Presenting an agile supply chain mathematical model for COVID-19 (Corona) drugs using metaheuristic algorithms (case study: pharmaceutical industry)

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Abstract
This article focuses on the strategic issue of an agile supply chain. Different goals are considered in supply chain design. Today, the concept of sustainability in supply chains plays an important role in goal setting. In general, sustainability leads to less economic, social, and environmental risks, and attention to this type of sustainability covers many criteria in the literature. Therefore, in this study, optimization of the stability of a supply chain network has been considered. In addition, a lesser-known aspect of sustainability, the political aspect, has been added to the previous aspects. This paper assumes four levels, namely supplier, wholesaler, retailer, and customer. An optimal network structure is designed to consider economic, social, and environmental sustainability and the new measure of political sustainability. The design of this supply chain is done by defining a mathematical model that has several objective functions, including economic, political, and environmental goals. These objective functions select the relationships and links between the levels in a supply chain network. For this purpose, a directional graph corresponding to a supply chain is designed. Then, with the help of an ideal multi-objective planning problem, an optimal configuration is obtained, which is a subgraph of the main network graph. The target problem has been modeled for a holding company which is a supply chain for COVID-19 drugs. Then, problem is solved using Multi-objective Particle Swarm Optimization (MOPSO) metaheuristics algorithm and NSGAII multi-objective genetic algorithm. A comparison was carried out between these two methods, and the results indicated that MOPSO performed better. The value of the objective functions is calculated, and the best value for the considered functions is obtained. Also, the amount of drug supply has been obtained by two distributors. Also, the amount of medicine purchased by the customer from each pharmacy is determined.

Keywords Agile supply chain · Multi-objective Particle Swarm Optimization algorithm · COVID-19 · Political goals · Environment

Introduction
MSC is considered an essential global industry. Due to its impact on human life, any difficulty in accessing pharmaceutical items can endanger people’s lives during high-volume distribution and production. In developed societies, health status is an important criterion directly related to the time and adequate supply of vital drugs (Goodarzian et al. 2021; Chobar et al. 2022).

Due to increased uncertainty in the supply chain and factors such as political issues, demand fluctuations, technology changes, financial instabilities, and natural disasters, organizations were forced to spend resources to predict demand, supply, and internal uncertainties of the organization to reduce vulnerability and increase the supply chain tolerance. Due to these uncertainties and risk factors, the issue of supply chain management has been raised (Pourghader Chobar et al. 2021; Abolfazli et al. 2022).

Such issues are of utmost significance in sensitive supply chains such as MSCs. In general, the pharmaceutical industry seeks to increase the quality of life of individuals. However, today life-saving drugs are so small and expensive that they can easily be stolen, counterfeited, and smuggled. Since it is almost impossible for consumers to detect counterfeit medicine, counterfeit drugs and smuggling are on the rise worldwide. However, counterfeit drugs are just one of the...
pharmaceutical industry’s major problems. The drug distribution network is so complex that a product sometimes passes through ten layers of go-betweens in the market and reaches the customer. This increases the possibility of counterfeiting and increases the cost of the process and, therefore, increases the price of pharmaceutical products for customers.

The ability to track serial numbers in the pharmaceutical industry can solve both MSC problems. By using unique identification and tracking of each product unit in the supply chain, it is possible to identify suspicious products, respond quickly to incidents in the chain, and automate processes. This increases customer safety and improves business processes.

The following is a diagram of the MSC Fig. 1.

This paper assumes that there are four levels, namely supplier, wholesaler, retailer, and customer, and then an optimal network structure is designed considering economic, social, and environmental sustainability and the new measure of political sustainability. The design of this supply chain is done by defining a mathematical model that has several objective functions, including economic, political, and environmental goals. These objective functions select the relationships between the levels in a supply chain network. For this purpose, a directional graph corresponding to a supply chain is designed. Then, with the help of an ideal multi-objective planning problem, an optimal configuration is obtained, which is a subgraph of the main network graph. The target problem has been modeled for a holding company which is a supply chain for COVID-19 drugs. Then the problem was solved using Multi-objective Particle Swarm Optimization (MOPSO) metaheuristics algorithm and NSGAII multi-objective genetic algorithm. A comparison was carried out between these two methods, and the results indicated that MOPSO performed better. Therefore, main contributions of the paper are as follows:

- Development of a multi-echelon and multi-product mathematical modeling to evaluate the pharmaceutical supply chain during the COVID-19 pandemic.
- The cost of lost cost for unmet customer demand is considered addressing deficiencies in customer needs.

The rest of the paper is organized as follows: in the “Research background” section, a literature review is presented. In the “Problem definition” section, research methodology is provided. In the “Mathematical model of the problem” section, main research finding is presented. Finally, in the “Discussion and conclusion” section, conclusion and suggestion for future studies are presented.

