they_k, y_m, y_p and y_n matrices were randomly generated and then the other matrices (model variables) were initialized as feasible according to the model constraints. Suppose the population size is N, each time a solution is generated as described, it is added to the solution population if it is not iterative. This procedure continues until the number of solutions in the population reaches $\alpha \times$ N, where α is a number greater than 1.

The solution initialization method is stopped after the$\alpha \times$ N iteration. On the other hand, the number of solutions in each iteration is N. So from the$\alpha \times$ N existing solution, the N solution should be selected as the initial production sequence. In this study, the initial population of responses was selected based on a fast non dominated sorting approach described by Deb et al. (2002) [35]. In this method, the existing $\alpha \times$ N solutions designed by the above algorithm are sorted and leveled. The number of each level indicates the quality of its solutions. For example, the quality of solutions at level 1 is higher than those at level 2. Then, for solutions at each level, a scale called crowding distance is calculated according to the same level. The scale for solutions at each level indicates the distribution of solutions at the same level. In this paper, a criterion called Cs was defined to select the initial solutions, which was calculated using the following equation [35]:

$$C_s = \frac{rank}{crowding\_dis} \tag{4.1}$$

The above criterion was calculated for each solution.

Rank: Indicates the level number of the solution.

crowding_dis: It is the crowding distance of any solution proportional to its rank.

After calculating the above criterion for all solutions, they were arranged in ascending order of Cs, and the first N solutions with lower Cs were selected as the initial solutions of the algorithm. Applying the Cs criterion is based on the logic that higher quality and dispersed solutions are selected as the initial population.

The solutions generated were improved as far as possible using the optimization process. How the optimization process works is described in the next section.

4.1.3. Optimization process

In the structure proposed for the WOA, an optimization process was designed, applied to the selected solutions in the previous section and optimized them. The output solutions of the optimization process were selected as the population of the next iteration of the algorithm. In this study, the optimization process was implemented based on variable neighborhood search (VNS). The VNS structure uses four neighborhood search structures (NSS). These structures are used in the VNS format (its general structure is described in the reference [36]). Each of the solutions in the solution population was given to the VNS algorithm and a solution was obtained as output. Then, the other solution matrices were modified as feasible and replaced with the input solution. The neighborhood search operators used in the VNS structure are as follows:

The first neighborhood search operator: In this structure, one of the distributor facilities is randomly selected and the location matrix is changed.

The second neighborhood search operator: In this structure, one of the collection centers is randomly selected and the location matrix is changed.

The third neighborhood search operator: In this structure, one of the recycling centers is randomly selected and the location matrix is changed.

The fourth neighborhood search operator: In this structure, one of the disposal centers is randomly selected and the location matrix is changed.
To change the location matrices in the above operators, the index of one of the centers was randomly selected, and its cell was changed to 0 if it was 1 and 0 if 1 (in compliance with the constraints on the minimum number of established centers).
To check the feasibility of the solutions and convert the non- feasible solutions to the feasible ones, a procedure was designed that would check all the constraints on the solution generated as new solutions were generated during the implementation of the algorithm. If one or more of the constraints in the solution were violated, the procedure attempted to make the answer feasible. The feasibility procedure worked in such a way that, due to the new location matrices, the flow of goods between the facilities was established using previous or new vehicles considering the volume and weight capacity constraints of vehicles as well as the capacity constraints of the distribution centers, and the product flow variables were re-initialized.

4.1.4. Updating search solutions and parameters

In the WOA, search solutions and parameters are updated based on the following equations:

$$\vec{D} = \left| \vec{C}.\vec{X}^{*}(t) - \vec{X}(t) \right| \tag{4.2}$$

$$\vec{X}(t+1) = \vec{X}^{*}(t) - \vec{A}.\vec{D} \tag{4.3}$$

Where $\vec{D}$ is the search space, $\vec{C}$ and $\vec{A}$ are the coefficients, $\vec{X}^{*}(t)$ is the best solution of the iteration t, $\vec{X}(t)$ is the solution of the iteration t, and $\vec{X}(t+1)$ is the solution of the iteration t + 1.
In addition, the following equations are used to update $\vec{C}$ and $\vec{A}$:

