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Supply Chain Network Design Using Particle Swarm Optimization (PSO) Algorithm

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Abstract
A supply chain is a complex network which involves the products, services and information flows between suppliers and customers, get the desired combination of low cost and high quality. Cooperating with good strategic partners is the sure way to tackle the potential problems arising from competition. The single-objective supply chain model to find the optimum configuration of a given supply chain problem which minimizes the total cost. There is need for a business model to realize mass customization in the industry. In this paper, we propose the setting method of the optimum order quantity by particle swarm optimization for supply chain management to minimize the combined facility location and shipment costs subject to a requirement that all customer demands be met.

1. Introduction

Supply chain management is basically a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements. Its design and management has the purpose of obtaining the best global performances under unions operating criteria [20]. A typical supply chain is composed of the following elements: suppliers, manufacturing plants, warehouses, distribution centers, customers/final markets. It becomes very important in future to remove waste of the production business and to realize needs of an individual customer and the conformity nature to a change of a market. The concrete purpose for a company is improvement of customer satisfaction by appointed date of delivery shortening, and maximization of cash flow by reduction of stock including circulation stock. In particular, we are satisfied a variety of customer specification in product and service, without dropping the productive efficiency in great need of mass customization in supply chain management (SCM)[21,23]. Owing to faster convergence, better exploration and exploitation abilities, and consistent performance in producing near-optimal results, this paper utilizes particle swarm optimization (PSO) as its basic search mechanism. PSO is inspired by the natural behavior of flocking birds. The movement of each particle of the swarm depends upon the particle's cognitive and social components. The cognitive component motivates the particle to attain the best position found by it so far, whereas the social component moves the particle toward the global optimum. In this paper, we propose the setting method of the optimum order quantity by PSO for supply chain management. Proposed method provides new optimal model in logistics of supply chain management which consisted of a retailer, a wholesaler, a

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distributor and a factory. And we set up the optimum order quantity from which the profits of the whole supply chain management become the maximum by using PSO.

2. Literature review

One characteristic that differentiates the problem introduced by Olivares-Benitez et al. [1], from previous works in the literature is the study of the tradeoff between lead time and cost in the supply chain design, related to transportation choices. The review by Current et al. [2], makes evident that the balance of these criteria had not been studied extensively. After that, Arntzen et al. [3], addressed the supply chain design problem for a company that handled the cost-time tradeoff as a weighted combination in the objective function. The decision variable was the quantity of product to be sent through each transportation mode available. Transportation time was variable with respect to the quantity shipped. The problem was solved using elastic penalties for violating constraints, and a row-factorization technique. Zeng [4], emphasized the importance of the lead time- cost tradeoff, associated to the transportation modes available between pairs of nodes in the network. A mixed-integer programming model was proposed to design the supply chain optimizing both objectives. In this work facility location was not addressed. The method proposed was a dynamic programming algorithm to construct the efficient frontier assuming the discretion of time. In the model proposed by Graves and Willems [5], cost and time were combined in the objective function. The supply chain was configured selecting alternatives at each stage of the production and distribution network. A dynamic programming algorithm was used to solve this problem. Most of the early studies focus on heuristic methods. Laporte [6], Nagy and Salhi [7], apply a "nested heuristic method" and a Tabu search to solve problems with 400 demand points. A two-phase Tabu search approach is also proposed by Tuzun and Burke [8]. Wu et al. [9], use simulated annealing as the basis to develop search methods. Laporte and Nobert [10], classify the exact algorithms into three categories: (i) direct tree search, (ii) dynamic programming, and (iii) integer programming algorithms. Berger et al. [11], provide a set-partitioning-based formulation and describe a successful implementation. Pourghader Chobar et al [22], presented a novel milti-objective model for hub location problem with dynamic demand and environmental issue. The model aims to minimize the routing cost between production centers and retailers, along with emitting pollution from vehicles as less as possible. As the proposed model is bi-objective, that is minimizing costs and pollution emission, two Pareto-based solution methodologies, namely the non-dominated sorting genetic algorithm (NSGA-II) and non-dominated ranking genetic algorithm (NRGA), are used. Lotfi et al [16], proposed a novel viable a medical waste chain network design (MWCND) by a novel two-stage robust stochastic programming that considers resiliency (flexibility and network complexity) and sustainable (energy and environment) requirements. Lotfi et al [17], explored a Robust, Risk-aware, Resilient, and Sustainable Closed-Loop Supply Chain Network Design (3RSCLSCND) to tackle demand fluctuation like COVID-19 pandemic. For this purpose, a two-stage robust stochastic multiobjective programming model serves to express the proposed problems in formulae. Lotfi et al. [18], indicated resilience and sustainable supply chain network design (SCND) by considering renewable energy (RE) (RSSCNDRE) for the first time. A two-stage new robust stochastic optimization is embedded for RSSCNDRE. The first stage locates facility location and RE and the second stage defines flow quantity between Supply chain components.

