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A Multi-objective Sustainable Medicine Supply Chain Network Design Using a Novel Hybrid Multi-objective Metaheuristic Algorithm

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ABSTRACT

End-of-life products have a severe impact on the ecological system. Potential production policies and distribution strategies for the newly manufactured product have attracted significant attention to sustainable development. Sustainability in supply chain management has much importance to achieve eco-friendly goals. In this study, we have developed sustainable objectives in the supply chain optimization framework with different constraints. The trade-off between economic, environmental and social effects objectives have identified by ensuring the optimal allocation of different products among various levels. In this regard, a new sustainability multi-objective mixed-integer linear programming mathematical model in the medicine supply chain network is developed. Although the proposed model is an NP-hard problem, we develop a novel hybrid Particle Swarm Optimization and Genetic Algorithm to achieve Pareto solutions. Then, to adjust the important parameters of the algorithms and chose the optimum levels of the significant factors for more efficiency is employed the Taguchi method. The results show that the economic and environmental effects tend to be decreased and the social impacts tend to be increased in the medicine supply chain network which can exhibit the best sustainability performance. The various outcomes of numerical experiments indicate that the proposed solution algorithm is more reliable than other algorithms. The solution methods are complemented with several sensitivity analyses on the input parameters of the model.

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1. INTRODUCTION

Over the past few decades, significant attention has put on sustainability in supply chain design. To fulfill the market need on time, the maximum coverage distance of the customer's zone is much needed and falls under social issues. As the production and consumption processes of products involve various phases in which environmental impacts are very severe and harmful. Especially, end-of-use (EOU) and end-of-life (EOL) phases of products have significant impacts on the environment [1-3]. Therefore, a sustainable supply chain management (SSCM) network is designed and implemented efficiently by many researchers to overcome the social issue and environmental impacts. The SSCM contemplates over three objectives such as economic cost, social issues and environmental impacts, known as Tripple Bottom Line (TBL) objectives for sustainable development [4-6].

The concept of sustainability in the medicine supply chain management (MSCM) network has much importance and adaptability due to the significant involvement of social and environmental aspects [6, 7]. The demand for pharmaceutical products is very high due to continuous degradation in human health standards and life expectancy. Various fatal diseases require regular vaccination doses to cure the patient. For vaccination purposes, injections are one of the most extensively used medicated products. Presently, the one-time-use (OTU) needle and syringes are prevailing in the market. The usage of injections for different diseases such as Hepatitis, HIV, and AIDS annually yield in 16 billion

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used needle and syringes which are toxic and severe [8-10]. Consequently, the environment and ecosystem have a significant adverse impact. Literature reveals that various research domain of medicine supply chain network MSCM has been covered in the last few years [11].

Some extensive literature survey papers in the field of SSCM have been presented by Cum et al. [12], Seuring [13], Brandenburg et al. [14]. Zhang et al. [15] discussed the multiple distribution channels in supply chain management (SCM) under stochastic uncertainty. They also developed the sustainable objectives comprising economic cost, improvement of customer services and reduction in environmental influences. The propounded Multi objective decision making supply chain management (MDCSCM) has been solved using the ant-bee colony method (MOABC) and made a comparative study with conventional SCM. Tsao et al. [16] also developed a computational study for sustainability in SCM. The multi-objective mathematical programming problem has formulated under uncertainty. The uncertain interactive method based on stochastic and fuzzy theory has been used to solve the model.

Pishvaee and Razmi [17] discussed the environmental effects of EOL products in supply chain management under uncertainty. The assessment of environmental impact has been done using the Eco-indicator 99 (LCA-based method) based on proposed supply chain design. A case study based on Iranian pharmaceutical companies has been presented under uncertainty. Lin et al. [18] presented the combination of sustainability and supply chain in terms of theoretical and managerial gaps. To identify the deficiencies of financing patterns, fuzzy TOPSIS has been adopted. After analyzing the results, significant aspects of the product delivery management policies have been highlighted or evacuated. Ahmadi et al. [19] incorporated the optimization mechanism in pharmaceutical supply chain management. The integrated component of PSCM has emerged into a good practice scheme for managerial points of view. Hulea et al. [20] recently suggested the optimal distribution of pharmaceutical products and presented a solution for pharmaceutical cold chain management using distributed ledger technology. The modeling of data and communication of system entities have well performed in the proposed study. Nasrollahi and Razmi [21] also discussed the integrated framework for PSCM design with a maximum expected coverage of demand. The proposed mathematical model has captured the sustainable objectives along with a set of constraints. The multi-objective Particle Swarm Optimization (PSO) and NSGA-II have been suggested to solve the propounded model. A computational study based on the private medical sector in the remote provinces of Iran has been presented to validate the model and solution algorithm.

The concept of sustainability has not been still incorporated in mathematical modeling of the MSCN problem. Therefore, all the above studies are confined to either economic objectives or environmental objectives related to their case study and lagging behind the sustainable objectives.

The first aim of this paper was to propose a new sustainable multi-objective MSCN which considers TBL objectives include minimization of total cost represents the economic cost, maximization of customer service coverage distance depicts the social issues and reduction in the environmental impacts reflects the environmental objective under a set of dynamic constraints which consequently results in the TBL approach.

Hence, an MSCN along with sustainable objectives is quite worth important to reveal the actual real-life scenario and could assist the decision-makers or managers to design the fruitful policies and strategies for the firm or company. Moreover, we have designed the model according to the input information of the parameter.

In addition, the second aim of this paper is to develop a novel multi-objective metaheuristic algorithm, namely, Hybrid Particle Swarm Optimization and Genetic Algorithm (HPSOGA) to find Pareto solutions and to solve the model. To summarize, the proposed paper illustrates some concerns that cover the literature gaps and can be categorized as follows:

- Designing a new sustainability MSCN considering,
- The aims of this MSCN include minimizing economic and environmental impacts and maximizing social effects,
- Developing a new hybrid metaheuristic algorithm for the first time to solve the sustainability MSCN,
- Providing several sensitivity analyses on the main parameters.