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \tag{4.4}$$

$$\vec{C} = 2\vec{r} \tag{4.5}$$

In the above equations, $\vec{a}$ starts with an initial value of 2 and decreases linearly in each iteration; also, $\vec{r}$ is a random value in the range [0,1].
In the updating process, the solutions became feasible and a procedure was needed to make the infeasible solutions feasible. For this purpose, for the variable Y in each solution, the non-zero cells were first converted to 0 and 1 in accordance with the relevant constraints, and the variable X cells values were then initialized based on the variable Y values, considering to the model constraints.
For the variable Y in each path and also to update the best solution, of all the solutions found, if the best solution was better than$\vec{X}^{*}$, $\vec{X}^{*}$ would be replaced and otherwise, it remained unchanged.

4.1.5. The choice of next generation solutions

At each stage of the WOA, among the previous and new solutions, the N (population size) solution was selected as the best solution according to the level of fitness that was here the same as the Cs criterion (described in the initial solution generation section). To select the best location, the Cs value was calculated for all locations and then they were sorted in ascending order of Cs value and finally, N first locations were selected.

4.1.6. Updating Pareto Archive

Since there is no single solution in solving multi-objective problems where all objectives are optimal due to the inconsistency between objectives, a set of dominant solutions is presented as optimal (near optimal). In this study, a Pareto -based approach was used to solve the problem, the quality of solutions of which was very important. Therefore, this archive was updated in each iteration of the algorithm. All of the solutions in this archive and the new generated solutions were poured into a solution pool and leveled for updating. Then, all first level solutions were selected as new Pareto archive solutions.

5. Computational results

In this study, the model for a small size sample problem was solved by GAMS software and WOA. Then, the results of the GAMS solution and the proposed algorithm were compared to evaluate the validity of the model and the algorithm. After validation of the model and algorithm, the WOA and genetic algorithms were implemented in MATLAB software, and the results were compared with respect to the indices such as quality, uniformity, dispersion and solution time, in order to test the efficiency of the algorithms. All calculations were performed using a i7 7500U -12GB -1TB -R5 M335 4GB Core PC computer.

5.1. Comparison indices

There are various indices for evaluating the quality and dispersion of multi-objective meta- heuristic algorithms. In this study, the indices of quality, uniformity and dispersion [36] were considered for comparison.

Quality - This index compares the quality of Pareto solutions obtained by each method. In fact, it levels all the Pareto solutions obtained by each of the two WOA and genetic algorithms together and determines how many percent of the level 1 solutions belong to each method. The higher the percentage, the higher the quality of the algorithm.

Uniformity - This index tests the uniformity of the distribution of Pareto solutions obtained at the solution boundary and is defined as follows:

$$s = \frac{\sum_{i=1}^{N-1} |d_{mean} - d_i|}{(N-1) \times d_{mean}} \tag{5.1}$$

Where d_i is the Euclidean distance between two found neighboring non-dominated solutions and d_{mean} is the mean of d_i.

Dispersion - This index determines the number of non-dominated solutions found on the optimal boundary and is defined as follows:

$$D = \sqrt{\sum_{i=1}^{N} \max\left(\|x_t^i - y_t^i\|\right)} \tag{5.2}$$

Where $\|x_t^i - y_t^i\|$ donates the Euclidean distance between two neighboring solutions x_t^i and y_t^i on the optimal boundary.

5.2. Experimental problems

In this study, several experimental problems were designed in small, medium and large sized groups. To generate some of the experimental problems, some of the previous studies were selected, their sample problems were used to the extent that they fit the model, and some of the parameters not covered by the studies were randomly selected since there were no sample problems in the literature that fit the model presented in this study and cover all parts of the model. Past studies were also reviewed to determine some of the other experimental problems. Experimental problems were designed according to the size range of the selected problems in these studies.