Research background

Abdolazimi et al. (2021) presented designing a new mathematical model based on ABC analysis for inventory control problem. In this paper, a mathematical model is presented to classify inventory items, taking into account significant profit and cost-reduction indices. The model has an objective function to maximize the net profit of items in stock. Limitations such as budget even inventory shortages are taken into account too. The mathematical model is solved by the Benders decomposition and the Lagrange relaxation algorithms. Then, the results of the two solutions are compared. The TOPSIS technique and statistical tests are used to evaluate and compare the proposed solutions with one another and to choose the best one. Subsequently, several sensitivity analyses are performed on the model, which helps inventory control managers determine the effect of inventory management costs on optimal decision-making and item grouping. Finally, according to the results of evaluating the efficiency of the proposed model and the solution method, a real-world case study is conducted on the ceramic tile industry. Based on the proposed approach, several managerial perspectives are gained on optimal inventory grouping and item control strategies. Ghasemi et al. (2021) presented a bi-level mathematical model for logistic management considering the evolutionary game with environmental feedbacks. This paper
proposed a bi-level mathematical model for location, routing, and allocation of medical centers to distribution depots during the COVID-19 pandemic outbreak. The developed model has two players including interdictor (COVID-19) and fortifier (government). Accordingly, the aim of the first player (COVID-19) is to maximize system costs and causing further damage to the system. The goal of the second player (government) is to minimize the costs of location, routing, and allocation due to budget limitations. Lotfi et al. (2021) have researched renewable energy. The most important innovations in their study included the use of robust two-level programming techniques and game theory (Stackelberg competition) for locating renewable energy sites. The results show that the combination of uncertainties can increase energy production and supplier profits. In addition, the objective functions of the proposed model are compared with those under uncertain conditions. Sensitivity analysis of the main parameters is performed to validate the proposed model. As uncertainty increases, the energy produced decreases, and the supplier’s profit increases. Supplier profits gradually decrease as the discount rate increases. In addition, as the scale of the problems increases, the energy produced and the profit of the supplier increase. Jahangiri et al. (2021a) provided a ranking for key resources in the humanitarian supply chain in the emergency department of Iranian hospital using hybrid decision-making method under COVID-19 conditions. According to the obtain results, nurses in RK 1, receptionists RK 2, general surgeon RK 3, heart residents RK 4 and pulmonologist RK 5. Hybrid decision-making method in this paper is an invaluable contribution to the emergency department and medical managers for evaluation of current situation in the emergency department when crisis occur. Khalili-Damghani et al.’s (2022) study proposes a bi-level two-echelon mathematical model to minimize pre-disaster costs and maximize post-disaster relief coverage area. The model uses a geographic information system (GIS) to classify the disaster area and determine the optimal number and location of distribution centers while minimizing the relief supplies’ inventory costs. A simulation model is used to estimate the demand for relief supplies. A case study is presented to demonstrate the applicability and efficacy of the proposed method. The results confirm the difficulty of relief operations during the night as the cost of night-time relief operations is higher than daytime. In addition, the results show the coverage area increases as the demand surges. Therefore, establishing more distribution centers will increase operating costs and expand coverage area. In Babaeinesami et al.’s (2022) research, the question concerns a closed-loop supply chain (CLSC) network design considering suppliers, assembly centers, retailers, customers, collection centers, refurbishing centers, disassembly centers, and disposal centers. It aims to design a distribution network based on customers’ needs in order to simultaneously minimize the total cost and total CO2 emission. The findings demonstrate that the proposed self-adaptive NSGA-II is capable of generating efficient Pareto solutions. Moreover, according to the results obtained from sensitivity analysis, it is revealed that

![Diagram](image_url)
with increasing the capacity of distribution centers, the amount of shortage of products decreases. Moreover, as the demand increases, the number of established retailers rises. The number of retailers is increasing to some extent to establish 7 retailers.

**Problem definition**

The problem is the mathematical modeling of an agility supply chain network that minimizes the cost of environmental issues and the risk of supplying raw materials to pharmaceutical companies. In this research, network design has considered economic, environmental, and supply risk objectives and added social and political sustainability. In the network in this research, which is a multi-echelon and multi-product network, first, the products are manufactured in production centers and then sent to customers through distribution centers. Defective products are also recalled and stored in recall centers and sent to disposal centers. In the case of pharmaceutical companies, recalled products are not reused due to the issue’s sensitivity and are sent directly to disposal centers. In this regard, first, a directional graph is drawn for the process as mentioned above to make the supply chain model under study clearer. The directional graph of the supply chain network in this study is presented in Fig. 2:

**Modeling the problem**

General assumptions are given below:

- The model is multi-echelon and multi-product.
- Product flow exists only between consecutive facilities, and product flow between similar facilities is impossible.
- The location and number of market customers are known, and the suppliers are fixed and known.
- Deficiencies are considered in meeting customers’ needs, and a cost as a lost cost for unmet customer demand is considered.
- The locations of potential centers of production, distribution, recall, and disposal are identified.
- Not all recalled products are collected at recall centers, and there is a charge as a penalty for uncollected recalls.
- Inventory in production, distribution, and recall centers is considered for products.
- Three levels of capacity are considered for each of the centers that can be constructed.

