Optimizing Bi-Objective Multi-Echelon Multi-Product Supply Chain Network Design Using New Pareto-Based Approaches

Hamid Reza Jafari
Department of Industrial Engineering, Science and Research branch, Islamic Azad University, Tehran, Iran

Mehdi Seifbarghy*
Department of Industrial Engineering, Alzahra University, Tehran, Iran

ABSTRACT

The efficiency of a supply chain can be extremely affected by its design which includes determining the flow pattern of material from suppliers to costumers, selecting the suppliers, and defining the opened facilities in network. In this paper, a multi-objective multi-echelon multi-product supply chain design model is proposed in which several suppliers, several manufacturers, several distribution centers as different stages of supply chain cooperate with each other to satisfy various costumers' demands. The multi-objectives of this model which considered simultaneously are 1-minimize the total cost of supply chain including production cost, transportation cost, shortage cost, and costs of opening a facility, 2-minimize the transportation time from suppliers to costumers, and 3-maximize the service level of the system by minimizing the maximum level of shortages. To configure this model a graph theoretic approach is used by considering channels among each two facilities as links and each facility as the nodes in this configuration. Based on complexity of the proposed model a multi-objective Pareto-based vibration damping optimization (VDO) algorithm is applied to solve the model and finally non-dominated sorting genetic algorithm (NSGA-II) is also applied to evaluate the performance of MOVDO. The results indicated the effectiveness of the proposed MOVDO to solve the model.

Keywords: Supply chain design, Graph theory, MOVDO, NSGA-II

* Corresponding Author, E-mail: M.Seifbarghy@qiau.ac.ir

1. INTRODUCTION

Nowadays, rapidly changing environment makes the corporations to accommodate with the entire supply chain. A supply chain consist of multi-stages such as suppliers, plants, distribution centers and costumers in which suppliers produce raw material for the plants, the plants manufacture the products based on the costumer's requirements (demands) and transport them through channels to the distribution centers (DCs) which are responsible for distributing final products to the costumer's zones (Sim-

chi-Levi *et al.*, 2003).

In the recent years, supply chain network (SCN) design problems have been attended as an important issue in market globalization. A multi-product supply chain includes several products which should be produced and transported to costumers' zones through flow of materials among different facilities such as suppliers, manufacturers and DCs. Determining a flow pattern for each product which means selecting the facilities consist of plants and DC, to be opened and choosing the transportation channels to meet some objective functions such as

minimizing total cost, minimizing transporting time, and etc, is considered as an important problem.

Supply chain design problems have an important role in the global competition (Chopra and Meindl, 2004). An inefficient supply chain with undesirable transportation system and unsuitable open facilities encounters with critical problem gradually. Hence, the survival of a supply chain network can be guaranteed by designing an efficient supply chain in which transportation channels and open facilities are determined properly.

In this paper, we proposed a multi objective, multi-echelon, multi-product supply chain design problem in which some factory produces several products assembled from some parts supplied by suppliers. The end products go through some distribution centers and lead to costumers zones by using some exist transportation channels. Selecting the suppliers, determining the open facilities and the products should be produced and defining the proper transportation channels in the entire supply chain network is considered based on multi-objective functions includes: total cost, transportation time, and customer satisfaction. According to the complexity of the proposed model, a multi-objective meta heuristic approach called MOVDO is used.

The rest of this paper is organized as follows: in Section 2, the literature review is investigated. In Section 3, the multi objective, multi-echelon, multi-product supply chain design problem is described. In Section 4 the solution method for this model is determined. Section 5 analyzed the results and comparisons. At end, conclusion and future works are given.

2. LITERATURE REVIEW

Related literature indicates that there are several objective functions for supply chain design problems. One of the traditional objective functions is maximizing the profit of the chain or minimizing the total cost (Tsiakis *et al*., 2001; Elhedhli and Gzara, 2008; Altiparmak *et al*., 2009). Another prevalent objective function in the researches is transporting time which aim to select the facilities in a supply chain so that the transportation time be minimized (Sabri and Beamon, 2000; Guillén *et al*., 2005; Chen *et al*., 2008). In the recent years some researches consider total cost and transportation time simultaneously (Cardona-Valdés *et al*., 2011; Moncayo-Martı́nez and Zhang, 2011).

In this paper, despite of minimization of the total cost and minimization of transporting time of the products to the costumers' zones, the problem of maximizing the customer service level as third objective function is also considered. In order to maximizing service level, we attempt to minimize the maximum shortage in all the customers' zones and the customers' satisfaction can be exceeded.

In the recent years a graph theoretic approach is applied in configuring supply chain network design pro-

blems (Moncayo-Martinez and Zhang, 2011; Pishvaei and Rabbani, 2011). According to the concept of a graph configuration which includes some places as nodes and the link among these nodes, for sake of simplicity the graph theoretic approach can be used to form the supply chain network design problem. In this graph, the facilities of the supply chain network can be indicated with nodes and relationships among the facilities of two stages can be shown by using direct links.

In the related researches, many techniques have been used to solve supply chain design problems. One of the main approaches is mathematical programming in which the problem is formulated as a Mixed Integer Programming (MIP) model. Cakravastia *et al*. (2002) used a MIP model for supplier selection in a multi-stage supply chain design problem. Guillen *et al*. (2005) presented a supply chain design problem as a multi-objective stochastic MIP model and take into account the uncertainty of demand forecasting, then a branch and bound method is used for solving this model. Taskin Gumus *et al*. (2011) applied an integrated neuro-fuzzy and mixed MIP approach to a supply chain network to realize the design effectively. One of the most important advantages of using MIP model is their ability in finding the exact optimal solution. But as a disadvantage of these approaches, one can refer to the amount of computation time that increases when the problem size increases.