5.2.1. Experimental problems

Small-sized problems were selected according to the problems solved by Kanan et al. (2010) [37]. Problems solved by them did not cover all model parameters. The selection of parameters that were not covered by their study was performed randomly. As with the problems cited in the article, for all problems, the number of products was 1, the number of forward logistics facilities was 2, and the number of reverse logistics facilities was 2 to 5.

In this study, a number of problems in the literature was first examined to designing and generate experimental medium to large sized problems. It was then attempted to determine medium and large sized problems as well as a number of problems with sizes larger than those found in previous studies with respect to the sizes available in the literature [38, 39].

5.3. Setting parameters

The algorithm parameters were set as follows:

- In the whale algorithm, the population size was 150, the number of VNS iterations was 5, and the number of algorithm iterations was 300.
- In the genetic algorithm, the crossover rate was 0.8, the mutation rate was 0.1, and the population size was 150.

The model parameters were set and initialized using the study by Pour-Alikhani et al. (2013) [40]. It should be noted that some of the model parameters presented in the present study were not covered by the model presented in the study by Pour-Alikhani et al. (2013). In order to determine the parameters, random values which were reasonable compared to other values were tried to be generated.

The following values were considered in the production of sample problems:

- Customer I demand for product s was in the uniform interval [50,100].
- Capacity of all supply centers was 6000, capacity of all production centers was 9000, warehouse capacity of all production centers was 5000, capacity to reproduce products in all production centers was 4000, capacity of all distribution centers was 4000, capacity for distribution of second-hand products in all distribution centers was 4000, capacity to produce raw materials from second-hand products in all supply centers was 3,000, capacity of recovery / collection centers was in the uniform interval [2000,4000], recycling was in the uniform interval [4000,6000], and the capacity of the disposal centers was in the uniform interval [2000,4000].
- Cost of establishing disposal centers was in the uniform interval [4000, 6000], cost of Establishing recovery / collection centers was in the uniform interval [8000, 10000], cost of establishing recycling centers was in the uniform interval [12000, 16000], and cost of establishing distribution centers was in the uniform interval [5000,000,000].

Table 1: The optimal price for a unit returned product (variable $fp^{sen}{}_{s,qs}$)

Scenario / quality level	Sen1	Sen2
qs1	12	15
qs2	15	10
qs3	10	15

- The return rate of product from collection centers to the other centers was randomly in the interval [0, 1].
- The return rate of product from customers was randomly in the uniform interval [0, 50].
- All shipping costs were randomly in the uniform interval [1, 1000].
- The inventory maintenance cost was in the uniform interval [400, 600].
- The quality level for all problems and all products was 3.
- The minimum and maximum prices were in the uniform intervals [10, 30] and [50, 100], respectively.
- The value added to the system for each product returned to the system was calculated as 10% of the average minimum and maximum price.
- The cost of recycling and disposal of a unit of product was in the uniform interval [5, 15].

It is worth noting that the above values are only designed for small sized problems. The parameter values for medium and large sized problems were determined using trial and error, because the algorithms were unable to find solutions to these problems with these values. The capacity of each center for the medium and large sized groups was equal to the values of the small sized problems multiplied by the number of potential points of that center.

5.4. Model validation results

First, the four-objective model was transformed into a single-objective model using the LP-Metric, and then the resulting single-objective model was solved in the GAMS software for small sized problems to validate the model.
In this study, the LM-Metric, one of the popular methods in the multi-objective problems literature, was used. We always seek to minimize the deviations of the objective functions from their optimal value. In this method, the individual solutions are first calculated for the optimality of each of the objectives functions and then the objective function is minimized.
The model provided was coded by GAMS software and solved by the BARON solver. In this method, the value of P was 1 and the objectives weight was considered to be equal, namely 0.5.
To solve the model in GAMS software, a small-sized problem was considered where the number of suppliers, producers and distributors was 2, the number of customer centers was 3, the number of collection, recycling and disposal centers was 2. , the number of products was 1, the number of periods was 2, the number scenarios was 2, and the number of quality levels was 3. The results of solving this problem are described below.
The value of the objective function of the GAMS solver was 4.963. The results of GAMS were evaluated based on the values of variables and the existence of constraints. According to the results, the model was feasible and valid.