**Sets and indices**

- Set of fixed places for suppliers \( (i = 1, 2, \ldots, I) \)
- Set of potential places for construction of production centers \( (j = 1, 2, \ldots, J) \)
- Set of potential places for construction of distribution centers \( (k = 1, 2, \ldots, K) \)
- Set of fixed places for market customers \( (l = 1, 2, \ldots, L) \)
- Set of potential places for construction of recall centers \( (m = 1, 2, \ldots, M) \)
- Set of potential places for construction of disposal centers \( (c = 1, 2, \ldots, C) \)
- Set of products \( (p = 1, 2, \ldots, P) \)
- Set of raw materials \( (z = 1, 2, \ldots, Z) \)
- Set of capacity levels for potential locations \( (h = 1, 2, \ldots, H) \)
- Set of potential options for transportation \( (f = 1, 2, \ldots, F) \)

**Parameters and decision variables**

In this section, the model parameters are introduced:

- Product manufacturing cost \( p \) in production center \( j \) \( (\text{MC}_{pj}) \)
- Disposal cost of each unit of product \( p \) in disposal center \( c \) \( (\text{DISD}_{pc}) \)
- Cost of inspection and collection of each unit of product \( p \) in recall center \( m \) \( (\text{CI}_{pm}) \)
- Cost of maintenance of each unit of product \( p \) in production center \( j \) \( (\text{HC}_{pj}) \)
- Cost of maintenance of each unit of product \( p \) in recall center \( m \) \( (\text{HC}_{pm}) \)
- Cost of fines for unmet demand per unit of product \( p \) \( (\text{PCY}_{p}) \)
- Cost of purchase or supply of each unit of material \( z \) from supplier \( i \) \( (\text{PC}_{zi}) \)
- Cost of purchasing each recalled product \( p \) from customer \( l \) \( (\text{RPC}_{pl}) \)
- Maximum number of production centers for construction \( (\text{MAJ}) \)
- Maximum number of distribution centers for construction \( (\text{MAK}) \)
- Demand for product \( p \) in customer center \( l \) \( (\text{D}_{pl}) \)
- Number of product \( p \) recalls from customer \( l \) \( (\text{RR}_{pl}) \)
- Production capacity of production centers \( j \) with capacity level \( h \) \( (\text{CAQ}_{jh}) \)
- Capacity of disposal of products in disposal center \( c \) with capacity level \( c \) \( (\text{CAZ}_{ch}) \)
- Shipping cost of each unit of raw material \( z \) from supplier \( i \) to production centers \( j \) by means of \( f \) \( (\text{TCK}_{zi}) \)
- Rate of use of raw material \( z \) in product production \( p \) \( (\text{PER}_{pz}) \)
- Rate of recall of used product \( p \) from customer region \( l \) to recall center \( m \) \( (\text{RR}_{pl}) \)
- Fixed cost of constructing a production center \( j \) with capacity level \( h \) \( (\text{FR}_{pj}) \)
- The capacity of transport \( f \) to transport raw materials from supplier \( i \) to manufacturer \( j \) \( (\text{CAP}_{fi}) \)
- Carbon emission rate per unit of product production \( p \) in production center \( j \) \( (\text{EM}_{pj}) \)
– Amount of carbon dioxide emissions per shipment of each raw material z from supplier i to production center j using transport f (ETM_{zifraw})
– Cost of reducing the risk of material supply z from supplier i (RC_{z})
– Risk of supplying of raw material from supplier i (\overline{SUR}_{z})
– Maximum permissible risk for supplying of raw material z (MSUR_{z})
– The amount of raw material transported z from supplier i to the production center j by transportation means of f (QZI_{zif})
– The amount of product p that is manufactured in production center j (QMP_{pj})
– The amount of product inventory p in distribution center k (QIC_{pk})
– The number of unmet customer demands l for product p (NNS_{lp})
– The binary variable of selection or non-selection of transport vehicle f to transport raw material from supplier i to production center j (A_{fij})
– The binary variable of construction of production center j with technology t and capacity level h (O_{jth})

The binary variable of supplying of raw material z by supplier i (W_{z})

Mathematical model of the problem

In this section, the four objective functions are introduced in the proposed model, and each function’s constraints is stated. Objective functions are represented by Z variables and are as follows:

– Economic objective function (Z_{1})
– The social or environmental objective function (Z_{2})
– Supply risk function (Z_{3})
– Political stability objective function (Z_{4})

Constraints on objective functions are discussed in the next section. Also, at the end of this chapter, the values of each objective function for different conditions applied in the multi-objective optimization algorithm will be listed and analyzed in the relevant tables.

The economic objective function of the research is as follows:

\[
\begin{align*}
\min Z_{1} &= \sum_{z} \sum_{i} \overline{SUR}_{zj} \times RC_{zj} \times W_{z} + \sum_{j} \sum_{h} FR_{jth} \times O_{jth} + \sum_{k} \sum_{h} FS_{kth} \times P_{jth} \\
&+ \sum_{m} \sum_{h} FT_{mth} \times Q_{mnh} + \sum_{j} \sum_{h} FR_{jth} \times O_{jth} + \sum_{c} \sum_{h} FR_{ch} \times U_{ch} \\
&+ \sum_{z} \sum_{i} \sum_{j} TCK_{zif} \times QZI_{zif} + \sum_{p} \sum_{j} \sum_{k} TCL_{pjkhf} \times QPI_{pjkhf} \\
&+ \sum_{z} \sum_{i} \sum_{j} TCK_{zif} \times QZI_{zif} + \sum_{p} \sum_{j} \sum_{k} TCL_{pjkhf} \times QPI_{pjkhf} \\
&+ \sum_{m} \sum_{c} \sum_{f} TCR_{pmcf} \times QPMC_{pmcf} + \sum_{p} \sum_{m} \sum_{c} \sum_{f} DISD_{pc} \times QPMC_{pmcf} \\
&+ \sum_{z} \sum_{i} \sum_{j} \sum_{f} CI_{pm} \times QPL_{plmf} + \sum_{z} \sum_{i} \sum_{j} \sum_{f} PCI_{j} \times QZI_{zif} + \sum_{p} \sum_{m} \sum_{f} RPC_{pl} \times QPL_{plmf} \\
&- SCB \times \sum_{z} \sum_{i} \sum_{j} QZV_{zif}
\end{align*}
\]