Another technique that is applied in solving the supply chain design problem is using the heuristic approaches. In other word, since the multi-stage design problem is difficult to solve (Santoso *et al*., 2005), researchers have used heuristic approaches to solve this problem. Syam (2002) used a simulated annealing algorithm (SA) for a multi-source, multi-product, multi-location framework. Syarif *et al*. (2002) developed a spanning tree-based Genetic Algorithm (GA) approach for the SCN design problem. Jayaraman and Ross (2003) employed simulated annealing for the designing of distribution network. Yeh (2005) combined a greedy method, linear programming technique and three local search methods for solving the supply chain design problem. Altiparmak *et al*. (2006) proposed a GA based procedure for designing a four-echelon supply chain including suppliers, plants, warehouses and customers. Yeh (2006) proposed a Memetic Algorithm (MA) which is a combination of GA, greedy heuristic, and local search methods for the same problem. Moncayo-Martinez and Zhang (2011) proposed an algorithm based on Pareto Ant Colony Optimisation as an effective meta-heuristic method for solving multi-objective supply chain design problems. As an advantage, although the heuristic techniques do not find the optimum solutions necessarily, they can produce a near optimum solution with a rational computation time. In this paper, multi-objective version of Vibration Damping Optimization (VDO) is presented to solve the model. VDO which is presented by Mehdizadeh and Tavakkoli-Moghaddam (2009) is according to the concept of vibration damping in mechanical vibration. Hajipour

et al. (2013) introduced a multi-objective version of VDO for optimization problems. In this paper, to solve the proposed supply chain design problem a multi-objective version of VDO is applied.

The main of this paper can be summarized as follows:
- A multi-objective multi-echelon multi-product supply chain network design model is presented in which suppliers, manufacturers, DCs, and costumers organize different echelons and the materials should be transported among these stages with regard to several existent links between each two facilities in different echelons so that the total cost of supply chain be minimized, the transporting time be minimized too, and the service level in the network be maximized, simultaneously.
- An efficient multi-objective version of VDO (MOVDO) is presented to solve the proposed model in supply chain design scope.

3. MODEL DESCRIPTION

The proposed multi-objective, multi-product, multi-echelon supply chain network design problem can be described as follows:

There are multi suppliers, multiple manufacturing plants, a set of candidate distribution centers and costumers in this network. Each factory produces several products assembled from some parts supplied by suppliers. The manufactured products should be transported to the costumer zones through distribution centers. In this study we assumed that there is a set of candidate trans-

portation channels for each pair of facilities between stages of supply chain. Since all suppliers, plants, DC and costumers are spread, the transportation time and cost for channels between them can be varied. The capacity of suppliers, plants and DCs is limited. Each candidate site has a fixed cost for installing a DC. The costumers' demand for each product should be supplied by a single DC. Figure 1 indicates a supply chain network schematically.

As a graphical configuration of the proposed model, each member of the mentioned supply chain can be assumed as a node and the communication channels between each pair can be described as the links. In other word with regarding the prespecified transportation links, the model can be transformed into directed graph $G = (N, L)$ in which N indicates the nodes and L indicates the links. In this four-partite directed graph, the nodes can be classified into four groups: suppliers, plants, DCs, and costumers. Each group receives the commodities by using links from previous group (except suppliers which make the start group) and transported them to next group (except costumers which constitute the end group). Figure 2 depicts the configured graph G. In Figure 2, the facilities (suppliers, manufacturers, DCs, and costumers) are showed with circular nodes and channels between each two facilities are indicated with directed links.

The considerable notation in Figure 2 is that each given link individually may consist of various channels between each two nodes. In other word, it might be several transportation channels between each two facilities and transportation among them is possible with regard to different transferring time, for example LS_{11} may com-
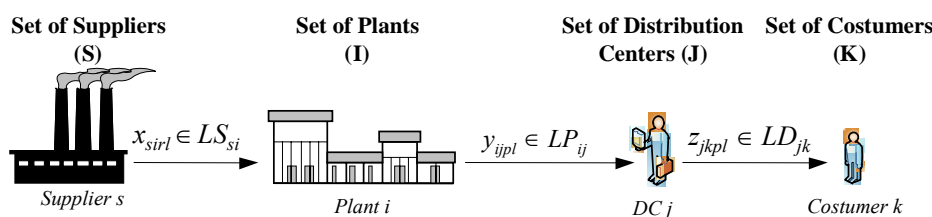

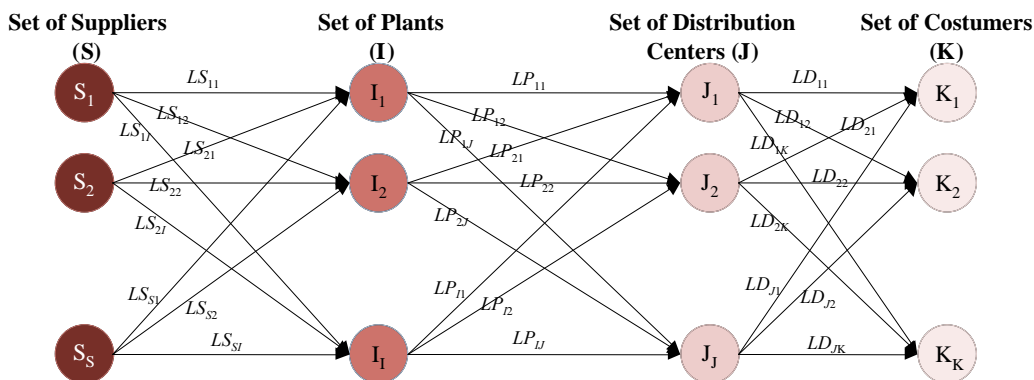**Figure 1.** Schematic view of supply chain network.