Table 2: Values of locating distribution centers (y_k)

y_k	**Distribution center**
0	**1**
1	**2**

Table 3: Values of locating collection centers (y_m)

y_m	**Collection center**
0	**1**
1	**2**

Table 4: Values of locating recycling centers (y_p)

y_p	**Recycling center**
0	**1**
1	**2**

Table 5: Values of locating disposal centers

y_n	**Disposal center**
0	**1**
1	**2**

Table 6: The flow rate of product from supply centers to production centers ($x^{st}_{ij,sen}$)

(I,j)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(i1,j1)	0	0	0	0
(i1,j2)	183	179.48	174.5	187.48
(i2,j1)	0	0	0	0
(i2,j2)	0	0	0	0

Table 7: The flow rate of product from production centers to distribution centers ($x^{st}_{jk,sen}$)

(j,k)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(j1,k1)	0	0	0	0
(j1,k2)	0	0	0	0
(j2,k1)	0	0	0	0
(j2,k2)	256.2	254.78	245.6	255.28

Table 8: The flow rate of product from production centers to their own warehouses ($Q^{st}_{jj,sen}$)

(j)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
J1	0	0	0	0
J2	0	0	0	0

Table 9: The flow rate of product from distribution centers to customer centers ($x^{st}_{jk,sen}$)

(j,k)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(k1,l1)	0	0	0	0
(k1,l2)	0	0	0	0
(k1,l3)	0	0	0	0
(k2,l1)	100	110	95	100
(k2,l2)	85	90	88	90
(k2,l3)	120	110	110	115

Table 10: The flow rate of product from producer's warehouse to distribution centers ($Q^{st}_{jk,sen}$)

(j,k)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(j1,k1)	0	0	0	0
(j1,k2)	0	0	0	0
(j2,k1)	0	0	0	0
(j2,k2)	0	0	0	0

Table 11: (a) The flow rate of product returned from customers to collection centers with quality level 1 ($x^{st}_{lm,qs,sen}$)

(l,m)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(l1,m1)	0	0	0	0
(l1,m2)	20	18	22	15
(l2,m1)	0	0	0	0
(l2,m2)	10	15	15	18
(l3,m1)	0	0	0	0
(l3,m2)	29	26	27	26

Table 11: (b) The flow rate of product returned from customers to collection centers with quality level 2 ($x^{st}_{lm,qs,sen}$)

(l,m)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(l1,m1)	0	0	0	0
(l1,m2)	28	30	25	23
(l2,m1)	0	0	0	0
(l2,m2)	20	22	20	20
(l3,m1)	0	0	0	0
(l3,m2)	32	35	30	31

Table 11: (c) The flow rate of product returned from customers to collection centers with quality level 3 ($x^{st}_{lm,qs,sen}$)

(l,m)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(l1,m1)	0	0	0	0
(l1,m2)	35	35	32	30
(l2,m1)	0	0	0	0
(l2,m2)	30	28	28	26
(l3,m1)	0	0	0	0
(l3,m2)	40	42	38	37

Table 12: Product flow rate from collection centers to distribution centers ($x^{st}_{mk,sen}$)

(m,k)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(m1,k1)	0	0	0	0
(m1,k2)	0	0	0	0
(m2,k1)	0	0	0	0
(m2,k2)	48.8	55.22	47.4	49.72

Table 13: Product flow rate from collection centers to recycling centers ($x^{st}_{mp,sen}$)

(m,p)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(m1,p1)	0	0	0	0
(m1,p2)	0	0	0	0
(m2,p1)	0	0	0	0
(m2,p2)	24.4	15.06	23.7	13.56

Table 14: Product flow rate from collection centers to disposal centers ($x^{st}_{mn,sen}$)

(m,n)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(m1,n1)	0	0	0	0
(m1,n2)	0	0	0	0
(m2,n1)	0	0	0	0
(m2,n2)	97.6	105.42	94.8	94.92

Table 15: Product flow rate from collection centers to production centers ($x^{st}_{mj,sen}$)