Also, the environmental objective function is defined as follows:

\[
\begin{align*}
\min Z_{2} &= \sum_{z} \sum_{i} \sum_{j} EM_{p} \times O_{jth} + \sum_{p} \sum_{h} ERECO_{p} \times R_{ph} + \sum_{p} \sum_{c} \sum_{h} EDIS_{pc} \times U_{ch} \\
&+ \sum_{z} \sum_{i} \sum_{j} ETM_{zif} \times QZI_{zif} + \sum_{p} \sum_{k} \sum_{l} ETN_{pkfr} \times QPK_{pkfr} \\
&+ \sum_{p} \sum_{k} \sum_{l} ETO_{pkfl} \times QPK_{pkfl} + \sum_{p} \sum_{k} \sum_{l} ETP_{plmf} \times QPL_{plmf} \\
&+ \sum_{p} \sum_{m} \sum_{f} ETR_{pmcf} \times QPMC_{pmcf} + \left[ \sum_{p} \sum_{j} \left( 1 - \bar{W}_{j} \right) \right] \times DAM_{j} \times QMP_{pj}
\end{align*}
\]
And the supply risk function in this study, which a multi-objective optimization algorithm must minimize, is considered as follows:

\[ Z_3 = \sum_i \sum_{z} \sum_j \text{SUR}_{zj} W_{ij} \]

For the fourth objective, which is political stability, since the supply chain does not control political parameters for planning, non-economic factors involved in the supply chain are considered the objective political function. Parameters such as technology level, resistance to payment, level of cooperation with foreign suppliers, and previous history of collaboration to prior suppliers are considered parameters of the objective political function, which \( Z_4 \) defines as:

\[ Z_4 = \sum_i \sum_{j} \sum_k \text{DL}_{ij} x_{ij} + \sum_i \sum_{j} \sum_{k} T_{ij} \frac{x_{ij}}{\sum_{k} D_{ik}} + \sum_i \sum_{j} \sum_{k} R_{ij} \frac{x_{ij}}{\sum_{k} D_{ik}} + \sum_i \sum_{j} \sum_{k} C_{ij} \frac{x_{ij}}{\sum_{k} D_{ik}} \]

The first objective function minimizes total costs; the second objective function minimizes environmental impacts, the third objective function minimizes environmental impacts, and the fourth objective function minimizes the effects of non-economic decisions under the political stability title (including policies to deal with suppliers, etc.).

**The constraints of the problem**

First constraint: The ensuring of construction of production, recall, distribution, and disposal centers with a maximum capacity of one level:

\[ \sum_k P_{kh} \leq 1 \quad \forall k \]

Second constraint: Limited capacity of product flow between different centers:

\[ \sum_k P_{kh} \leq \text{MAK} \]

Third constraint: The ensuring of the maximum of one type of facility for flow transfer between facilities.

\[ \sum_j A_{ij} \leq 1 \quad \forall i, j \]

Forth constraint: Ensuring that the input current to the recall centers is equal to or larger than the output current from them.

\[ \sum_i \sum_j QPL_{plmf} \geq \sum_i \sum_j QPMN_{pmnf} + \sum_i \sum_j QPMO_{pmof} + \sum_i \sum_j QPMC_{pmcf} \quad \forall p, m \]

Fifth constraint: Ensuring that the total production of products in production centers is greater than or equal to the output current from them.

\[ \sum_i \sum_j QMP_{pj} \geq \sum_i \sum_j QPJ_{pjf} \quad \forall p \]

Sixth constraint: Ensuring that the amount of transfer from recall centers to disposal centers is at least proportional to the amount of input current to recall center or equal to it:

\[ \sum_j QPMN_{pmnf} \geq \sum_j QPL_{plmf} \quad \forall p, m \]

Seventh constraint: Ensuring the product flows between different centers to facilitate the choice of means of transportation.

\[ A_{ij} \leq \sum_z QZI_{zij} \quad \forall i, j, f \]

Eighth constraint: Ensuring the absence of transport between places that have nothing to do with each other. This constraint ensures that product flow is only allowed through active transportation network options.

\[ A_{ij} \leq \sum_z QZI_{zij} \quad \forall i, j, f \]

Ninth constraint: Indicates the need for production centers for a raw materials ratio provided by suppliers.

\[ \sum_z QZI_{zij} < MA_{ij} \quad \forall i, j, f \]

Tenth constraint: Ensuring that the total output flow of raw materials from each supplier to the production centers is not more than the supplier’s capacity.

\[ \sum_z \sum_j \sum_i QZI_{zij} \leq CAS_i \quad \forall i \]

**Solution**

The proposed mathematical model is solved using the multi-objective algorithm, MOPSO, and NSGA-II. As the genetic algorithm, this algorithm starts with an initial population of randomly generated particles, P. In the next step, the generated population is evaluated in terms of defined objective functions. In the proposed model, we have four minimization objective functions. After dividing the population into different categories, we calculate the control parameter, called swarm distance, using the non-dominated sorting process. This parameter is calculated for each member in each group and indicates the degree of proximity of the target member to other members of the population of that group.
The basic idea of the MOPSO algorithm is that by having several objective functions instead of one, the concept of optimality changes. In the case of multi-objective optimization, the goal is always to find a good compromise rather than finding a single solution to the overall optimization. The concept of optimality had to be changed in general, and this was done by Vilfredo Pareto.