The suggested formulation and metaheuristic algorithms can be used for solving other similar multi-objective problems related to pharmaceutical and blood supply chain, perishable products supply chain networks, home health care problems, vehicle routing problems, green supply chain network, and other optimization problems. In any case, each algorithm or approach has its own advantages and limitations depending on the specific problem, so the comparison of performances could also be a significant and interesting issue for future research works.

The rest of this paper is organized as follows: section 2 is a mathematical model, problem description. The solution methodology to solve the presented model is stated in section 3. Section 4 is concerned with the Taguchi method and a numerical example, computational results. Section 5 explain the sensitivity analysis of parameters. Eventually, conclusions and future works are in section 6.

2. MATHEMATICAL MODELLING

2. 1. Problem Description

The proposed MSCN paper is concerned with the one-time-use (OUT) medicated needle and syringe, multi-level and for a single period. The propounded MSCN has been depicted in Figure 1. The whole supply chain design comprises a forward and reverses chain. The flow of newly medicated products initiates from the manufacturing plants to different levels. Customer zones receive the products either directly from manufacturing plants or via distribution centers. The EOL phase of products starts from customer zones where the possible use of the products takes place. The reverse chain includes collection centers that are responsible for the accumulation of EOU products from different customer zones. Then EOL needle and syringes are shipped for incineration and underground disposal purposes. Thus, the continuous repetition of this procedure ensures the management of medicated infectious wastes.

The proposed sustainable MSCN model has integrated the versatile aspects of sustainability. The sustainable goals inherently capture the commercial purpose, i.e., minimization of the total cost incurred over each product; social target, i.e., maximize customers' service facility by covering the maximal distance of markets and environmental goals i.e., reduction in the ecological impacts, respectively.

2. 2. Notation

Indices

s Index for supplier $s \in S$
m Index for manufacturer $m \in M$
d Index for distribution center $d \in D$
c Index for customer $c \in C$
k Index for collection center $k \in K$
n Index for incineration center $n \in N$

Parameters

φ_s Supplier capacity s
φ_m Manufacturer capacity m
φ_d Distribution center capacity d
φ_c Customer demand c
φ_k Collection center capacity k
φ_n Incineration center capacity n
β_m Fixed cost of manufacturer m
β_d Fixed cost of distribution center d
β_k Fixed cost of collection center k
β_n Fixed cost of incineration center n
γ_m Environmental impact of manufacturer m
γ_d Environmental impact of distribution center d
γ_k Environmental impact of collection center k
γ_n Environmental impact of incineration center n
D_{ij} Distance between two levels $[i,j \in S \cup^M \cup^D \cup^C \cup^K \cup^N, i \neq j]$
T_{ij} Transportation cost between two levels $[i,j \in S \cup^M \cup^D \cup^C \cup^K \cup^N, i \neq j]$
E_{ij} Environmental impacts between two levels $[i,j \in S \cup^M \cup^D \cup^C \cup^K \cup^N, i \neq j]$

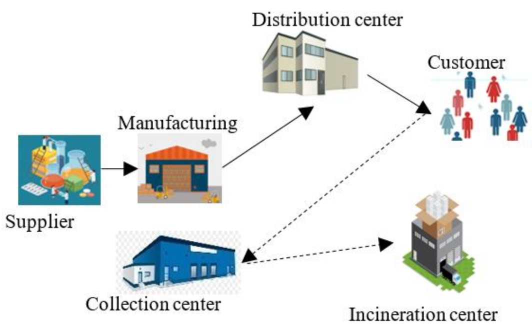

Figure 1. The structure of sustainability MSCN

Decision Variables

X_m If manufacturers m is opened and closed1; otherwise 0
X_d If distribution centers d is opened and closed1; otherwise 0
X_k If collection centers k is opened and closed1; otherwise 0
X_n If incineration centers n is opened and closed1; otherwise 0
Y_{sm} If the products shipped from suppliers s to manufacturers m1; otherwise 0
Y_{md} If the products shipped from manufacturers m to distribution centers d1; otherwise 0
Y_{dc} If the products shipped from distribution centers d to customer c 1; otherwise 0
Y_{mc} If the products shipped from manufacturers m to customer c 1; otherwise 0
Y_{ck} If the products shipped from customer c to collection center k 1; otherwise 0
Y_{kn} If the products shipped from collection center $k$to incineration center n1; otherwise 0
A_{sm} The amount of products transported from different suppliers s to manufacturers m
A_{md} The amount of products transported from manufacturers m to distribution centers d
A_{dc} The amount of products transported from distribution centers d to customer c
A_{mc} The amount of products transported from manufacturers m to customer c
A_{ck} The amount of products transported from customer c to collection center k
A_{kn} The amount of products transported from collection center $k$to incineration center n

2. 3. Mathematical Modeling

$$Min\ F_1 = \sum_{m \in M} \beta_m X_m + \sum_{d \in D} \beta_d X_d + \sum_{k \in K} \beta_k X_k + \sum_{n \in N} \beta_n X_n + \sum_{s \in S} \sum_{m \in M} T_{sm} A_{sm} + \sum_{m \in M} \sum_{d \in D} T_{md} A_{md} + \sum_{d \in D} \sum_{c \in C} T_{dc} A_{dc} + \sum_{m \in M} \sum_{c \in C} T_{mc} A_{mc} + \sum_{c \in C} \sum_{k \in K} T_{ck} A_{ck} + \sum_{k \in K} \sum_{n \in N} T_{kn} A_{kn} \quad (1)$$

$$Min\ F_2 = \sum_{m\in M}\gamma_m X_m + \sum_{d\in D}\gamma_d X_d + \sum_{k\in K}\gamma_k X_k + \sum_{n\in N}\gamma_n X_n + \sum_{s\in S}\sum_{m\in M} E_{sm}\,A_{sm} + \sum_{m\in M}\sum_{d\in D} E_{md}\,A_{md} + \sum_{d\in D}\sum_{c\in C} E_{dc}\,A_{dc} + \sum_{m\in M}\sum_{c\in C} E_{mc}\,A_{mc} + \sum_{c\in C}\sum_{k\in K} E_{ck}\,A_{ck} + \sum_{k\in K}\sum_{n\in N} E_{kn}\,A_{kn} \quad (2)$$

$$Max\ F_3 = \sum_{c\in C}\varphi_c\left(\sum_{m\in H_m} A_{mc} + \sum_{d\in H_d} A_{dc}\right) \quad (3)$$