The Particle Swarm Optimization (PSO) method is a member of the wide category of Swarm Intelligence methods for solving Global Optimization problems [12, 19]. PSO has been proved to be an efficient method for many GO problems and in some cases it does not suffer the difficulties encountered by other EC techniques. Touti and Pourghader chobar [13], has considered the supply chain network analysis using PSO for deterministic problem with assumption that all the plants kept open for manufacturing and distribution but real life application is not so. We need to analyze the network design for binary and continuous variables for the location and capacity allocation of facilities.

3. Problem description and mathematical model

The problem introduced previously was a two-echelon distribution system for one product in a single time period. A set of manufacturing plants produce and send the product to distribution centers in the first stage. Later, the distribution centers transport the product to the customers. The number and location of plants and customers, along with demands and capacities respectively, are known. The distribution centers must be selected from a discrete set of potential locations with fixed opening costs and limited capacities. A single sourcing policy was assumed for the transportation from the distribution centers to the customers. Fig. 1 depicts the structure of the supply chain.

A single objective programming model was proposed to solve the problem described previously, as follows.

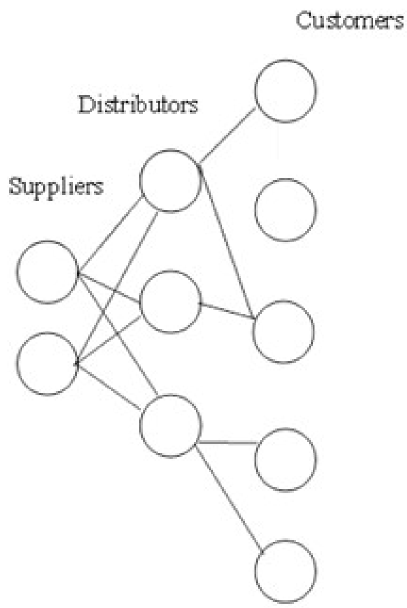

Fig. 1. Single product, single period, and two-echelon distribution system**.**

Sets:
K: set of plants *k*
J: set of potential distribution centers *j*
I: set of customers *i*

Parameters:

b_{kj} : Cost of transporting one unit of product from plant (*k*) to distribution center (*j*); $k \in K, j \in J$

a_{ji} : Cost of sending one unit of product from distribution center (*j*) to customer (*i*); $j \in J, i \in I$

P_k : Capacity of plant (*k*); $k \in K$

D_j :Capacity of distribution center (*j*); $j \in J$

R_i : Demand of customer (*k*); $k \in K$

Decision variables:

y_{kj} : Quantity transported from plant (*k*) to distribution center (*j*); $k \in K, j \in J$

x_{ji} : Quantity transported from distribution center (*j*) to customer (*i*); $j \in J, i \in I$

Model:

Min (f)

$$f = \sum_k \sum_j b_{kj} y_{kj} + \sum_j \sum_i a_{ji} x_{ji} \tag{1}$$

Subject to:

$$\sum_j x_{ji} \geq R_i \qquad i \in I \tag{2}$$

$$\sum_j x_{ji} \leq D_j \qquad j \in J \tag{3}$$

$$\sum_j y_{kj} \leq P_k \qquad k \in K \tag{4}$$

$$\sum_k y_{kj} = \sum_i x_{ji} \qquad j \in J \tag{5}$$

$$x_{ji}, y_{kj} \geq 0 \qquad k \epsilon K, j \epsilon J, i \epsilon I \tag{6}$$

