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CAT SWARM OPTIMIZATION FOR SINGLE STAGE SUPPLY CHAIN DISTRIBUTION SYSTEM WITH FIXED CHARGES

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Abstract
In this paper, Cat Swarm Optimization (CSO) Algorithm is proposed for single stage supply chain distribution system with a fixed cost. This paper considers two kinds of cost: a continuous cost, that linearly increases with the amount transported between a supplier and a customer and a fixed cost, which is incurred whenever a non-zero quantity is transported between a supplier and a customer and it is independent of the amount transported. The aim of this paper is to determine the quantities to be distributed to satisfy the customer demand with minimum cost. Since fixed costs results discontinuities in the objective function, solution procedures are become more difficult and are known to be non-deterministic polynomial (NP) hard. In this paper Cat Swarm Optimization (CSO) Algorithm is proposed for the optimization of single stage supply chain problem to provide optimal or near optimal solution. The results of the proposed model of this paper have been compared with a spanning tree-based Genetic Algorithm and binary coded Genetic Algorithm. Computational results show the superiority of CSO algorithm over other algorithms.

Keywords:
Cat Swarm Optimization (CSO) Algorithm, Single Stage, Supply Chain Problem, Fixed Cost

1. INTRODUCTION

In today's world, industries have to cope with the growing markets and with the increasing customer expectations. Because of the high level of customer expectations about acquiring the products at the right time and right quantity at minimum cost and besides this, the improvements against the risks created by the sudden fluctuations in local and global markets, companies need to examine their working techniques. Today, the success proportion for the industries are thought as minimum costs, lesser production time, shortening product life cycle, less reserve, larger product range, more reliable delivery time, better customer services, higher quality, and providing the effective coordination among demand, supply and production.

The supply chain distribution problem with fixed charge is a special case of the fixed cost linear programming problem, previously introduced in the origins of the Operations Research [1]. In the presence of onetime costs like fixed costs, the transportation problem is called fixed cost transportation cost (FCTP). Many practical transportation and distribution problems can be modeled as FCTP in which the transportation cost consists of a continuous cost, that linearly increases with the amount transported between a supplier and a customer and a fixed cost, which is incurred whenever a non-zero quantity is transported between a supplier and a customer and it is independent of the amount transported. Examples of these fixed costs are the toll fee paid on the highways, landing fee at the airport, permit fee or property tax, the reward given to the driver, set-up costs in production system or cost of building roads in transportation systems, etc [2].

This problem is characterized entirely by the presence of a transportation network structure. It is used in a wide range of practical business, commerce, and industrial applications and simultaneously received so thorough a theoretical development, in such a short period of time. The cost of distribution accounts for about 30% of the total cost of the product and plays a vital role in the determination of its price.

The objective is to find the combination of routes that minimizes the total variable and fixed costs while satisfying the supply and demand requirements of each origin and destination. While similar to the transportation problem, the FCTP is more difficult to solve due to the fixed costs that result in discontinuities in the objective function and renders it unsolvable by the direct application of the transportation algorithm. It has been shown that this FCTP is Nondeterministic Polynomial-time hard (NP-hard) problem and that is difficult to solve using general solving methodology [1-5] Since the problem is NP-hard, the computational time to obtain an exact solution increases in a polynomial fashion and, as the size of the problem increases, quickly becomes difficult and long.

FCTP is often formulated and solved as a mixed integer network-programming problem. Due to the excessive amount of computation time required, exact solution algorithms are not very useful when a problem reaches a certain level of complexity. Therefore, many heuristic methods have been proposed and developed [4-7]. Although they are usually computationally efficient, one major problem with heuristics methods is the possibility of terminating at a local optimal solution that may have an objective function value that is much worse than that of a global optimum [8]. Gen Li and Ida [9] proposed spanning tree-based Genetic Algorithms (GA) for FCTP using Prüfer number encoding. Syarif et al. [10] presented spanning tree-based GA using Prufer number representation to study the choice of facilities to be opened and the distribution network designed to satisfy the customer demand with minimum cost. Adlakha and Kowalski [7] proposed a simple heuristic algorithm for solving small FCTP. However, it is stated that the proposed method is more time consuming than the algorithms for solving a regular transportation problem. Jo et al. [5] presented the spanning tree-based Genetic Algorithm approach for solving non-linear FCTP. Kowalski and Lev [11] considered step FCTP in which the fixed cost is in the form of a step function dependent on the load in a given route, and developed a computationally simple heuristic algorithm for solving small two-step FCTP. Jawahar and Balaji [12] used GA