$s.t.$

$$\sum_{m\in M} Y_{mc} + \sum_{d\in D} Y_{dc} \geq 1;\ \ \forall c \in C \quad (4)$$

$$\sum_{m\in M} A_{mc} + \sum_{d\in D} A_{dc} \cong \varphi_c;\ \ \forall c \in C \quad (5)$$

$$\sum_{m\in M} A_{mc} + \sum_{d\in D} A_{dc} \leq \varphi_m;\ \ \forall c \in C \quad (6)$$

$$\sum_{m\in M} A_{mc} \leq \varphi_d;\ \ \forall c \in C \quad (7)$$

$$\sum_{k\in K} A_{ck} \leq \varphi_k;\ \ \forall c \in C \quad (8)$$

$$\sum_{n\in N} A_{kn} \leq \varphi_n;\ \ \forall k \in K \quad (9)$$

$$A_{mc} = \{Y_{mc} = 1;\ \ \varphi_p; 0\};\ \forall\, m \in M, c \in C \quad (10)$$

$$A_{dc} = \{Y_{dc} = 1;\ \ \varphi_p; 0\};\ \forall\, d \in D, c \in C \quad (11)$$

$$Y_{mc} \leq X_m;\ \ \forall m \in M, c \in C \quad (12)$$

$$Y_{dc} \leq X_d;\ \ \forall\, d \in D, c \in C \quad (13)$$

$$X_m, X_d, X_k, X_n, Y_{sm}, Y_{md}, Y_{dc}, Y_{mc}, Y_{ck}, Y_{kn} \in \{0,1\} \quad (14)$$
$$A_{sm}, A_{md}, A_{dc}, A_{mc}, A_{ck}, A_{kn} \geq 0$$

The first objective (1) represents the economic cost function which includes fixed price and transportation costs among different echelons.

In terms of the second objective (2), in this proposed sustainable MSCN, the computational study background is presented in Figure 1 and the OTU needle and syringes are the functional units which effectively ensures the fulfillment of timely demand from the customer by manufacturing and distributing the products in the forward chain and safely collection of EOL products in reverse chain. The essence and purpose of the implementation of the Eco-indicator method are to estimate and predict the environmental impacts throughout the life cycle of the process and products in the propounded sustainable MSCN configurations. The second step concerned with the description of the life cycle system. In this proposed sustainable MSCN paper, the different stages of new and EOL products include (I) production of OTU needles and syringes at manufacturing plant, (II) transportation of the products from production facility to customers and distribution centers, (III) transportation from production centers to customers, (IV) shipments of used products from customers to collection centers, (V) operating of EOL products at collection centers, e.g., disassembling, (XI) transportation from collection centers to incineration facility, and (XII) further handling and processing at incineration centers and under-ground disposal pits. In the third step, the quantification of life cycle stages of products and processes has performed by considering the most common characteristic features. Finally, at the fourth step, the final accurate value is determined by (I) predicting the relevant Eo-indicator, (II) performing the multiplication between amounts and corresponding indicator score and (III) summing up the auxiliary outcomes. Consequently, the modeling approach much requires the environmental impact values in terms of per one unit of products and materials.

The third objective function (3) addresses social benefit by maximizing customer services in terms of customer demand coverage. To ensure the maximal coverage of customer demand, few additional parameters are needed to express in the form of mathematical expression. Assumed that the maximum coverage distance is represented by R_{max}. Customers who fall within this distance range with an open facility are supposed to be well-served. The different echelons of manufacturing plant and distribution centers are responsible for the fulfillment of demand. The manufacturing plant and distribution centers would serve different customer c who fall within the coverage spectrum of maximum distance and are depicted as $H_m = \{m \in M: D_{mc} \leq R_{max}\}$ and $H_d = \{d \in D: D_{dc} \leq R_{max}\}$, respectively.

The following are the relevant constraints or restrictions under which the objective functions are to be optimized by yielding the most promising and systematic strategies for the distribution of syringe and needles among different customers in the proposed MSCN designed model. After the use of the syringe, the maximum collection of waste syringes has been developed for further disposal or incineration. For the sake of convenience, we have formulated the dynamic constraints that reveal each restriction efficiently. Since demand is allowed to fulfill by mainly two-echelon, i.e., manufacturing plant and distribution centers. Therefore, it has been assured that the demand would be met at least by one echelon and represented in Equation (4). The demand from customers is not always stable, but some estimation of the demand pattern is used to determine the actual consumption of the products. Flexibility among demand constraint has been postulated to reveal reality more clearly. Hence we have developed an equality constraint (≅) meaning "essentially equal to" which signifies that more or less the constraints should be satisfied and are more flexible than inequality constraint.

To ensure that the demand must be satisfied by the shipping of the products from different sources point to customers, Equation (5) has been formulated. Different echelons have a certain capacity of the products to which the flow of products towards its destination is possible. Therefore, to ensure the capacity constraints over different echelons, Equations (6), (7), (8) and (9) have been effectively designed. The significance of to and for movement of products have also been depicted in Equations (10) and (11) by establishing the relationship between flow connectivity and the flow amount of the products between two echelons. The constraints are given in Equations (12) and (13) represents the flow of products that are associated with only open facilities in the proposed MSCN design network. Finally, constraint (14) states the type of decision variables.