- MOPSO

In computational science, particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. It solves a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search space according to simple mathematical formula over the particle’s position and velocity. Each particle’s movement is influenced by its local best known position but is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions.

PSO is a metaheuristics as it makes few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. Also, PSO does not use the gradient of the problem being optimized, which means PSO does not require that the optimization problem be differentiable as is required by classic optimization methods such as gradient dicend and quasi-newton method. However, metaheuristics such as PSO do not guarantee an optimal solution is ever found.

- NSGA-II

Genetic Algorithm II is one of the most popular and widely used optimization algorithms in the field of multi-objective optimization. This algorithm was introduced by Deb in 2002. In addition to all the functions that NSGAI has, it can be mentioned as a model for the formation of many multi-objective optimization algorithms. This algorithm and its unique way of dealing with multi-objective optimization problems have been used many times by different people to create newer multi-objective optimization algorithms. By adding two necessary operators to the normal single-objective genetic algorithm, this algorithm has become a multi-objective algorithm, which instead of finding the best one-dimensional solution gives a set of best solutions known as the Pareto frontier.

This algorithm has shown great power in finding answers to problems, especially problems like the one in question, which includes a very large state space, and it is practically impossible for humans to check all its states in high dimensions. In other words, the speed of this algorithm in moving toward the solution of the problem is one of the salient features and positive points of this algorithm. Another positive point of this algorithm is that, unlike some other algorithms that search the solution space of the problem in only one direction, it simultaneously searches for the solution in several directions. Genetic algorithm’s lack of continuity and convexity of the objective function can also be considered another positive feature of this algorithm.

### Defining the basic parameters

The problem model is an agile supply chain model for pharmaceutical, single-cycle, and multi-product items. Table 1 presents the initial values of some of the main parameters.

| Parameter                          | Symbol | Value  |
|------------------------------------|--------|--------|
| Suppliers                          | s      | 4      |
| Production centers                 | f      | 2      |
| Distribution-recall centers        | Dc     | 5      |
| Disposal centers                   | Di     | 2      |
| Recycling centers                  | r      | 2      |
| Customers                          | C      | 10     |
| Employees                          | k      | 5      |
| Product sets                       | p      | 3      |
| Equipment sets                     | l      | 4      |
| Types of vehicles                  | m      | 3      |
| Number of manufactured products    | Np     | 1000   |
| Production cost per unit           | Cp     | 50000  |
| Cost of purchasing each unit of raw materials from the supplier | fp | 10000 |
| Cost of staff training             | Cs     | 1200000|
| Cost of product recycling          | Cpr    | 20000  |
| Cost of product disposal           | Cpr    | 13000  |
| Inspection cost per unit of recalled products | Fchp | 30000 |

### Results

The results for all four objective functions are presented based on the number of particles set to 50 and the dumping coefficient equal to 0.95. On the other hand, since the proposed model has several levels based on ten customers, five retailers (pharmacy), and two manufacturers (Table 1), the drug transfer flow is determined based on customer demand. Therefore, Table 2 presents the demand of each of the ten customers.

Based on the above table, it is clear that the first customer has a demand of 176 units of drugs related to the treatment of Corona, the second customer has a demand of
329 units, etc. It should be noted that the maximum time required to deliver drugs to any customer that does not cause dissatisfaction is 120 h. Another point to note is that since the initial values of the model are determined entirely randomly by the MOPSO algorithm, it may have an unreasonable or infeasible answer that the algorithm immediately tries to overcome to reach a feasible answer. This process is intended for the algorithm to run for 300 iterations. This can be seen in Table 3.

As shown in Table 3, up to iteration 116, all the solutions are feasible. However, the solution to the first objective function (cost) becomes infeasible due to reaching a local solution. It switches from local mode to global mode and solves the problem in general conditions to overcome this. The difference between feasible and infeasible is in terms and conditions that is necessary to solve the problem in the model (depicted in Table 4).

Accordingly, Table 5 reports the results of the proposed model using the MOPSO algorithm for all four objectives. As is reported in Table 5, the proposed model demonstrates acceptable results based on a numerical example.

Tables 6 and 7 show the transfer rate of drugs from manufacturer to distributors and from manufacturer to customers, respectively, to satisfy customer demand during the desired period. These values are the desired values to determine the optimal values of the objective functions. 

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### Table 2
The amount of drug demand by customers

| Customer | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|----------|---|---|---|---|---|---|---|---|---|----|
| Demand   | 176 | 329 | 427 | 729 | 102 | 356 | 449 | 224 | 234 | 332 |

### Table 3
Overcoming infeasible answers by MOPSO Algorithm

| Iteration | Best value | Status     |
|-----------|------------|------------|
| 113       | 11316401   | Feasible   |
| 114       | 11304029   | Feasible   |
| 115       | 11289397   | Feasible   |
| 116       | 11289397   | Feasible   |
| 117       | 11277298   | Infeasible |
| 118       | 11267925   | Feasible   |
| 119       | 11261608   | Feasible   |
| 120       | 11255978   | Feasible   |
| 121       | 11241246   | Feasible   |
| 122       | 11235875   | Feasible   |
| 123       | 11226372   | Feasible   |