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for the two stage supply chain distribution problem associated with a fixed charge in which the capacity of the distribution center is assumed as very large. Kim and Kim [13] developed a mixed integer programming model and a three-phase heuristic algorithm to solve the FCTP. Hajiaghaei-Keshteli et al. [14] presented GA based on spanning tree for FCTP and design a chromosome that does not need a repairing procedure for feasibility. Manimaran et al. [15] developed a binary coded GA for single stage supply chain network associated with fixed cost. Molla- Alizadeh-Zavardehi et al. [16] proposed artificial immune and genetic algorithms with a Prüfer number representation to solve a capacitated two-stage FCTP, by considering unit transportation cost, fixed cost associated with each route, fixed cost for opening potential distribution centers, and capacitated distribution centers or warehouses. Othman et al, [17] applied two Genetic Algorithm for FCTP and also two fuzzy logic controllers are developed to automatically tune two critical parameters (*P*c and *P*m) of one of these two GA's. Hajiaghaei-Keshteli [18] developed GA and artificial immune algorithm for selecting some potential places as distribution centers in order to supply demands of all customers. Antony Arokia Durairaj and Rajendran [19] represented the two stage FCTP as a single stage FCTP and developed GA to solve the problem.

Chu and Tsai [20] introduced the cat swarm optimization (CSO) algorithm in 2007. This optimization algorithm was proposed based on inspecting the behavior of the cat. The strong curiosity of moving objects and the outstanding hunting skill are two distinctive features of a cat. These two behavioral traits of cats are modeled for CSO: seeking mode and tracing mode. Each cat has the following attributes: its own position composed of K dimensions, velocity for each dimension, a fitness value that delineates the accommodation of the cat to the fitness function, and a flag to identify whether the cat is in seeking mode or tracing mode. The final solution of CSO algorithm is to find the cat that has the best fitness value.

Tsai et al. [21] presented a parallel cat swarm optimization (PCSO) method based on the framework of parallelizing the structure of the CSO method. Xu and Hu [22] presented a CSO algorithm for resource constrained project scheduling problem. CSO based scheme for the RCPSP has three main stages: first randomly initialize the parameters of cats, then update the position in iteration and calculate the fitness through serial SGS method, finally terminate the process if the condition is satisfied.

The IIR system identification task is formulated as an optimization problem and a recently introduced Modified Cat Swarm Optimization (MCSO) is used to develop a new population based learning rule for the model [23]. Liu and Shen [24] introduced a recent metaheuristic method CSO to find the proper clustering of data sets. Two clustering approaches based on cat swarm optimization called Cat Swarm Optimization Clustering (CSOC) and K-harmonic means Cat Swarm Optimization Clustering (KCSOC) are proposed. IIR system identification task is formulated as an optimization problem and a recently introduced cat swarm optimization (CSO) is used to develop a new population based learning rule for the model [25].

Carle, Martel and Zufferey [26] proposed an agent-based metaheuristic to solve large-scale multi-period supply chain network design problems. The generic design model formulated covers the entire supply chain, from vendor selection, to production–distribution sites configuration, transportation options and marketing policy choices. Furthermore Wang, Chang and Li [27] adopted the CSO strategy to obtain the optimal or near optimal solution of the stego-image quality problem. The CSO strategy is generated by observing the behavior of cats, which has been proved to achieve better performance on finding the best global solutions. CSO algorithm is utilised as the training algorithm and the Optimal Brain Damage method as the pruning algorithm used for Optimizing Artificial Neural Networks [28].

For the past two decades, meta-heuristics have replaced the analytical methods. These meta-heuristics includes Genetic Algorithm, Artificial Bee Colony Algorithm Simulated Annealing, Ant Colony Optimization, Particle Swarm Optimization, Scatter search, Tabu search etc. On class of solution procedures that is receiving renewed attention, and considered in this study is the Cat Swarm Optimization (CSO) Algorithm.

This literature shows that several researchers have made valuable contributions in developing models and efficient algorithms for linear FCTP. To the best of our knowledge, there is no published work for solving FCTP by using CSO Algorithm. Hence this paper proposes CSO Algorithm to provide optimal or near optimal solution for the single stage FCTP.

The organization of the paper is as follows: Section 2 presents a mathematical formulation of the single stage FCTP. Section 3, describes various modules of the proposed ABC Algorithm. Section 4 provides numerical illustration and section 5, presents conclusion and future work.