3. SOLUTION METHODOLOGY

It has been proven that the sustainable MSCN problem is NP-hard [22-27]. Hence, the literature has seen several metaheuristics that were ordered to solve these NP-hard problems [28-30]. Among them, GA and PSO as a well-known population-based metaheuristic algorithm outperform most of the similar ones [31]. This advantage motivates us to use it again in our research. Besides, No Free Lunch theory says that there is no metaheuristic to show a good performance for all optimization problems [30]. Accordingly, the recent decade has seen a rapid development of metaheuristic methods [30, 31]. In this study, two nature-inspired algorithms, namely, GA and PSO as a population-based metaheuristic is used. A new hybrid method through integrating GA and PSO have been validated. The experimental results indicate that hybrid methods are always better than only using only one algorithm. Another main novelty of this study is to consider and to introduce a hybridization of these two algorithms for the first time. This study, a new hybrid algorithm (HPSO-GA) introduced due to the strength of search phrases, high convergence, and less computational time for the main two individual ones.

The reason for using these algorithms is that the real numbers are executed directly in the continuous space, and unlike other algorithms, it does not guarantee the existence of a definite solution. These algorithms require less number of parameters for adjusting that have an easy implement than other algorithms, have certain memory characteristics, high convergence rate, and highly flexible against optimal problems.

Therefore, the aim of this section is to present three effective meta-heuristic algorithms to solve the proposed model in real sizes. The MSCN model seeks to minimize the economic cost and environmental impacts and to maximize the social impacts. Although software programs make utilization of the branch and bound algorithm, it is not possible to overtake optimum or a near-optimum solution for large-size problems in a reasonable time. Then, the meta-heuristic algorithms to solve real size problems are used. Hence, we utilize two multi-objective meta-heuristic algorithms (PSO and GA). For more information about these algorithms refer to literature [25-30], respectively. Besides, our contribution in this paper, we developed a novel HPSOGA algorithm to solve the presented model.

In the present paper, the general framework of the solution representation performed for three products, two suppliers and two manufacturers are displayed in Figure 2. The numerical outcomes were obtained utilizing MATLAB (R2016b) on a computer with 6 GB RAM and a 2.50 GHz processor.

3. 1. HPSOGA Algorithm

In this section, we will develop a novel hybrid algorithm for solving the sustainability MSCN problem by integrating GA and PSO. This hybrid algorithm will be described as follows.

1. Set up parameters involving:

(i) w: inertial weight,
(j) N: particle numbers,
(k) c_1 and c_2: learning factors,
(l) W_{max}:the maximum of velocity,
(m) $rand_1, rand_2$ and $rand_3$: random numbers in interval [0, 1],
(n) m_{rate}: mutation rate, and
(o) c_{rate}: crossover rate.

2. Adjust the range of searching for x. The domain will affect the searching velocity. Starts each particle randomly with an initial position, X_{id}, in the pre-determined domain and velocity, V_{id}, within the domain of maximum speed, V_{max}. Utilize the float coding procedure to create random numbers for the upper-level variables. Hence, variable y solves at a lower level. The position of each particle X_{id}, is as follows:

$$X_{id} = (x_{i1}, \dots, x_{in}, y_{i1}, \dots, y_{im}) \quad (15)$$

3. Calculate the value of fitness for each particle utilizing the following equation:

$$F = c^t X_{id} \quad (16)$$

4. All the particles into two clusters divide based on the efficiency of fitness value. The first group is particles with better the value of fitness:

$$X_{id}^{n\acute{e}w} = \left(x_{11}, \dots, x_{(i/2)n}, y_{11}, \dots, y_{(i/2)m}\right) \quad (17)$$

Y_{sm}	s_1						s_2					
$m = 1$	1	0	0	1	1	0	0	1	1	0	0	1
$m = 2$	1	0	0	1	1	0	0	1	1	0	0	1

Figure 2. Solution representation

The second group is the particles with worse the value of fitness:

$$X_{id}^{n\acute{e}w} = \left(x_{(\frac{i}{2}+1)1}, \dots, x_{in}, y_{(\frac{i}{2}+1)1}, \dots, y_{im}\right) \quad (18)$$

5. Performance of the mutation and crossover for the first group to update the particles and calculate the corresponding the value of fitness. The equation of crossover is:

$$X_{id}^{new1} = Uniform(0,1)X_{id}^{n\acute{e}w} + (1 - Uniform(0,1)X_{id+1}^{n\acute{e}w}), id = 1,2, \dots, \frac{i}{2} - 1 \quad (19)$$

$$X_{id}^{new1} = Uniform(0,1)X_{id}^{n\acute{e}w} + (1 - Uniform(0,1)X_{id1}), id = i/2 \quad (20)$$

while the equation of mutation is:

$$X_{id}^{new2} = X_{id}^{new1} + rand_3 \times N(0,1) \quad (21)$$

Moreover, calculate the value of fitness for each new particle utilizing the following equation:

$$F = c^t X_{id}^{new2} \quad (22)$$

6. Update the current local best position, P_{id}, and global best position, P_{gd}.
7. Update all the particles, $X_{id} = (x_{i1}, \dots, x_{in}, y_{i1}, \dots, y_{im})$, attain from 5 utilizing the following equations:

$$v_{id}^{new} = v_{id}^{old} + c_1 \times rand_1 \times (P_{best\ id} - X_{id}) + c_2 \times rand_2 \times (G_{best\ id} - X_{id}) , \quad (23)$$

$$X_{id}^{new} = X_{id}^{old} + v_{id}^{new} \quad (24)$$

Each particle's speed is limited by the pre-specified the maximum of speed, V_{max} , and each the position of particle, X_{id} which should be in the determined domain:

$$l \leq x_i \leq u \quad (25)$$

8. Stop condition if the determined number of generation is satisfied; otherwise, go back to 3.

3. COMPUTATIONAL RESULTS

In this section, the Taguchi procedure is utilized to tune the parameters of the PSO, GA, and HPSOGA algorithms, due to the algorithms parameter values on the quality of the solution is affected. Table 1 indicates various levels of the factors for PSO, GA, and HPSOGA. In the present paper based on the number of the factors and the levels, Taguchi procedure L27 for multi-objective PSO, GA, and HPSOGA algorithms are employed for the adjustment of the parameters for metaheuristics, respectively. Figures 3-5 display the S/N ratios.