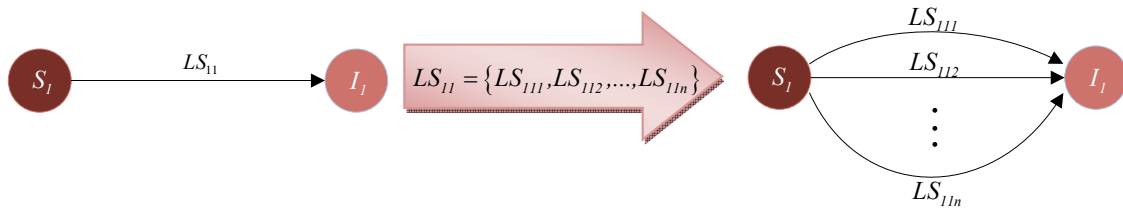**Figure 2.** Graphical configuration of the proposed model.

Figure 3. Graphical configuration of the proposed model.

prise a set of several links between supplier 1 and plant 1, which is indicated in Figure 3.

The aim of this paper is selecting appropriate suppliers, determining activated facilities (plants and distribution centers), and defining transportation channels and flow among the facilities so that the following objective function can be satisfied at the same time.

- minimizing the total cost of the network
- minimizing the transportation time
- maximizing the customer service level by minimizing the maximum shortages among all the costumers

3.1 Notations

The following notations are used to define the mathematical model:

Indices:

S — set of suppliers
I — set of plants
J — set of distribution centers
K — set of costumers
P — set of products
R — set of raw materials
LS_{si} — set of arcs l between nodes s and i
LP_{ij} — set of arcs l between nodes i and j
LD_{jk} — set of arcs l between nodes j and k

Parameters:

cs_{sirl} — unit transportation cost of raw material r from supplier s to plant i using arc l
cp_{ijpl} — unit transportation cost of product p from plant i to distribution center j using arc l
cd_{jkpl} — unit transportation cost of product p from DC j to costumer k using arc l
MS_s — maximum capacity of suppliers
MP_i — maximum capacity of plant i
MD_j — maximum capacity of distribution center j
TS_{sirl} — transportation time of raw material r from suppliers to plant I using arc l
TP_{ijpl} — transportation time of product p from plant i to distribution center j using arc l
TD_{jkpl} — transportation time of product p from distribution center j to customer k by arc l
FP_i — fixed cost for opening plant i
FD_j — fixed cost for opening distribution center j
d_{kp} — demand of product p for in costumer's zone k

PC_{ip} — unit production cost for product p at plant i
π_{kp} — shortage cost of product p in customer's zone k

Variables:

QS_{sirl} — quantity of raw material r transported from suppliers to plant i using arc l
Q_{ip} — quantity of product p produced at plant i
QP_{ijpl} — quantity of product p transported from plant i to DC j using arc l
QD_{jkpl} — quantity of product p transported from DC j to customer k using arc l
P_i — 1 if plant p is open and 0 otherwise
DC_j — 1 if DC j is open and 0 otherwise
x_{sirl} — 1 if arc l between supplier s and plant i is used for shipping raw material r and 0 otherwise
y_{ijpl} — 1 if arc l between plant i and DC j is used for shipping product p and 0 otherwise
z_{jkpl} — 1 if arc l between DC j and customer k is used for shipping product p and 0 otherwise

3.2 Model Formulation

The problem can be formulated as follows:

$$\min f_1 = \sum_j FD_j DC_j + \sum_i FP_i P_i + \sum_i \sum_p PC_{ip} Q_{ip} \qquad (1)$$
$$+ \sum_k \sum_p \pi_{kp} B_{kp} + \sum_s \sum_i \sum_r \sum_l cs_{sirl} QS_{ijpl}$$
$$+ \sum_i \sum_j \sum_p \sum_l cp_{ijpl} QP_{ijpl} + \sum_j \sum_k \sum_p \sum_l cd_{jkpl} QD_{jkpl}$$

$$\min f_2 = \max_j \left(\max_{i, l \in LP_{ij}} \left(\max_{s, l \in LS_{si}} \left(TP_{ijpl} y_{ijpl} \right) + TP_{ijpl} y_{ijpl} \right) \right. \qquad (2)$$
$$\left. + \max_{k, l \in LD_{jk}} \left(TD_{jkpl} z_{jkpl} \right) \right)$$

$$\min f_3 = \max_k \sum_p B_{kp} \qquad (3)$$

s.t.