2. SINGLE STAGE SUPPLY CHAIN PROBLEM

The Supply chain problem can be stated as a distribution problem in which there are m suppliers (warehouses or plants) and *n* customers (destinations or demands). Each of the *m* suppliers can ship to any of the n customers at a shipping cost per unit c_{ij} (unit cost for shipping from supplier *i* to customer *j*) plus a fixed cost f_{ij}, assumed for opening this route. Each supplier $i = 1; 2; : : : ; m$ has a_i units of supply and each customer $j = 1; 2; : : : ; n$ has a demand of b_j units.

The objective is to determine which routes are to be opened and the size of the shipment on those routes, so that the total cost of meeting demand, given the supply constraints, is minimized.

The various assumptions involved in this paper are described below:

1. Single product is delivered.
2. Capacities of suppliers and demands of customers are deterministic and are known in advance.
3. Each customer will be served by one or more facility.
4. Shortages are not allowed.

The mathematical model for the single stage Supply chain problem is as follows.

$$\text{minimize}\, Z = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(c_{ij}x_{ij} + f_{ij}\sigma_{ij}\right) \tag{1}$$

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$$\sum_{j=1}^{n} x_{ij} \le S_i, \quad \text{for } i = 1,2,\ldots m \text{ (supplier constraint)} \tag{2}$$

$$\sum_{i=1}^{m} x_{ij} \ge D_j, \quad \text{for } j = 1,2,\ldots n \text{ (customer constraint)} \tag{3}$$

$$\sum_{i=1}^{m} S_i \ge \sum_{j=1}^{n} D_j \tag{4}$$

$$x_{ij} \ge 0, \text{ for } i = 1,2,\ldots,m \text{ and } j = 1,2,..n$$

$$\sigma_{ij} = 1 \text{ if } x_{ij} > 0$$
$$= 0 \text{ otherwise}$$

The Eq.(1) minimizes the total cost Z. The Eq.(2), implies that the product shipped from the suppliers does not exceed its capacity. The Eq.(3) indicates that the total quantity of products shipped from the plants to the customers is to satisfy demand of the customer. Finally, Eq.(4) describes that the total capacities of the plant must be greater than or equal to total demand of the customers.

3. CAT SWARM OPTIMIZATION ALGORITHM

Chu and Tsai have proposed a new optimization algorithm which imitates the natural behavior of cats. Cats have a strong curiosity towards moving objects and possess good hunting skill. Even though cats spend most of their time in resting, they always remain alert and move very slowly. When the presence of a prey is sensed, they chase it very quickly spending large amount of energy. These two characteristics of resting with slow movement and chasing with high speed are represented by seeking and tracing, respectively. In CSO these two modes of operations are mathematically modeled for solving complex optimization problems.

3.1 SEEKING MODE

The seeking mode corresponds to a global search technique in the search space of the optimization problem. A term used in this mode is seeking memory pool (SMP). It is the number of copies of a cat produced in seeking mode. The steps involved in this mode are:

1. Create T (= SMP) copies of j^{th} cat i.e. Y_{kd} where (1 6 k 6 T) and (1 6 d 6 D). D is the total number of dimensions.
2. Apply a mutation operator to Y_k.
3. Evaluate the fitness of all mutated copies.
4. Update the contents of the archive with the position of those mutated copies which represent nondominated solutions.
5. Pick a candidate randomly from T copies and place it at the position of j^{th} cat.

3.2 TRACING MODE

The tracing mode corresponds to a local search technique for the optimization problem. In this mode, the cat traces the target while spending high energy. The rapid chase of the cat is mathematically modeled as a large change in its position. Define position and velocity of i^{th} cat in the D-dimensional space as $X_i = (X_{i1}, X_{i2}, \ldots, X_{iD})$ and $V_i = (V_{i1}, V_{i2}, \ldots, V_{iD})$ where d (1 6 d 6 D) represents the dimension. The global best position of the cat swarm is represented as,

$$X_g = (X_{g1}, X_{g2}, \ldots, X_{gD}).$$

The steps involved in tracing mode are:

1. Compute the new velocity of i^{th} cat using Eq.(5),
$$V_{id} = w^* V_{id} + c^* r^* \left(X_{gd} - X_{id}\right) \tag{5}$$
where, w is the inertia weight, c is the acceleration constant and r is a random number uniformly distributed in the range [0, 1]. The global best X_g is selected randomly from the external archive.
2. Compute the new position of i^{th} cat using Eq.(6).
$$X_{id} = X_{id} + V_{id} \tag{6}$$
3. If the new position of i^{th} cat corresponding to any dimension goes beyond the search space, then the corresponding boundary value is assigned to that dimension and the velocity corresponding to that dimension is multiplied by _1 to continue the search in the opposite direction.
4. Evaluate the fitness of the cats.
5. Update the contents of the archive with the position of those cats which represent non-dominated vectors.