Moreover, several numerical experiments are presented to validate the sustainable MSCN model and also to evaluate the efficiency and performance of the suggested four multi-objective meta-heuristic algorithms (PSO, GA, and HPSOGA) algorithm in terms of needed CPU time and the objective function value. To the best of our knowledge and according to the novelty of developed sustainable MSCN model, no existing study has treated a similar model in the literature. Therefore,

TABLE 1. Factors and levels of algorithms

Factor	Algorithm	Level	Value
Max-iteration		3	50,100,150
C_1 , C_2	PSO	3	0.5,0.75,1
W		3	0.5,0.75,1
W_{damp}		3	0.2,0.25,0.3
N_{pop}		3	50,75,100
Max-iteration		3	50,100,150
P_c	GA	3	0.25,0.5,0.75
P_m		3	1,3,5
N_{pop}		3	50,75,100
Max-iteration		3	50,100,150
Max-sub iteration GA		3	1,2,3
Max-sub iteration PSO	HPSOGA	3	2,3,4
N_{pop}		3	50,75,100

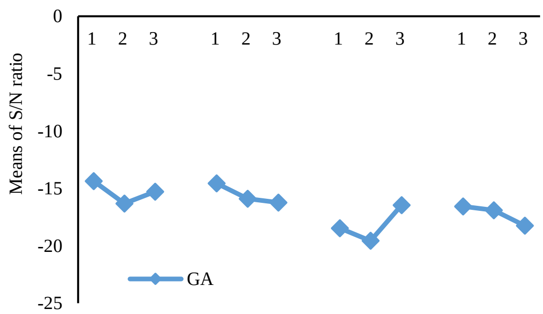

Figure 3. S/N ratio for the GA

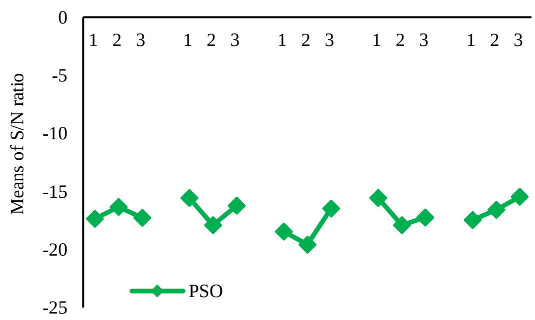

Figure 4. S/N ratio for the PSO

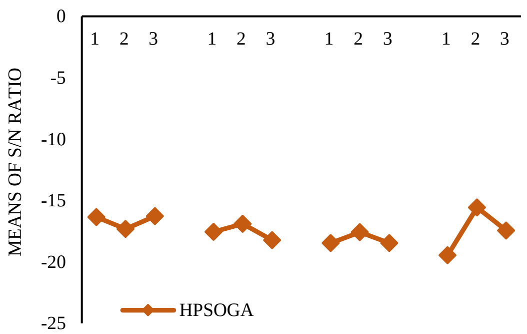

Figure 5. S/N ratio for the HPSOGA

the benchmarks existing in the literature are not available for the model, and an approach is needed to design the test problems. To show the complexity of the model, we need to design problems in different sizes. Then, six test problems are presented with ten runs including random data based on a uniform distribution. The problem sizes and parameter values are proposed in Tables 2 and 3, respectively.

Each instance was repeated 10 times for each run utilizing multi-objective PSO, GA, and HPSOGA algorithms for more accurate calculations. Furthermore, the average outcomes of the objective function of ten runs were chosen as the conclusion basis for the VNS algorithm. The objective function outputs for each problem size employing the multi-objective PSO, GA, and HPSOGA algorithms are presented in Table 4. Table 5 depicts the CPU time of meta-heuristic algorithms in each example. Computational times of the meta-heuristic algorithms in Figure 6 are displayed.

TABLE 2. The sample problem sizes

Example no.	Levels (*#s#m#d#c#k#n#p#t*)
1	(#2#2#3#3#4#5#5#1)
2	(#4#4#5#5#5#7#6#1)
3	(#6#6#7#7#6#8#7#1)
4	(#8#7#8#8#7#9#8#1)
5	(#10#8#9#9#8#10#9#1)
6	(#12#9#10#10#9#12#10#1)

TABLE 3. The generated parameters according to the uniform distribution

Parameters	Value	Parameters	Value
φ_s, φ_m,φ_d, φ_c, φ_k, φ_n	$\sim U(50000{,}60000)$	β_m, β_d, β_k, β_n	$\sim U(70000{,}80000)$
γ_m, γ_d, γ_k, γ_n	$\sim U(40000{,}50000)$	D_{ij}	$\sim U(25000{,}35000)$
T_{ij}	$\sim U(40000{,}80000)$	E_{ij}	$\sim U(35000{,}65000)$

4. SENSITIVITY ANALYSIS

To recognize the behavior of the MSCN model, two sensitivity analyses have been carried out on the significant parameters of the suggested model. Furthermore, an experiment problem such as 4 considering eight suppliers, seven manufacturers, eight DCs, eight customers, seven collection centers, nine

TABLE 4. The average outcomes for algorithms

Example no.		GA	HPSOGA	PSO
	F1	3156	2677	3788
1	F2	2788.1	1933.2	3208.1
	F3	3467	2921	3954
	F1	4322.1	3126.2	4801.3
2	F2	3780.2	2799.1	4102.4
	F3	4713	3741	5003
	F1	4977.3	3702.4	5963.1
3	F2	4105.4	2967.4	5288.1
	F3	5174	3944	6134
	F1	5477.9	4012.5	6512.4
4	F2	4901.3	3661.2	5880.2
	F3	5677	4231	6788
	F1	6034.7	4566.2	7212.4
5	F2	5632.7	4012.3	6770.3
	F3	6134	4677	7421
	F1	7323.5	5334.8	7966.3
6	F2	6944.3	4908.2	7239.1
	F3	7532	5466	8134