In this model, objective function Eq. (1) minimizes the sum of the transportation cost. Constraints Eq. (2) force the demand satisfaction for each customer. Constraints Eq. (3) the flow going out from a distribution center must not exceed its capacity. Constraints Eq. (4) imply that the capacities of the plants are not exceeded. Constraints Eq. (5) keep the flow balance at each distribution center and Constraints Eq. (6) is for declaration of variables. About the computational complexity of the problem, it has been demonstrated that the well-known UFLP (Incapacitated Fixed-Charge Facility Location Problem) is polynomial reducible to the model described above [1]. Since the UFLP is NP-hard [14], the model above is NP-hard too.

4. Methodology

4.1. Introduction to particle swarm optimization

A population based optimization technique inspired by social behavior of bird flocking or fish schooling, Individual swarm members can profit from the discoveries and previous experience of all other members of the school. Developed by Kennedy and Eberhart [15].

PSO consists of a swarm of particles which Each particle resides at a position in the search space, The fitness of each particle represents the quality of its position, The particles fly over the search space with a certain velocity and the velocity (both direction and speed) of each particle is influenced by its own best, position found so far and the best solution that was found so far by its neighbors and eventually the swarm will converge to optimal positions. The original PSO algorithm is discovered through simplified social model simulation. It is related to the bird flocking and swarm theory according to which the bird would find food through social cooperation with other birds around it.

4.2. Original PSO – Algorithm

- Randomly initialize particle positions and velocities
- While not terminate

- For each particle *i*:

-Evaluate fitness y_i at current position x_i

-If y_i is better than $pbest_i$ then update $pbest_i$ and p_i

-If y_i is better than $pbest_i$ then update $gbest_i$ and g_i
-For each particle
-Update velocity v_i and position x_i using:

$$\begin{cases} \vec{v_i} \leftarrow \vec{v}_i + \vec{U}(0,\varphi_1) \otimes (\vec{p}_i - \vec{x}_i) + \vec{U}(0,\varphi_2) \otimes (\vec{g}_i - \vec{x}_i) \\ \vec{x}_i \leftarrow \vec{x}_i + \vec{v}_i \end{cases} \tag{7}$$

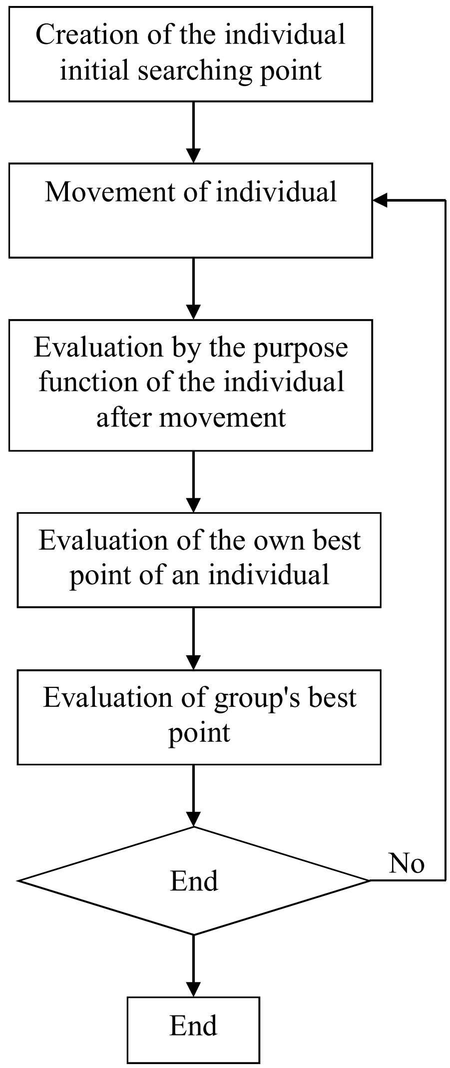

Fig. 2. Algorithm of PSO.