(m,j)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(m1,j1)	0	0	0	0
(m1,j2)	0	0	0	0
(m2,j1)	0	0	0	0
(m2,j2)	73.2	75.3	71.1	67.8

Table 16: Product flow rate from recycling centers to production centers ($x^{st}_{pj,sen}$)

(p,j)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(p1,j1)	0	0	0	0
(p1,j2)	0	0	0	0
(p2,j1)	0	0	0	0
(p2,j2)	0	0	0	0

Table 17: Product flow rate from recycling centers to supply centers ($x^{st}_{pi,sen}$)

(p,i)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
(p1,i1)	0	0	0	0
(p1,i2)	0	0	0	0
(p2,i1)	0	0	0	0
(p2,i2)	24.4	15.06	23.7	13.56

Table 18: The remaining inventory in the warehouse of production centers ($U^{st}_{j,sen}$)

(j)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
J1	0	0	0	0
J2	0	0	0	0

Table 19: Unmet demand ($q^{st}_{l,sen}$)

(l)/(sen,t)	(sen1,t1)	(sen1,t2)	(sen2,t1)	(sen2,t2)
L1	0	0	0	0
L2	0	0	0	0
L3	0	0	0	0

Table 20: Results of solving small sized problems

Prob.	WOA(whales optimization algorithm)			GA		
	Quality metric	Spacing metric	Diversity metric	Quality metric	Spacing metric	Diversity metric
1/2/2/2/2/2/2/2	100	1.1	698.2	0	0.70	445.8
1/2/2/2/2/3/3/3	95.05	1.13	605.2	4.95	0.70	356.2
1/2/2/2/2/4/4/4	87.9	0.84	717.2	12.1	0.46	287.4
1/2/2/2/2/5/5/5	73.1	0.71	732.8	26.9	0.31	557.3

On the other hand the model was solved by the WOA with the aim of optimizing the LP-Metric method. The objective function value of the WOA was 4.963 and was exactly in accordance with GAMS solver result. The same results of the GAMS software and the WOA indicated the convergence of the algorithm to the optimal and near optimal solution.

5.5. Executive results

In this section, the design problems were solved using two WOA and NSGA-II algorithms and their results were analyzed. Table 20 shows the results of the two algorithms with respect to the comparison indices.

The notation S / I / J / K / L / M / P / N was used to represent the sample problems where S is the number of products, I is the number of supply centers, J is the number of production centers, K is the number of distribution centers, M is the number of collection centers, P is the number of recycling centers, and N is the number of disposal centers (the number of periods was 4 and the number of scenarios was 2 for all problems).

According to the tables above, in all small, medium and large sized problems, the quality and dispersion indices values obtained for the WOA were larger than those calculated for the genetic algorithm, indicating the higher ability and power of the WOA in achieving near optimal solution as well as higher ability to discover and extract the solution feasible region than the genetic algorithm. Moreover, the uniformity index value suggested that in most cases, the genetic algorithm searched the solution region more uniformly. According to Figure (3.4), the time to solve the problems by the WOA was higher than the genetic algorithm, meaning that the WOA needed more time to solve these problems than the genetic algorithm. As the size of the problem became larger, the time to solve the problem by the algorithm was increasingly changed, and the time to solve the large sized problems was much higher than that for the small and medium size ones, indicating the difficulty of the problem. In the following figure, a comparison of the running time of the two algorithms for all problems can be seen.

6. Conclusion

This study was conducted aimed at optimizing the sustainable closed-loop supply chain planning, considering passive defense. For this purpose, a four-objective optimization model was presented and solved using WOA and genetic algorithms. Experimental sample problems were designed in three groups of small, medium and large size according to previous studies to solve the proposed model. Then, the results of the two WOA and genetic algorithm were compared with respect to indices including quality, dispersion, uniformity and solution time. According to the results, in all cases,