4. NUMERICAL ILLUSTRATION

To evaluate the performance of the presented algorithm, two previously addressed problems by Jo et al. with different sizes are solved and comparing with the solution presented by them, Manimaran et al. [15] using binary coded Genetic Algorithm and with solution from LINGO. The sizes of the problems are 4 × 5 and 5 × 10 respectively. The fixed cost, capacity of the plants, demands of the customer and transportation cost are shown in Table.1 for the problem 1 and Table.2 & Table.3 shows for the problem 2.

Table.1. Fixed cost and unit transportation cost for Problem 1

Plants	**Fixed costs**					**Capacity**	**Transportation cost**				
	Customers						1	2	3	4	5
	1	2	3	4	5						
1	60	88	95	76	97	57	8	4	3	5	8
2	51	72	65	87	76	93	3	6	4	8	5
3	67	89	99	89	100	50	8	4	5	3	4
4	86	84	70	92	88	75	4	6	8	3	3
Demand	88	57	24	73	33	275					

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Table.2. Fixed cost for Problem 2

Plants	Customers										Capacity
	1	2	3	4	5	6	7	8	9	10	
1	160	488	295	376	297	360	199	292	481	162	157
2	451	172	265	487	176	260	280	300	354	201	293
3	167	250	499	189	340	216	177	495	170	414	150
4	386	184	370	292	188	206	340	205	465	273	575
5	156	244	460	382	270	180	235	355	276	190	310
Demand	225	150	90	215	130	88	57	124	273	133	1485

Table.3.Unit transportation cost for Problem 2

Plants	Customers									
	1	2	3	4	5	6	7	8	9	10
1	8	4	3	5	2	1	3	5	2	6
2	3	3	4	8	5	3	5	1	4	5
3	7	4	5	3	4	2	4	3	7	3
4	1	2	8	1	3	1	4	6	8	2
5	4	5	6	3	3	4	2	1	2	1

The CSO algorithm reaches its optimal solution using two groups of cats, i.e. one group containing cats in seeking mode and other group containing cats in tracing mode. The two groups combine to solve the optimization problem. A mixture ratio (MR) is used which defines the ratio of number of cats in tracing mode to that of number of cats in seeking mode (Chu and Tsai).

The computational procedure of the basic CSO algorithm is described as follows:

1. Randomly initialize the position of cats in D-dimensional space for the population, i.e. X_{id} representing position of i^{th} cat in d^{th} dimension.
2. Randomly initialize the velocity for cats, i.e. V_{id}.
3. Evaluate the fitness of each cat and store the position of the cat with best fitness as P_{gm} where $m = 1, 2,. . . , D$.
4. According to MR, cats are randomly picked from the population and their flag is set to seeking mode, and for others the flag is set to tracing mode.
5. If the flag of i^{th} cat is seeking mode, apply the cat to the seeking mode process, otherwise apply it to the tracing mode process.

The steps of the corresponding modes are followed.

6. Evaluate the fitness of each cat and store the position of the cat with best fitness as P_{lm} where $m = 1, 2,. . . , D$.
7. Compare the fitness of P_g and P_l and update P_g.
8. Check the termination condition, if satisfied, terminate the program.

Otherwise repeat steps 4–7.

The comparison is shown in Table.4.

Table.4. Comparison of Results

Sl. No.	Problem Size	Jo et al. st-GA	Manimaran et al. GA	LINGO	Proposed CSO
1	4×5	1,642	1,484	1,544	1,484
2	5×10	6,696	6,467	6,719	6,290

5. CONCLUSION AND FUTURE WORK

In this paper, a mathematical model and solution procedure for single stage Supply chain problem using CSO Algorithm is proposed to find the minimum transportation cost. To validate the efficiency of the developed algorithm, the results are compared with spanning tree based GA and binary coded GA. The proposed method is more efficient concerning the total cost. The structure of the proposed method is very simple and we believe that this method will be efficient to solve Supply chain problems.

The work may be extended for multi products, Customer demand is assumed as not deterministic and for multi objective – time and customer service level etc. This work may be attempted with other heuristics such as Genetic Algorithm, Particle Swarm Optimization, Simulated Annealing Algorithm, Tabu search, Scatter Search, Firefly Algorithm etc.,

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