### Table 4
Final feasible solution of MOPSO algorithm

| Iteration | Best value | Status     |
|-----------|------------|------------|
| 291       | 10981185   | Feasible   |
| 292       | 10981185   | Feasible   |
| 293       | 10981185   | Feasible   |
| 294       | 10981185   | Feasible   |
| 295       | 10981185   | Feasible   |
| 296       | 10981185   | Feasible   |
| 297       | 10981185   | Feasible   |
| 298       | 10981185   | Feasible   |
| 299       | 10981185   | Feasible   |
| 300       | 10981185   | Feasible   |
| 301       | 10981185   | Feasible   |

### Table 5
Results of running the model with the MOPSO algorithm

| Objective function | Cost objective function (Toman) | Pollutant emission objective function (PPM) | Risk objective function (%) | Political objective function | Execution time (seconds) | Value  |
|--------------------|---------------------------------|---------------------------------------------|------------------------------|------------------------------|--------------------------|--------|
|                    | 10981185                        | 11744                                       | 0.27                         | 117                          | 14.5963                  |

### Table 6
Transfer of product (unit) from manufacturer to distributor

| Distributors (pharmacies) | First manufacturer | Second manufacturer |
|---------------------------|--------------------|---------------------|
|                          | 0                  | 1853                |
|                          | 0                  | 2                  |
|                          | 0                  | 272                |
|                          | 1231               | 0                  |

### Table 7
Product transfer (unit) from pharmacies to customers

| Customers | First pharmacy | Second pharmacy | Third pharmacy | Fourth pharmacy | Fifth pharmacy |
|-----------|----------------|-----------------|----------------|-----------------|---------------|
|           | 0              | 0               | 0              | 176             | 0             |
|           | 0              | 0               | 2              | 0               | 327           |
|           | 427            | 0               | 0              | 0               | 0             |
|           | 691            | 0               | 0              | 0               | 38            |
|           | 0              | 0               | 96             | 6               | 0             |
|           | 277            | 0               | 0              | 0               | 79            |
|           | 449            | 0               | 0              | 0               | 0             |
|           | 0              | 0               | 0              | 0               | 227           |
|           | 0              | 0               | 0              | 0               | 225           |
|           | 0              | 0               | 0              | 0               | 332           |
Based on the above table, it can be seen that the first manufacturer has transferred 1231 units of the product to the fifth distributor (pharmacy), and the second manufacturer has transferred 1853 units to the first, two units to the third, and 272 units to the fourth distributors of the requested drugs. No drugs have been transferred to the second distributor.

It should be noted that the total amount of customer demand reported in Table 2 is equal to 3358 units, which, as stated earlier, to satisfy all customer demands must meet the total amount of drugs given in Table 4, which is also equal to 3358 units. Also, the maximum production capacity for the first manufacturer was equal to 1577 units, of which 1231 units

### Table 8 Absolute relative error (ARE)

| Objective function | Cost objective function (Toman) | Pollutant emission objective function (PPM) | Risk objective function (%) | Political objective function | Execution time (seconds) |
|--------------------|---------------------------------|---------------------------------------------|-----------------------------|-----------------------------|--------------------------|
| Mathematical       | 10981185                        | 11744                                      | 0.27                        | 117                         | 14.5963                  |
| MOPSO              | 10994123                        | 12564                                      | 0.29                        | 120                         | 13.2631                  |
| NSGA-II            | 11236925                        | 13561                                      | 0.35                        | 125                         | 12.364                   |
| ARE (Mathematical; MOPSO) | 0.001                        | 0.06                                       | 0.06                        | 0.02                         | 0.1                      |
| ARE (Mathematical; NSGA-II...) | 0.02                        | 0.1                                        | 0.2                         | 0.06                         | 0.1                      |