$$\sum_j \sum_{l \in LD_{jk}} QD_{jkpl} = d_{kp} + B_{kp} \quad \forall k, p \qquad (4)$$

$$\sum_j \sum_{l \in LP_{ij}} QP_{ijpl} = Q_{ip} \quad \forall i, p \qquad (5)$$

$$\sum_p Q_{ip} \leq MP_i . P_i \quad \forall i \qquad (6)$$

$$\sum_k \sum_p \sum_{l \in LD_{jk}} QD_{jkpl} \leq MD_j . DC_j \quad \forall j \qquad (7)$$

$$\sum_p u_{rp} Q_{ip} \leq \sum_s \sum_{l \in LS_{si}} QS_{sirl} \quad \forall i, r \qquad (8)$$

$$\sum_k \sum_{l \in LD_{jk}} QD_{jkpl} \leq \sum_i \sum_{l \in LP_{ij}} QP_{ijpl} \quad \forall j, p \qquad (9)$$

$$\sum_s \sum_{l \in LS_{si}} x_{sirl} \leq 1 \quad \forall i, r \qquad (10)$$

$$\sum_i \sum_{l \in LP_{ij}} y_{ijpl} \leq 1 \quad \forall j, p \qquad (11)$$

$$\sum_j \sum_{l \in LD_{si}} z_{jkpl} \leq 1 \quad \forall k, p \qquad (12)$$

$$\sum_p \sum_{l \in LP_{ij}} y_{ijpl} = DC_j \quad \forall i, j \qquad (13)$$

$$\sum_r \sum_{l \in LS_{si}} x_{sirl} = P_i \quad \forall s, i \qquad (14)$$

$$MS_S z_{sirl} - QS_{sirl} \geq 0 \quad \forall s, i, r, l \qquad (15)$$

$$MP_i y_{ijpl} - QP_{ijpl} \geq 0 \quad \forall i, j, p, l \qquad (16)$$

$$MD_j z_{jkpl} - QD_{jkpl} \geq 0 \quad \forall j, k, p, l \qquad (17)$$

$$P_i, DC_j, x_{sirl}, y_{ijpl}, z_{jkpl} = \{0, 1\}, \qquad (18)$$

$$Q_{ip}, QS_{sirl}, QP_{ijpl}, QD_{jkpl} \geq 0 \quad \forall s, i, j, k, r, p$$

Objective (1) minimizes the total cost of the system including the cost for opening the plants, opening the DCs and transportation costs. Objective (2) minimizes the sum of the maximum lead time from plants to the costumers' zones. Objective (3) maximizes the service level, through minimizing the maximum shortages at costumers' zones. Constraint (4) applies a balance among sum of transported products to a costumer, the demand of this costumer and the amount of shortages. Constraint (5) guarantees that a plant transports its entire produced products. Constraint (6) prevents total production of plants to exceed the capacity limits of them. Constraint (7) guarantees that the flow going out from a DC does not exceed the capacity of the facility. This constraint also ensures that the flow of product is allowed only through open DCs. Constraint (8) assures that number of manufactured product in a plant depends on number of required raw materials to do that. Constraint (9) indicates the output of a specific product for a specific DC is limited by its input. Constraints (10-12) guarantee that each facility can be supplied at most with one supplier and through only one link. In other word, single sourcing constraint can be considered with these equations which means each facility prefers to supply its requirement through only one facility in previous echelon. Constraints (13) and (14) ensure that a distribution center or a plant is not open if it has no active incident arc on it. Constraints (15-17) indicate that the flow can be done only through active arcs. Constraint (18) denotes the decision variables types.

4. A PARETO-BASED META-HEURISTIC APPROACH

According to the complexity of the supply chain design problems, meta heuristic algorithms can be used to solve them. In the literature, the lack of a good algo-rithm which leads to near optimum solution in a rational CPU time to solve the supply chain design problem still is felt. With regarding the complexity of proposed supply chain design problem, in this section, a Pareto-based meta-heuristic algorithm called MOVDO is proposed to solve the proposed multi-objective mathematical formulation at hand. However, some required multi-objective backgrounds are first defined in the following subsection.

4.1 Solution Representation

To code the solutions, we presented a three-part solution representation structure as following descriptions:

I. **First part:** As $1 \times S$ random vector, specifies the priority of suppliers for transporting materials into the plants

II. **Second part:** As $1 \times I$ random vector, specifies the priority of manufacturers for producing the products and transporting it to the DCs

III. **Third part:** As $1 \times J$ random vector, specifies the priority of DCs for transporting the products into the customers

Figure 4 represents this structure, schematically. In this structure, each gene of vectors is random number between zero and one. Besides, customers' demands will never exceed the capacity limitations. To clarify the trend of encoding the problem, Figure 5 indicates an example of DCs selection in which $J = 5$. In this figure, the random numbers are generated; their positions are kept, and then sorted in ascending order. Based on our capacity, e.g. three of first genes are selected. The position of these numbers are selected DCs (DCs numbers 2, 5, and 1 is selected based on corresponding capacity). Moreover, the continuous decision variables including $Q_{ip}, QS_{sirl}, QP_{ijpl}, QD_{jkpl}$ are encoded based on upper bounds and randomly generated between zero and its upper bound. For more details about the structure of this type of representation, one can refer to Hajipour *et al.* (2013).

To prevent violation of constraints, Yeniay and Ankare (2005) method is used to penalize them. Hence, infeasible solutions are fined using Eq. (19).

$$P(x) = M \times \left[\left(\frac{g(x)}{b} \right) - 1 \geq 0 \right] \qquad (19)$$

Part (I)	1	2	⋯	S
Part (II)	1	2	⋯	I
Part (III)	1	2	⋯	J

Figure 4. Scheme of solution representation structure.