4.2.1. Original PSO –Problems

- The acceleration coefficients should be set sufficiently high
- Higher acceleration coefficients result in less stable systems in which the velocity has a tendency to explode
- To fix this, the velocity v_i is usually kept within the range $[-v_{Max}, v_{Max}]$

- However, limiting the velocity does not necessarily prevent particles from leaving the search space, nor does it help to guarantee convergence

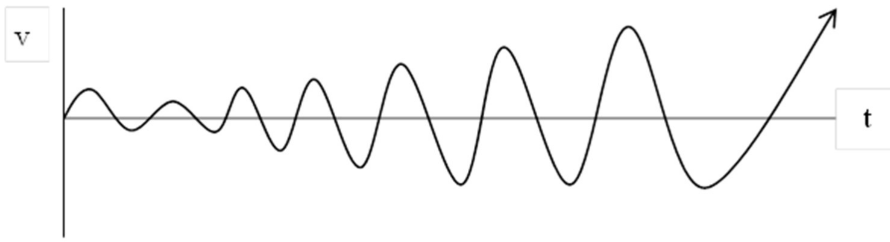

Fig. 3. Original PSO – Problems.

4.3. The Particle swarm in continuous numbers

The position of a particle is assigned the algebraic vector symbol. There can be any number of particles and each vector can be of any dimension. Change of position of a particle is called the velocity. Velocity is a vector of numbers that are added to the position co-ordinates in order to move the particle from one time step to another. As the system is dynamic, position of each individual is changing. The direction of movement is a function of current position and velocity, the location of individual's previous best success and best position found by any member of the neighborhood.

4.4. The best value save type mode

Gp in Eq. (9) expresses the individual (g best) which gives the best value in the whole group's inside in the k-th search. However, this serves as an individual that gives the best value in the inside of the point updated by Eq. (8) and Eq. (9). That is, p best is saved until the objective function is updated.

$$x_d^{k+1} = x_d^k + v_d^{k+1} \tag{8}$$
$$v_d^{k+1} = wv_d^k + c_1 r_1 (p_d^k - x_d^k) + c_2 r_2 (p_g^k - x_d^k) \tag{9}$$

However, best is updated for every number of searches. Thereby, not only global search capability but local search capability is decreased. Consequently, settling might be delayed. Then, it crowds together toward the best solution obtained in old search, the whole moves, and a model whose local search capability improves is also proposed. This is called the best value save type model. It is the model which replaced g p in Eq. (9) as follows.

$$v_d^{k+1} = wv_d^k + c_1 r_1 (p_d^k - x_d^k) + c_2 r_2 (p_g - x_d^k) \tag{10}$$

G_P expresses the individual which gives the best value obtained by old search. That is, G_P is not changed until the best value of p_d^k in old search isupdated. As a result, local search capability improves.

4.5. Numerical results

The developed simulator and optimization algorithm can be used to optimize the warehouses in the same time and calculate the optimum for the supply chain as a whole Authors developed a new component-based MATLAB simulator, as well as a novel PSO algorithm. The algorithm is based on an existing implementation form MATLAB Central. The reason we choose this Toolbox is that it can handle linear and Non-linear constraints also. It handles non lining equality constraints in the form *c(x) <= 0* using 'soft' or 'penalize' boundaries. The penalization is like "soft" boundaries, except that some kind of penalty value must be calculated from the degree of each constraint violation. Table 1 shows the amount of product that able to transmission from the factories to distributions and table 2 shows the amount of product that able to transmission from distributes to customers, with best shipping cost. Table 3 shows results for four groups. In particular, for the group 2-5-20 with iteration 3000 the total run time is less than the time for other groups'. In this case the instances are very small and the exact method can obtain true efficient sets easily. In the case of the Meta heuristic algorithm, the run time depends on the size of the iterations and then the time is expected to grow for larger iterations. But for the group 5-5-20 the total best cost is less than the total cost for other groups.