TABLE 5. The CPU time of algorithms

Example no.	GA	HPSOGA	PSO
1	4.61	3.02	6.73
2	15.21	10.23	19.27
3	21.43	15.45	38.31
4	87.91	63.52	143.48
5	94.78	75.33	178.54
6	123.45	81.21	212.27

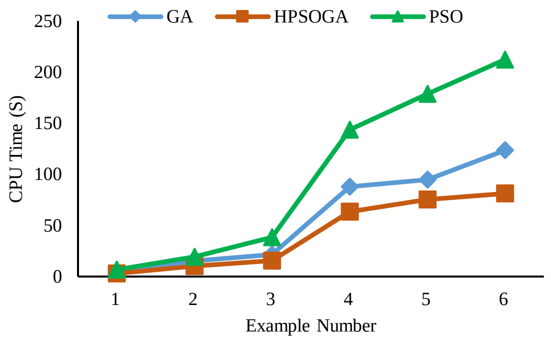

Figure 6. The average CPU time of algorithms

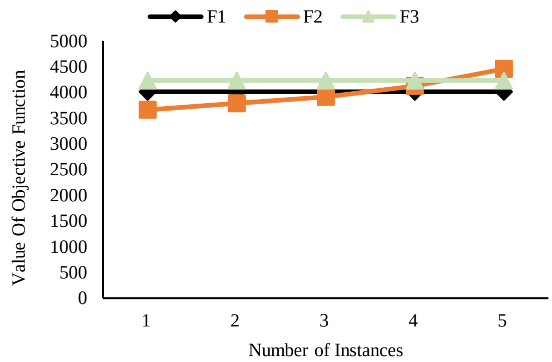

Figure 7. The sensitivity analysis based on transportation cost

incineration centers, eight products, and one time periods are chosen. Then, the VNS algorithm the most reliable in this paper is considered to handle the presented model. A set of changes containing the environmental impacts $(\gamma_m, \gamma_d, \gamma_k, \gamma_n)$ and the transportation costs (T_{ij}) for the proposed MSCN model is analyzed. Each analysis is divided into five instances numbered as I1 to I5. Eventually, all outcomes are depicted in Tables 6 and 7 as well as Figures 7 and 8.

According to the transportation cost value, sensitivity analyses by increasing the amount of this parameter have been carried out. Details are presented in Table 6. To recognize the three objective functions behavior i.e. economic cost $(F1)$, environmental impact $(F2)$ and social impact $(F3)$, meanwhile, the average values are considered in this comparison as indicated in Figure 8. The outcomes illustrate that although by increasing the amount of this parameter the environmental impact is increased while the economic cost and social impact remains no change.

TABLE 6. Sensitivity analysis on transportation cost

Instances no.	$\gamma_m, \gamma_d, \gamma_k, \gamma_n$	$F1$	$F2$	$F3$
1	400	4012.5	3661.2	4231
2	600	4012.5	3788.2	4231
3	800	4012.5	3912.9	4231
4	1000	4012.5	4122.5	4231
5	1200	4012.5	4456.2	4231

TABLE 7. Sensitivity analysis on transportation time

Instances no.	T_{ij}	$F1$	$F2$	$F3$
1	2000	4012.5	3661.2	4231
2	6000	4341.2	3661.2	4231
3	8000	4813.6	3661.2	4231
4	10000	5431.1	3661.2	4231
5	12000	5812.1	3661.2	4231

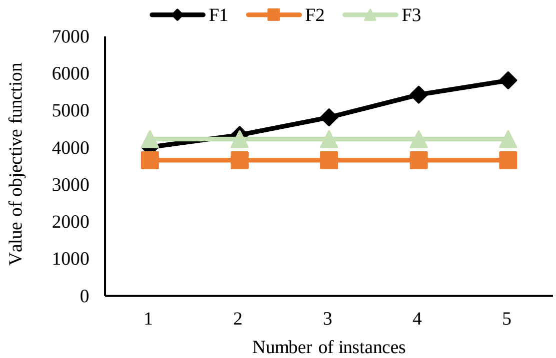

Figure 8. The sensitivity analysis based on transportation time

The transportation times to do some analyses are considered. The outcomes are indicated in Table 7. Moreover, the behavior of both objective functions is shown in Figure 9. By increasing the transportation costs, first of all, the behavior of the economic cost is increased. Hence, the environmental and social impacts are remained fixed and no change.

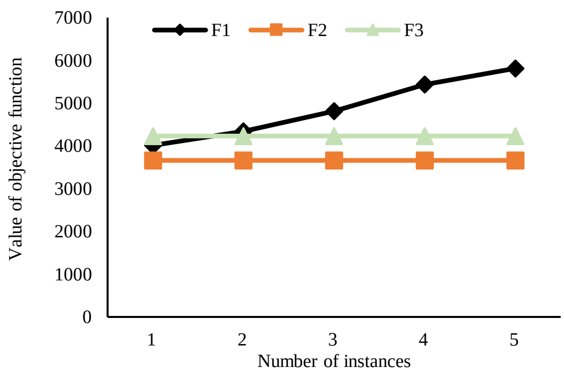

Figure 9. The sensitivity analysis based on transportation time

5. CONCLUSION AND FUTURE WORKS

The short communication taps into the collective experience and wisdom of global health supply chain professionals to identify and prioritize the top several global health medicine supply chain challenges: (1) lack of coordination, (2) inventory management, (3), absent demand information, (4) sustainability, (5) order management, (6) shortage avoidance. (7) expiration, (8) warehouse management, and (10) shipment visibility. These challenges must be addressed by researchers, policymakers, and practitioners alike if global medicine supply chains are to be developed and improved in emerging regions of the world.