Generated Vector	0.42	0.31	0.76	0.66	0.38
Sorted Vector	0.31	0.38	0.42	0.66	0.76
	(2)	(5)	(1)	(4)	(3)
Selected DCs					

Figure 5. An instance of DCs encoding.

where M, $g(x)$, $P(x)$, and $f(x)$ represent a large number, the constraint under consideration, the penalty value, and the objective function value of chromosome x, respectively. This equation that is designed for a constraint like $g(x) \leq b$, more violations receive bigger penalties. Moreover, penalty values are considered for all of the three objective functions through an additive function given in Eq. (20).

$$F(x) = \begin{cases} f(x) & ; \quad x \in \text{feasible region} \\ f(x) + P(x) ; & x \notin \text{feasible region} \end{cases} \qquad (20)$$

4.2 VDO Main Concepts

VDO is one of the recently known meta heuristic algorithms which is inspired by the concept of vibration damping in mechanical vibration improvisation of musicians and simulates the vibration phenomenon. This algorithm is proposed by Mehdizadeh and Tavakkoli-Moghaddam (2009) which they used it to solve the parallel machine scheduling problem. The abilities of VDO in single objective problems lead the researchers to use this algorithm in multi-objective cases. Hajipour *et al.* (2013) introduced a multi-objective version of VDO to solve the optimization problems. In this paper, this multi-objective version of VDO algorithm has been developed for discrete environments of the current research.

In an optimization problem using VDO, feasible solutions of the optimization problem can be represented by the states of the oscillation system, the energies of the states correspond to the objective function value computed at those solutions, rapid quenching can be viewed as local optimization, and the optimal solution of the problem can be determined by the minimum energy state.

In the vibration theory, the scope of oscillation which influence on frequencies of the solutions, plays an important role in defining the loop of algorithm. In other word high amplitudes lead to bigger scope of solution and the probability of achieving a new solution is larger in these ranges of amplitudes, and reducing the amplitudes results in decreasing the probability of receiving a new solution so that the scope of solutions can be reduced by decreasing the range of oscillations, and then the system stops from the amplitude state (Mehdizadeh and Tavakkoli-Moghaddam, 2009; Mousavi *et al.*, 2013).

The VDO algorithm starts by generating random solutions in search space and the parameters such as max of iteration at each amplitude (L), initial amplitude (A_0), damping coefficient (γ) and standard deviation (σ) are initialized. For each solution an objective function value (OFV) is considered and evaluating the solutions can be done based on these OFVs. The algorithm contains two following main loops:
1. Generating a solution randomly and then obtaining and choosing a new solution based on neighborhood structure. With regarding the Rayleigh distribution function, the solution with a lower OFV can be chosen. In

fact, the new solution is accepted if $\Delta = OFV(new\ solution) - OFV(old\ solution) < 0$. Besides, if $\Delta > 0$, generate a random number r between (0, 1). The current solution is selected with regards to the following criteria:

$$r < 1 - \exp(-\frac{A^2}{2\sigma^2}) \qquad (21)$$

2. Adjusting the amplitude which is used for reducing amplitude at each iteration.

$$A_t = A_0 \exp(-\frac{\gamma t}{2}) \qquad (22)$$

Finally, the algorithm is stopped when the stopping criterion is met.

4.3 MOVDO Considerations

To use VDO algorithm in multi-objective functions problems, comparing the solutions should be considered with regards to the whole objective functions. To do this, fast non-dominated sorting (FNDS) and crowding distance (CD) as the basis concepts of multi-objective meta-heuristics, are used. In FNDS, R initial populations are compared and sorted. In order to do this, all chromosomes in the first non-dominated front are first found. Since all objective functions in the mathematical model are to be minimized, the chromosomes are chosen using the concept of domination. In this case, x_i is the non-dominated solution within the solution set $\{x_i, x_j\}$. Otherwise, it is not. Then, in order to find the chromosomes in the next non-dominated front, the solutions of the previous fronts are disregarded temporarily. This procedure is repeated until all solutions are set into fronts.

After sorting the populations, a CD measure is used to compare solution fronts of populations in terms of the relative density of individual solutions (Deb *et al.*, 2002). To do this, consider Z and f_k; $k = 1, 2, \cdots, M$ as the number of non-dominated solutions in a particular front (F) and the objective functions, respectively. Besides, let d_i and d_j be the value of the CD on the solution i and j, respectively. Then, the CD is obtained using the following steps:
(I) Set $d_i = 0$ for $i = 1, 2, \cdots, Z$
(II) Sort all objective functions f_k; $k = 1, 2, \cdots, M$ in ascending order
(III) The CD for end solutions in each front (d_1 and d_Z) are $d_1 = d_Z \rightarrow \infty$
(IV) The crowding distance for d_j; $j = 2, 3, \cdots, (Z-1)$ are $d_j = d_j + (f_{k_{j+1}} - f_{k_{j-1}})$

A selection operator should be applied to select individuals of the next generation, so in this paper a crowded tournament selection operator "$\succ$" is applied (Coello *et al.*, 2007). To do this, n individuals should be chosen randomly in the population. Then non-dominated rank of each individual should be calculated. For the

solutions with equal non-dominated rank, the CD of them should be obtained too. Finally, the solutions with