Table 1. The results of the algorithm for the best transferring quantity from plants to distributors.

Plants	**1**		**2**	
Variables / Distributors	**Cost**	**X_{ij}**	**Cost**	**X_{ij}**
1	16	0.0289	14	96.159
2	22	0.0564	16	95.088
3	24	0.0883	12	175.84
4	14	0.1546	12	177.85
5	12	170.74	23	0

Table 2. The results of the algorithm for the best transferring quantity from distributors to customers.

Distributors	**1**		**2**		**3**		**4**		**5**	
Variables / Customers	**Cost**	**X_{ij}**	**Cost**	**X_{ij}**	**Cost**	**X_{ij}**	**Cost**	**X_{ij}**	**Cost**	**X_{ij}**
1	22	0.0083	30	0.0447	15	15.775	31	0.0089	10	27.163
2	18	0.0196	11	10.452	13	36.522	35	0	31	0.0065
3	19	5.1343	39	0.0036	11	4.564	23	5.2557	21	0.0424
4	33	0.0207	34	0	15	46.681	25	0.0793	23	0.2187
5	30	0.0487	31	0.0357	33	0.0572	18	34.839	31	0.0191
6	30	0.0164	15	7.9909	13	4.9541	25	0.0358	39	0.0027
7	20	0.769	28	0.4013	16	19.507	33	0.0261	17	0.2961
8	25	15.501	31	0.6871	37	0.0476	39	0.0112	26	15.753
9	14	18.251	14	10.224	17	2.692	36	0.0039	17	17.829
10	35	0.0202	17	19.93	38	0.0004	20	0.1048	16	28.945
11	17	7.7865	29	0.7475	24	2.2716	20	5.1859	35	0.0085
12	28	0.0361	27	0.0836	38	0.0089	18	48.865	33	0.0066
13	33	0.0009	21	0	27	0.0155	12	22.548	11	26.435
14	26	1.9495	34	0.0147	38	0.0033	14	27.026	27	0.0062
15	24	0.0057	10	24.907	20	2.3679	15	14.719	34	0
16	19	0.3651	26	0.0037	15	10.733	28	0.7767	18	3.1212
17	30	0.024	31	0.0016	33	0.0075	23	0.1341	12	26.833
18	17	21.263	38	0.01	14	25.719	35	0.0073	26	0
19	40	0.0109	12	19.598	23	4.0011	13	18.372	39	0.0176
20	10	24.957	34	0.009	35	0	36	0.0013	12	24.033

Table 3. Comparative results of different scenarios.

Group code	Run time(s)	Iteration	N	Best cost
2.5.20	425	3000	250	2.0042
2.5.20	492	4500	250	1.9885
2.5.20	564	4500	350	2.016
5.5.20	496	3000	250	1.9305
5.5.20	571	4500	250	1.9269
5.5.20	639	4500	350	1.8945
5.10.20	803	3000	250	2.0286
5.10.20	868	4500	250	2.0441
5.10.20	917	4500	350	1.9778
5.10.50	1121	4500	250	4.7473
5.10.50	1236	4500	350	4.7722
5.10.50	1416	5500	450	4.8159

Group code indicates [number of plants number of potential distributions number of customers]

5. Conclusions

In this study, a multi-objective PSO algorithm-based supply chain design model has been proposed and applied on a supply chain problem. This problem deals with the resource options' selection for a single-product and multi-delivery supply chain in order to minimize the objective functions simultaneously, namely, total cost of the network. Several tests have been conducted to find the optimum parameters for the PSO algorithm. Presented supply chain problem includes two plants, five distribution centers and twenty customers. As shown in column charts, all the arcs between plants and distribution centers are not necessarily used in transportation flow of supply chain. In other words, selection of plants and distribution centers are dependent to the transportation unit cost of products between plants and distribution centers and also distribution centers and customers. These unit costs are affected by many factors such as location of plants and distribution centers, type of transportation of products between them and etc. The optimization process is well done by PSO algorithm to address the optimum solution of supply chain problems.

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