### Table 9 Results of objective functions for the small-, medium-, and large-scale test (MOPSO)

| Scale | Sample | Number of distributors (pharmacy) | Number of customers | Cost objective function (Toman) | Pollutant emission (ppm) | Risk objective function (%) | Political objective function |
|-------|--------|----------------------------------|---------------------|---------------------------------|--------------------------|----------------------------|----------------------------|
| Small | 1      | 6                                | 1                   | 1038137                         | 350                      | 0.058                      | 7                          |
|       | 2      | 2                                | 1                   | 1041902                         | 384                      | 0.119                      | 8                          |
|       | 3      | 2                                | 2                   | 1049381                         | 399                      | 0.130                      | 10                         |
|       | 4      | 3                                | 4                   | 1098989                         | 450                      | 0.298                      | 13                         |
|       | 5      | 3                                | 7                   | 1104406                         | 459                      | 0.151                      | 19                         |
|       | 6      | 4                                | 7                   | 1204445                         | 632                      | 0.224                      | 25                         |
|       | 7      | 4                                | 8                   | 1339126                         | 885                      | 0.324                      | 39                         |
|       | 8      | 4                                | 8                   | 1455302                         | 935                      | 0.133                      | 44                         |
|       | 9      | 5                                | 9                   | 1458389                         | 1002                     | 0.237                      | 68                         |
|       | 10     | 5                                | 9                   | 1477815                         | 1027                     | 0.276                      | 75                         |
| Medium| 1      | 6                                | 12                  | 10868333                        | 1178                     | 0.059                      | 50                         |
|       | 2      | 6                                | 14                  | 11805323                        | 1208                     | 0.341                      | 51                         |
|       | 3      | 7                                | 14                  | 12097451                        | 1321                     | 0.367                      | 52                         |
|       | 4      | 7                                | 15                  | 12221653                        | 1342                     | 0.228                      | 62                         |
|       | 5      | 8                                | 15                  | 12328363                        | 1574                     | 0.309                      | 64                         |
|       | 6      | 8                                | 16                  | 12958917                        | 1622                     | 0.230                      | 69                         |
|       | 7      | 9                                | 16                  | 13027853                        | 1700                     | 0.399                      | 73                         |
|       | 8      | 12                               | 18                  | 13395293                        | 1765                     | 0.202                      | 77                         |
|       | 9      | 13                               | 18                  | 13449990                        | 1932                     | 0.217                      | 80                         |
|       | 10     | 14                               | 18                  | 13774016                        | 2120                     | 0.389                      | 84                         |
| Large | 1      | 20                               | 30                  | 15203980                        | 13526                    | 0.177                      | 112                        |
|       | 2      | 20                               | 45                  | 20265270                        | 13658                    | 0.346                      | 114                        |
|       | 3      | 25                               | 50                  | 21423701                        | 14002                    | 0.443                      | 123                        |
|       | 4      | 30                               | 50                  | 21654514                        | 14230                    | 0.303                      | 129                        |
|       | 5      | 32                               | 60                  | 22558487                        | 15200                    | 0.391                      | 135                        |
|       | 6      | 38                               | 65                  | 22579460                        | 16210                    | 0.408                      | 139                        |
|       | 7      | 41                               | 65                  | 23429301                        | 16890                    | 0.479                      | 145                        |
|       | 8      | 45                               | 70                  | 24112607                        | 17532                    | 0.587                      | 160                        |
|       | 9      | 50                               | 70                  | 24128172                        | 18050                    | 0.599                      | 175                        |
|       | 10     | 60                               | 70                  | 25953788                        | 19850                    | 0.631                      | 191                        |
were considered here. The second manufacturer was 3071 units, for which 2127 units were transferred. This means that the number of drugs sent from the manufacturer to the distributor was less than the manufacturer’s maximum capacity.

Table 7 also shows the transfer rates of drugs from distributors (pharmacies) to customers.

Based on the above table, it is determined that the first customer receives all of his 176 unit demands from the fourth distributor. Or, to satisfy the 234 requests of the ninth customer, they receive nine units from the first distributor and 225 units from the second distributor. Also, in this table, the sum of each row is equal to the number of customer requests that have been satisfied.

To show the capability of the proposed model against other considered calculation methods such as MOPSO and NSGA-II, the absolute relative error (ARE) has been calculated according to the recommendation of Abolghasemian et al. (2020) and Jahangiri et al. (2021b). According to the calculation errors based on the value of the obtained objective functions, it has been determined that the MOPSO method has a smaller distance with the mathematical model. Therefore, its results are more valid in terms of computational accuracy. Table 8 shows the calculation results of solving the model and calculating the intended error.

As shown in Table 6, in all cases considered, the calculation error between the mathematical model and MOPSO method is less than the NSGA-II.

### Sensitivity analysis

In this section, to evaluate the sensitivity analysis of the problem, the model is examined for different examples with small, medium, and large scales using two algorithms,

### Table 10 Results of objective functions for the small-, medium-, and large-scale test (NSGA-II)

| Scale | Sample | Number of distributors (pharmacy) | Number of customers | Cost objective function (Toman) | Pollutant emission (ppm) | Risk objective function (%) | Political objective function |
|-------|--------|----------------------------------|---------------------|---------------------------------|--------------------------|---------------------------|-----------------------------|
| Small | 1  2   | 1                                | 1                   | 1054525                         | 361                      | 0.061                     | 8                           |
|       | 2  2   | 2                                | 2                   | 1063522                         | 390                      | 0.128                     | 8                           |
|       | 3  2   | 4                                | 4                   | 1074479                         | 402                      | 0.135                     | 11                          |
|       | 4  3   | 4                                | 4                   | 1112415                         | 462                      | 0.314                     | 15                          |
|       | 5  3   | 7                                | 7                   | 1126336                         | 473                      | 0.163                     | 20                          |
|       | 6  4   | 7                                | 7                   | 1245528                         | 659                      | 0.239                     | 27                          |
|       | 7  4   | 8                                | 8                   | 1524180                         | 906                      | 0.341                     | 43                          |
|       | 8  4   | 8                                | 8                   | 1566321                         | 957                      | 0.158                     | 47                          |
|       | 9  5   | 9                                | 9                   | 1490413                         | 1012                     | 0.241                     | 72                          |
|       | 10  5  | 9                                | 9                   | 1539859                         | 1049                     | 0.301                     | 80                          |
| Medium | 1  6   | 12                               | 12                  | 11045889                        | 1322                     | 0.12                      | 53                          |
|       | 2  6   | 14                               | 14                  | 12154715                        | 1337                     | 0.356                     | 59                          |
|       | 3  7   | 14                               | 14                  | 12560326                        | 1592                     | 0.371                     | 69                          |
|       | 4  7   | 15                               | 15                  | 12644709                        | 1653                     | 0.231                     | 80                          |
|       | 5  8   | 15                               | 15                  | 12963328                        | 1950                     | 0.312                     | 80                          |
|       | 6  8   | 16                               | 16                  | 13599507                        | 1958                     | 0.239                     | 81                          |
|       | 7  9   | 16                               | 16                  | 13842155                        | 2069                     | 0.415                     | 84                          |
|       | 8  12  | 18                               | 18                  | 14263102                        | 2109                     | 0.210                     | 85                          |
|       | 9  13  | 18                               | 18                  | 14585772                        | 2111                     | 0.219                     | 89                          |
|       | 10  14 | 18                               | 18                  | 15080704                        | 2122                     | 0.415                     | 93                          |
| Large  | 1  20  | 30                               | 30                  | 15,878,009                      | 15,321                   | 0.201                     | 122                         |
|       | 2  20  | 45                               | 45                  | 16,508,714                      | 16,807                   | 0.359                     | 126                         |
|       | 3  25  | 50                               | 50                  | 21046485                        | 17243                    | 0.481                     | 131                         |
|       | 4  30  | 50                               | 50                  | 21245259                        | 17296                    | 0.329                     | 135                         |
|       | 5  32  | 60                               | 60                  | 22,857,772                      | 17,633                   | 0.405                     | 141                         |
|       | 6  38  | 65                               | 65                  | 23,429,838                      | 18,828                   | 0.415                     | 154                         |
|       | 7  41  | 65                               | 65                  | 23968083                        | 19,309                   | 0.502                     | 161                         |
|       | 8  45  | 70                               | 70                  | 24099886                        | 19,655                   | 0.592                     | 167                         |
|       | 9  50  | 70                               | 70                  | 25,479,452                      | 19,738                   | 0.621                     | 181                         |
|       | 10  60 | 70                               | 70                  | 26968907                        | 19,964                   | 0.640                     | 193                         |
NSGA-II and MOPSO. Therefore, in the first part, the results of all four objective functions for all three scales are presented using the MOPSO algorithm in Table 9 and in the second part with the NSGA-II algorithm in Table 10.