the least rank are selected. If more than one individual share the least rank, the individual with the highest CD
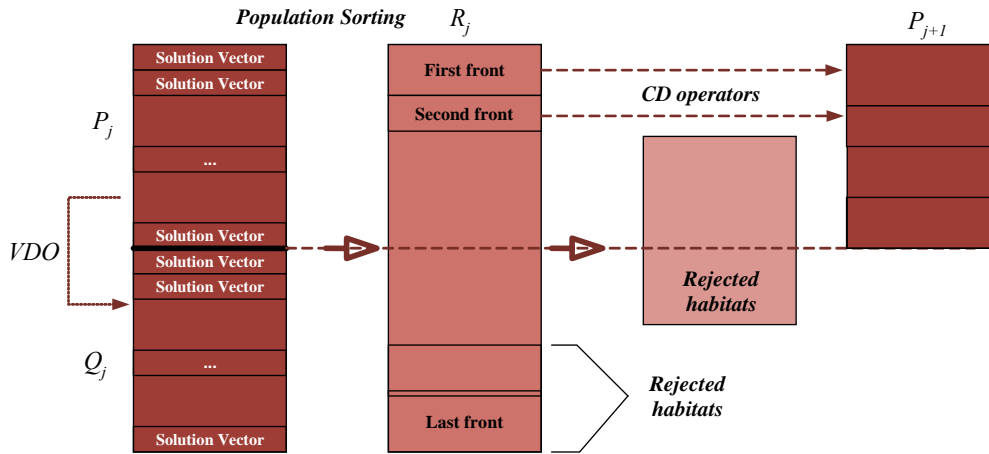

Figlure 6. Evolution process of the proposed MOVDO.
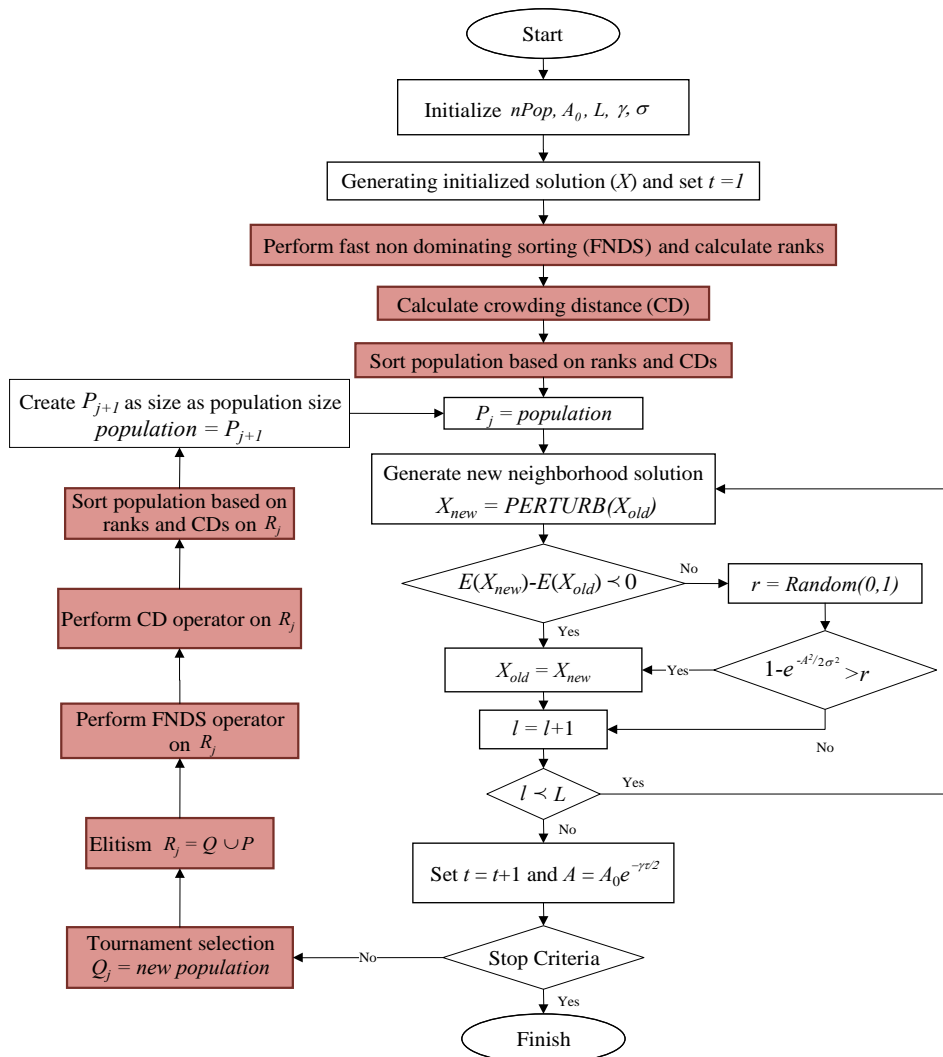

Figure 7. Flowchart of MOVDO.

should be selected.

The comparison criterion of MOVDO algorithm's solutions can be written as follows:

If $r_x < r_y$ or ($r_x = r_y$ and $d_x > d_y$) then $x \succ y$ where r_x and r_y are the ranks and d_x and d_y are the CDs. In this paper, a polynomial neighborhood structure for the selected chromosome is performed.

After implementing the mentioned concepts and operators, to ensure the elitism, the parents and offspring population should be combined and in this combined population, once more, non-domination sorting is performed so that chromosomes with higher ranks are selected and added to the populations until the population size becomes N. The last front is also consisted of the population based on the crowding distance. The algorithm stops when a stopping criterion (i.e. predetermined number of iterations) is reached.