Moreover, in the present paper, a new mathematical model for multi-objective sustainability MSCN was developed to address the fourth of challenge. The specific benefits of the presented model were as follows: a new MSCN with multi-suppliers, multi-manufacturers, multi-DCs, multi-customers, multi-collection centers, and multi- incineration centers. In this paper, we formulated the problem as a new mixed-integer linear programming model (MILP) to minimize the economic costs and environmental impacts and to maximize social impacts. To solve the presented model, we developed a novel hybrid particle swarm optimization and genetic algorithm (HPSOGA) and this algorithm is compared to original GA and PSO algorithms. Moreover, a parameter setting with carrying out the Taguchi procedure was proposed for choosing the optimal levels of the factors that affect the algorithm's efficiency. Besides, our sensitivity analysis over the environmental impacts and transportation cost displayed that an insensitive objective value to these parameters is selected enough large and the algorithm carries out correctly. The outcomes of the meta-heuristic algorithms indicated that the HPSOGA algorithm had better efficiency than the other algorithms in terms of CPU time and the objective function on 6 created random problems.

Furthermore, future studies can be used the hybrid meta-heuristic algorithms, heuristic method, and exact method *e.g.* Lagrangian relaxation or Benders algorithms as well as considering the model with stochastic and fuzzy parameters. Then, the interested scholars can add an objective function such as the maximization of the patient's satisfaction or quality level of service.

6. REFERENCES

1. Singh, S.K. and Goh, M., "Multi-objective mixed integer programming and an application in a pharmaceutical supply chain", ***International Journal of Production Research***, Vol. 57, No. 4, (2019), 1214-1237. Doi: 10.1080/00207543.2018.1504172
2. Weraikat, D., Zanjani, M.K. and Lehoux, N., "Improving sustainability in a two-level pharmaceutical supply chain through vendor-managed inventory system", ***Operations Research for Health Care***, Vol. 21, (2019), 44-55. Doi: pii/S2211692318300572
3. Chung, S.H. and Kwon, C., "Integrated supply chain management for perishable products: Dynamics and oligopolistic competition perspectives with application to pharmaceuticals", ***International Journal of Production Economics***, Vol. 179, (2016), 117-129. Doi: pii/S0925527316300913
4. Settanni, E., Harrington, T.S. and Srai, J.S., "Pharmaceutical supply chain models: A synthesis from a systems view of operations research", ***Operations Research Perspectives***, Vol. 4, (2017), 74-95. Doi: pii/S2214716016301105
5. Weraikat, D., Zanjani, M.K. and Lehoux, N., "Two-echelon pharmaceutical reverse supply chain coordination with customers incentives", ***International Journal of Production Economics***, Vol. 176, (2016), 41-52. Doi: pii/S0925527316000670
6. Tavakkoli-Moghaddam, R., Amiri, M. and Azizmohammadi, R., "Solving a redundancy allocation problem by a hybrid multi-objective imperialist competitive algorithm", ***International Journal of Engineering***, Vol. 26, No. 9, (2013), 1031-1042. Doi: article_72175.html
7. Mousazadeh, M., Torabi, S.A. and Zahiri, B., "A robust possibilistic programming approach for pharmaceutical supply chain network design", ***Computers & Chemical Engineering***, Vol. 82, (2015), 115-128. Doi: pii/S0098135415002203
8. Niaki, S., Najafi, A.A., Zoraghi, N. and Abbasi, B., "Resource constrained project scheduling with material ordering: Two hybridized meta-heuristic approaches", ***International Journal of Engineering***, Vol. 28, No. 6, (2015), 896-902. Doi: article_72530.html
9. Zahiri, B., Zhuang, J. and Mohammadi, M., "Toward an integrated sustainable-resilient supply chain: A pharmaceutical case study", ***Transportation Research Part E: Logistics and Transportation Review***, Vol. 103, (2017), 109-142. Doi: pii/S1366554517300509
10. Fathollahi-Fard, A.M., Ahmadi, A., Goodarzian, F. and Cheikhrouhou, N., "A bi-objective home healthcare routing and scheduling problem considering patients' satisfaction in a fuzzy environment", ***Applied Soft Computing***, Vol. 93, (2020), 106385. Doi: pii/S1568494620303252
11. Fakhrzad, M., Talebzadeh, P. and Goodarzian, F., "Mathematical formulation and solving of green closed-loop supply chain planning problem with production, distribution and transportation reliability", ***International Journal of Engineering***, ***Transactions C: Aspects,*** Vol. 31, No. 12, (2018), 2059-2067. Doi: article_82271.html
12. Crum, M., Poist, R., Carter, C.R. and Easton, P.L., "Sustainable supply chain management: Evolution and future directions", ***International Journal of Physical Distribution & Logistics Management***, (2011), Doi: 10.1108/09600031111101420/full/html
13. Seuring, S., "A review of modeling approaches for sustainable supply chain management", ***Decision Support Systems***, Vol. 54, No. 4, (2013), 1513-1520. Doi: pii/S0167923612001741
14. Brandenburg, M., Govindan, K., Sarkis, J. and Seuring, S., "Quantitative models for sustainable supply chain management: Developments and directions", ***European Journal of Operational Research***, Vol. 233, No. 2, (2014), 299-312. Doi: pii/S037722171300787X
15. Zhang, S., Lee, C.K.M., Wu, K. and Choy, K.L., "Multi-objective optimization for sustainable supply chain network design considering multiple distribution channels", ***Expert Systems with Applications***, Vol. 65, (2016), 87-99. Doi: pii/S0957417416304365
16. Tsao, Y.-C., Thanh, V.-V., Lu, J.-C. and Yu, V., "Designing sustainable supply chain networks under uncertain environments: Fuzzy multi-objective programming", ***Journal of Cleaner***