**MOPSO results**

The results of running the model in three experiments with the small, medium, and large scales using the MOPSO algorithm are presented in the following tables.

**NSGA-II results**

The results of solving the problem using the proposed model in three experiments with small, medium, and large data sizes using NSGA-II algorithm are presented in the following tables.

To compare the results obtained from both MOPSO and NSGA-II algorithms that determined all four objective functions in all three experiments, Figs. 3, 4, 5, and 6 are presented.

In this paper, the sustainable agile supply chain model was reviewed and solved in MATLAB software. Due to the NP-hardness of the problem, we used two
multi-objective metaheuristic algorithms, NSGAII and particle swarm MOPSO, and presented the model results for all four objective functions. Also, the result analysis revealed that the constraints of the problem are satisfied, and the amount of product delivery (drugs required for patients with coronavirus) is based on the amount of product demand by customers and the number of products received by customers. Then we analyzed the problem in more detail and solved the model for three different scales of small, large, and medium, each of which had ten examples. And finally, we presented the results as comparative diagrams between the two algorithms.

**Discussion and conclusion**

In this paper, multi-objective particle swarm optimization and multi-objective genetics were used to find the optimal solution for the pharmaceutical industry’s four-objective agile supply chain programming problem, and the optimal values obtained from each method were compared with each other and analyzed. The value of the objective functions is calculated, and the best value for the considered functions is obtained. Also, the amount of drug supply has been obtained by two distributors. Also, the amount of medicine purchased by the customer from each pharmacy is determined. According to the results gap between MOPSO and NSGA-II and mathematical model, it has been shown that the MOPSO method has high computational accuracy against NSGA-II. Therefore, the particle swarm method (MOPSO) has more variety in solution discovery due to finding optimal local and global solutions and its continuous nature. The genetic optimization algorithm (NSGA-II) establishes a more excellent balance between the detection and productivity criteria and prevents getting stuck in the local optimum. Therefore, the MOPSO-based method, in addition to its high ability to discover optimal responses, has a high speed and consequently a high rate of convergence and variability compared to the particle swarm method. The experimental results showed that the multi-objective particle swarm algorithm was better and more effective than the genetic algorithm in finding better and more efficient solutions. Compared to methods with non-evolutionary solutions works better in finding the optimal solution, maximizing profits, reducing environmental impacts, risk, and drug delivery policies. In other words, the advantage of the proposed method compared to other methods is automatic subset creation and finding global optimums along with local optimums to consciously
maximize the calculation of profit from each stage of the supply chain. According to the main advantages of the article, it can be concluded that in the process of drug distribution, in this article, four objectives of cost, pollution, risk, and government functions have been investigated. Based on the obtained results, we have come to the conclusion that all four mentioned goals are highly effective. Therefore, pharmaceutical companies should do the right thing in strengthening their collection in order to overcome the mentioned goals. In addition, the proposed method has wider applicability. In the future, we intend to focus on the design of supply chain systems with other purposes, in uncertain and ambiguous ranges and the like. Due to the fact that this article was designed during the COVID-19 epidemic, the collection of information due to strict laws is considered the most important limitation of the research. Also, development of the problem by considering random parameters such as demand in modeling through robust programming can be considered.

**Author contribution** Seyed Ahmad Shayannia: All done by one author.

**Data availability** The data that support the findings of this study are available from the corresponding author, upon reasonable request.

**Declarations**

**Ethical approval** This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue and has not self-plagiarism.

**Consent to participate and consent to publish** I hereby transfer the unlimited rights of publication of the above-mentioned paper in whole to the *Environmental Science and Pollution Research*.

**Competing interests** The authors declare no competing interests.

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