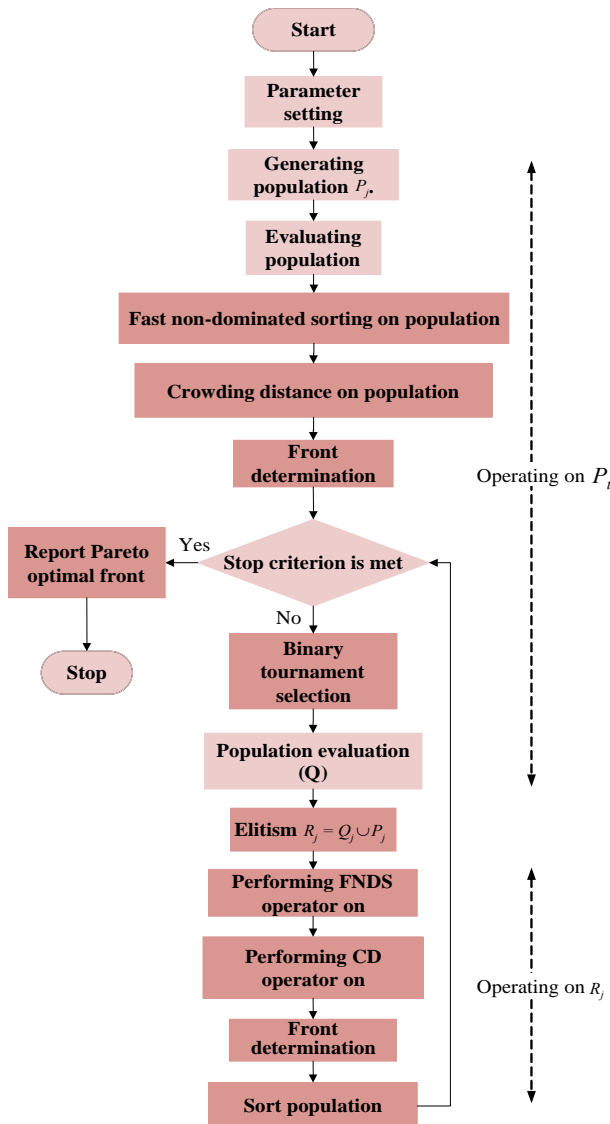As shown in Figure 6 the process of the proposed

MOVDO starts by generating P_j as initial population of the solution vectors. Then, new population Q_j is created based on applying some operators on P_j. In order to keep elitism in the algorithm R_j is obtained by combining P_j and Q_j. Finally, vectors of R_j should be sorted in several fronts based on FNDS and CD. To have a predetermined size a population of the next iteration P_{j+1} is chosen to according to proposed selection method.

Figure 7 illustrates the flowchart of MOVDO algorithm based on the basic operators of a VDO algorithm and the described multi-objective operators. The main multi-objective parts are shown using different color.

To evaluate the results of proposed MOVDO algorithm, another prevalent multi-objective meta-heuristic algorithm, called NSGA-II is used to solve the proposed mathematical model. NSGA-II is a modified version of NSGA which is presented by Srinivas and Deb (1995). To overcome the disadvantages of NSGA such as lack of elitism and complexity of calculations Deb et al. (2002) proposed NSGA-II as a Pareto-based algorithm in which both fast non-dominating sorting and CD concepts are considered. Figure 8 shows the flowchart of used NSGA-II algorithms.

5. RESULT ANALYSIS AND COMPARISONS

In this section, the applicability of the proposed methodology and the performance comparisons of the two meta-heuristic algorithms is presented. The developed algorithms are coded in MATLAB software (Version 7.10.0.499, R2010a) environment and the experiments are performed on a two GHz laptop with eight GB RAM; to estimate the response functions.

To evaluate and compare the performances of the solution methodologies under different environments, the experiments are implemented on 12 problems which reported in Table 1. Then, these instance problems are solved by three algorithms.

In order to evaluate the performances of the three multi-objective meta-heuristic algorithms four metrics are used as (Zitzler and Thiele, 1998):

Figure 8. Flowchart of NSGA-II.

Table 1. Generated test problems

Problem No.	S	I	J	K	P	R
1	1	1	2	2	1	2
2	2	1	2	2	3	2
3	2	2	2	4	5	5
4	3	3	3	4	10	5
5	3	5	3	10	10	5
6	3	5	3	10	10	10
7	5	10	8	10	25	10
8	5	10	12	20	35	20
9	12	30	15	40	60	20
10	18	50	25	50	100	30

Table 2. Computational results of multi-objective metrics comparisons for NSGA-II and MOVDO

Problem No.	MOVDO				NSGA-II			
	NOS	Spacing	Diversity	Time	NOS	Spacing	Diversity	Time
1	10	49,823,964	87,236,823	35.83	22	86,293,714	36,452,837	45.82
2	14	79,283,897	96,392,095	45.82	13	52,414,881	87,348,279	57.98
3	14	87,236,437	98,593,948	55.51	14	77,421,941	98,239,422	68.98
4	13	77,234,823	49,879,300	79.61	15	142,877,714	873,292,840	91.87
5	14	775,252,923	847,938,345	86.51	14	173,779,499	98,349,279	113.23
6	11	792,352,352	947,938,793	119.61	11	837,935,350	282,892,374	146.71
7	17	859,823,552	93,849,834	169.38	10	537,959,389	28,379,832	271.71
8	14	572,784,229	478,335,943	210.71	12	234,793,879	983,249,292	339.73
9	11	583,986,872	347,658,383	320.62	11	935,850,303	93,827,922	489.12
10	10	598,749,824	75,834,834	498.71	15	538,438,003	22,848,822	673.27

(I)   Number of Pareto solution (NOS)
(II)   Spacing
(III) Diversity
(IV) Computational time