Production, Vol. 174, (2018), 1550-1565. Doi: pii/S0959652617325763

17. Pishvaee, M.S. and Razmi, J., "Environmental supply chain network design using multi-objective fuzzy mathematical programming", ***Applied Mathematical Modelling***, Vol. 36, No. 8, (2012), 3433-3446. Doi: S0307904X11006615
18. Lin, K.-P., Tseng, M.-L. and Pai, P.-F., "Sustainable supply chain management using approximate fuzzy dematel method", ***Resources, Conservation and Recycling***, Vol. 128, (2018), 134-142. Doi: pii/S0921344916303421
19. Ahmadi, A., Mousazadeh, M., Torabi, S.A. and Pishvaee, M.S., Or applications in pharmaceutical supply chain management, in Operations research applications in health care management. 2018, Springer.461-491. Doi: 10.1007/978-3-319-65455-3_18
20. Hulea, M., Rosu, O., Miron, R. and Aştilean, A., "Pharmaceutical cold chain management: Platform based on a distributed ledger", in 2018 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR), IEEE. 1-6. Doi: https://ieeexplore.ieee.org/abstract/document/8402709
21. Nasrollahi, M. and Razmi, J., "A mathematical model for designing an integrated pharmaceutical supply chain with maximum expected coverage under uncertainty", ***Operational Research***, (2019), 1-28. Doi: 10.1007/s12351-019-00459-3
22. Li, Y., Wei, Z., Zhao, J., Zhang, C. and Liu, Y., "Ambidextrous organizational learning, environmental munificence and new product performance: Moderating effect of managerial ties in china", ***International Journal of Production Economics***, Vol. 146, No. 1, (2013), 95-105. Doi: pii/S0925527312004744
23. Yadegari, E., Alem-Tabriz, A. and Zandieh, M., "A memetic algorithm with a novel neighborhood search and modified solution representation for closed-loop supply chain network design", ***Computers & Industrial Engineering***, Vol. 128, (2019), 418-436. Doi: pii/S0360835218306570
24. Akbarzadeh, Z., Safaei Ghadikolaei, A., Madhoushi, M. and Aghajani, H., "A hybrid fuzzy multi-criteria decision making model based on fuzzy dematel with fuzzy analytical network process and interpretative structural model for prioritizing larg supply chain practices", ***International Journal of Engineering***, Vol. 32, No. 3, (2019), 413-423. Doi: article_85659.html
25. Sadri Esfahani, A. and Fakhrzad, M., "Modeling the time windows vehicle routing problem in cross-docking strategy using two meta-heuristic algorithms", ***International Journal of Engineering***, Vol. 27, No. 7, (2014), 1113-1126. Doi: article_72345.html
26. Fakhrzad, M.B. and Goodarzian, F., "A fuzzy multi-objective programming approach to develop a green closed-loop supply chain network design problem under uncertainty: Modifications of imperialist competitive algorithm", ***RAIRO-Operations Research***, Vol. 53, No. 3, (2019), 963-990. Doi: 2019/03/ro180357/ro180357.html
27. Goodarzian, F. and Hosseini-Nasab, H., "Applying a fuzzy multi-objective model for a production–distribution network design problem by using a novel self-adoptive evolutionary algorithm", ***International Journal of Systems Science: Operations & Logistics***, (2019), 1-22. Doi: 10.1080/23302674.2019.1607621
28. Fakhrzad, M.B., Goodarzian, F. and Golmohammadi, A., "Addressing a fixed charge transportation problem with multi-route and different capacities by novel hybrid meta-heuristics", ***Journal of Industrial and Systems Engineering***, Vol. 12, No. 1, (2019), 167-184. Doi: article_78694.html
29. Sahebjamnia, N., Goodarzian, F. and Hajiaghaei-Keshteli, M., "Optimization of multi-period three-echelon citrus supply chain problem", ***Journal of Optimization in Industrial Engineering***, Vol. 13, No. 1, (2020), 39-53. Doi: article_538019.html
30. Tavakkoli-Moghaddam, R., "Solving a new multi-objective inventory-routing problem by a non-dominated sorting genetic algorithm", ***International Journal of Engineering***, Vol. 31, No. 4, (2018), 588-596. Doi: article_73156.html
31. Goodarzian, F., Hosseini-Nasab, H., Muñuzuri, J. and Fakhrzad, M.-B., "A multi-objective pharmaceutical supply chain network based on a robust fuzzy model: A comparison of meta-heuristics", ***Applied soft computing***, Vol. 92, (2020), 106331. Doi: pii/S1568494620302714

Persian Abstract

چکیده

پایان عمر محصولات تاثیر شدیدی بر سیستم محیط زیست دارد. سیاست‌های تولید بالقوه و استراتژی‌های توزیع برای محصول تولیدشده جدید به‌طور قابل توجهی توسعه پایداری را جذب کرده است. پایداری در مدیریت زنجیره‌تامین برای دستیابی به اهداف سازگار با محیط زیست از اهمیت بسیاری برخوردار است. در این مقاله، اهداف پایداری در چارچوب بهینه‌سازی زنجیره‌تامین با محدودیت‌های مختلف توسعه داده شده است. تعادل بین اهداف اقتصادی، محیط‌زیست و اجتماعی توسط تخصیص بهینه محصولات مختلف در بین سطوح مختلف مشخص شده است. ابتدا مسئله را به صورت یک مدل ریاضی برنامه‌ریزی مختلط عددصحیح خطی فرموله شده است، اگرچه مسئله زنجیره‌تامین پایدار در دسته مسائل NP-hard قرار دارد ما یک الگوریتم ترکیبی بهینه‌سازی انبوه ذرات و ژنتیک (HPSOGA) برای حل مدل پیشنهادی توسعه داده شده است و این الگوریتم با الگوریتم‌های ژنتیک و بهینه‌سازی انبوه ذرات مقایسه خواهد شد. در همین راستا، برای تنظیم پارامترهای مهم از الگوریتم‌ها و انتخاب سطوح بهینه از فاکتورهای مهم برای کارائی و عملکرد بیشتر از رویکرد تاگوچی استفاده شده است. در نتیجه خروجی‌های متفاوتی از مثال عددی نشان می‌دهد که الگوریتم ترکیبی HPSOGA از سایر الگوریتم‌ها کاراتر می‌باشد.