Table 21: Results of solving medium sized problems

Prob.	WOA(whales optimization algorithm)			GA		
	Quality metric	Spacing metric	Diversity metric	Quality metric	Spacing metric	Diversity metric
1/3/7/7/7/7/5/4	85.2	0.92	985.2	14.8	0.78	740.7
2/3/7/7/7/7/5/4	83.5	0.51	1365.9	16.5	0.47	840.9
3/3/7/7/7/7/5/4	88.1	0.64	1439.9	11.9	0.56	850.2
1/6/8/10/10/8/6/5	100	1.06	1468.3	0	0.71	1130.6
2/6/8/10/10/8/6/5	87.7	0.68	1582.2	12.3	0.44	1220.4
3/6/8/10/10/8/6/5	87.6	0.91	1702.3	12.4	0.78	1261.3
1/7/9/15/15/9/7/7	83.4	0.71	1708.9	16.6	0.47	1349.1
2/7/9/15/15/9/7/7	85.8	0.73	1763.2	14.2	0.62	1360.6
3/7/9/15/15/9/7/7	88.1	1.01	1930.2	11.9	0.49	1218.4

Table 22: Results of solving large sized problems

Prob.	WOA(whales optimization algorithm)			GA		
	Quality metric	Spacing metric	Diversity metric	Quality metric	Spacing metric	Diversity metric
1/10/20/20/30/16/7/6	90	0.75	2871.6	10	0.74	1901.6
2/10/20/20/30/16/7/6	85.9	1.72	2685.3	14.1	0.64	1954.2
3/10/20/20/30/16/7/6	87.6	1.67	3063.5	12.4	0.76	2112.5
1/15/40/40/70/35/12/10	70.9	0.73	2636.3	29.1	0.65	1901.9
2/15/40/40/70/35/12/10	89.9	0.71	2816.5	10.1	0.70	2265.1
3/15/40/40/70/35/12/10	66.8	1.70	3486.3	33.2	0.54	2793.6
1/15/45/45/90/40/15/13	87.2	1.17	4121.9	12.8	0.65	3278.6
2/15/45/45/90/40/15/13	100	1.13	4565.9	0	0.64	3397.7
3/15/45/45/90/40/15/13	88.4	1.04	5054.1	11.6	0.73	4758.7

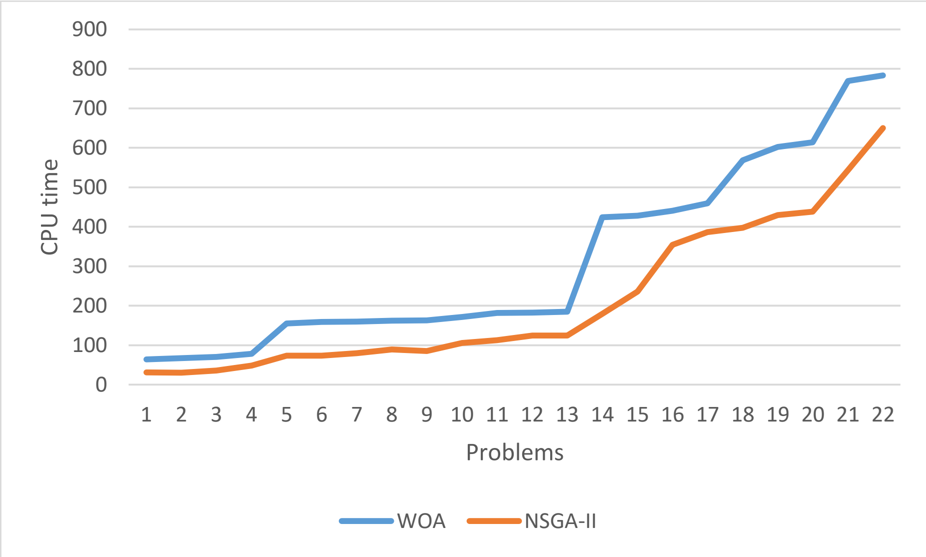

Figure 4: Comparison of runtime (in seconds)

the ability of the WOA to discover and extract the feasible region of the solution and to obtain near optimal solutions was higher than the genetic algorithm. However, the genetic algorithm performed better than the WOA in terms of uniformity and solution time. Investigating changes in problem solving time by increasing its size also confirmed that the problem was NP-HARD.

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