The results comparisons in terms of all multi-objective metrics for all algorithms are reported in Table 2. Moreover, the algorithms are compared based on the properties of their obtained solutions. For these cases, all metrics are also plotted and graphically compared in Figure 9-Figure 12.
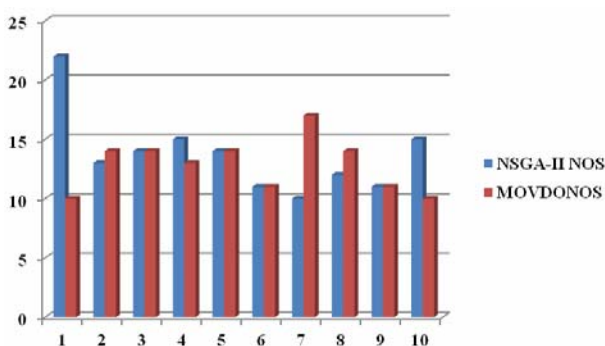

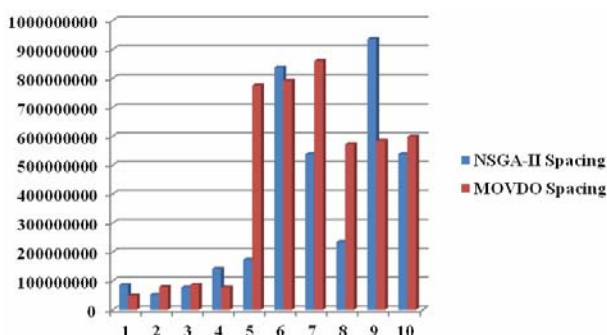**Figure 9.** Graphical comparisons of the algorithms in terms of *NOS* metric.

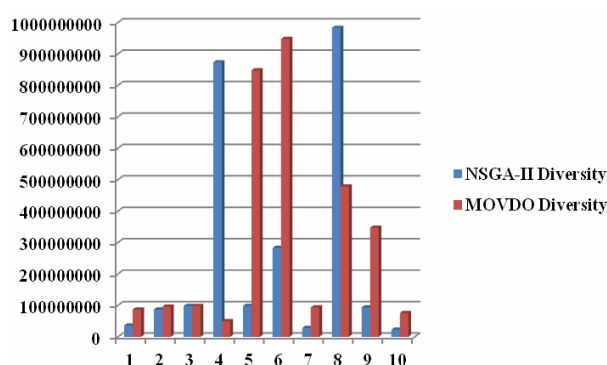**Figure 10.** Graphical comparisons of the algorithms in terms of *Spacing* metric.

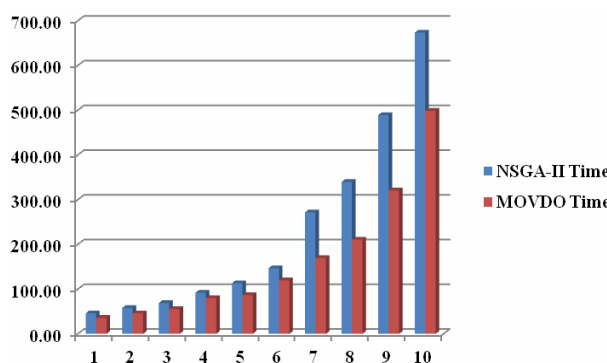**Figure 11.** Graphical comparisons of the algorithms in terms of *Diversity* metric.

Figure 12. Graphical comparisons of the algorithms in terms of *Time* metric.

We note that while in terms of the *diversity* and *NOS* metrics, bigger values are desired, for spacing, *MID* and CPU time, smaller values are better. Thus, in general, it is clear that MOVDO shows better performances in terms of *Time.* However, in terms of *Diversity*, *Spacing*, and *NOS* metrics, the algorithms almost work similar. This conclusion is confirmed at 95% confidence level. In order to increase readability of the proposed MOVDO, Figure 13 represents Pareto solutions obtained by MOVDO.
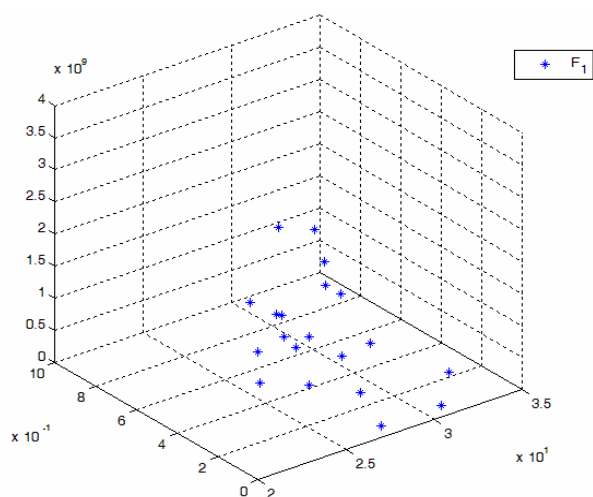
Figure 13. Pareto solutions for Problem No. 3 based on proposed MOVDO.

6. CONCLUSION

In this paper, a multi-objective multi-echelon multi-product supply chain design model is presented in which several suppliers, several manufacturers, several distribution centers as different stages of supply chain cooperate with each other to satisfy various costumers' demands. The goals are to minimize the total cost of supply chain, minimize the transportation time, and maximize the service level of the system, simultaneously. Not only a graph theoretic approach is applied to configure this model but different existent channels between each two facilities are linked. Since the proposed mathematical model is NP-Hard, to solve the model, we presented a novel multi-objective Pareto-based meta-heuristic algorithm called MOVDO in the supply chain literature. The results show the robustness of proposed MOVDO in terms of computational time. However, in other metrics, MOVDO can compete with best-developed NSGA-II.

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