Supply Chain Management Optimization using BFO

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***Abstract* –** The Supply Chain Management (SCM) is a critically significant strategy that enterprises depend on to meet challenges that they face because of highly competitive and dynamic business environments of today. Supply chain management involves the entire network of processes from procurement of raw materials/services/technologies to manufacturing or servicing intermediate products/services to converting them into final products or services and then distributing and retailing them till they reach final customers. A supply chain network by nature is a large and complex, engineering and management system. Oscillations occurring in a supply chain because of internal and/or external influences and measures to be taken to mitigate/minimize those oscillations are a core concern in managing the supply chain and driving an organization towards a competitive advantage. In this work, the optimal solution of the job-shop scheduling problem is obtained by using the non-linear optimisation technique like Bacterial foraging optimisation (BFO) and genetic algorithm (GA). GA was used previously in the literature for this work. We have applied both methods on same industry data with same constraints and found BFO has reduced the total cost of running the supply chain by 7% and profit is increased by 12%.

Keywords - SCM, BFO

I. INTRODUCTION

Many organizations today are forced to increase their global market share in order to survive and sustain growth objectives. At the same time, these same organizations must defend their domestic market share from international competitors. The challenge is how to expand the global logistics and distribution network, in order to ship products to customers who demand them in a dynamic and rapidly changing set of channels. Strategic positioning of inventories is essential, so that the products are available when the customer wants them [1][2] also claims that supply chain should actually be efficient and effective. In this case, efficient means to minimize resource use to accomplish specific outcomes; and effective, in terms of designing distribution channels. Efficiency is measured by delivery performance, product quality, backorders and inventory level, whereas effectiveness is measured by service quality and the service needs. Long-term competitiveness therefore depends on how well the company meets customer preferences in terms of service, cost, quality, and flexibility, by designing the supply chain, which will be more effective and efficient than the competitors'. Optimisation of this equilibrium is a constant challenge for the companies which are part of the supply chain network, shown in Figure 1. To be able to optimise this equilibrium, many strategic decisions must be taken and many activities coordinated. This requires careful management and design of the supply chain.

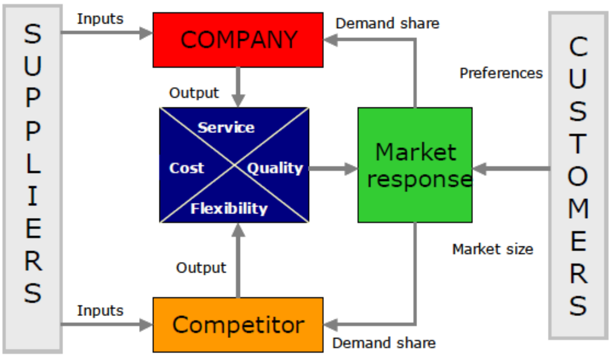

Figure 1: Competitive Framework in the Supply Chain [5]

The design of supply chains represents a distinct means by which companies innovate, differentiate, and create value [3]. The challenge of supply chain design and management is in the capability to design and assemble assets, organizations, skills, and competences. It encompasses the team, partners, products, and processes. To understand the term of supply chain management in depth, first the term of supply chain will be explained, then management and the role of management as a base for complete definition of supply chain management.

According to [4] the definition of "supply chain" is more consolidated as definition of supply chain management. In his paper, he tried to make a common definition of a supply chain, based on a comprehensive research study conducted by several co-authors. They came up with the following definition: "A supply chain is defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer". The supply chain may include internal divisions of the company as well as external suppliers that provide input to a focal company. A supplier for this company has his own set of suppliers that provide input (also called second tier suppliers). Supply chains are essentially a series of linked suppliers and customers until products reach the ultimate customer [5]. Supply chain of a company consists of an upstream supplier network and its downstream distribution channel (see Figure 2).

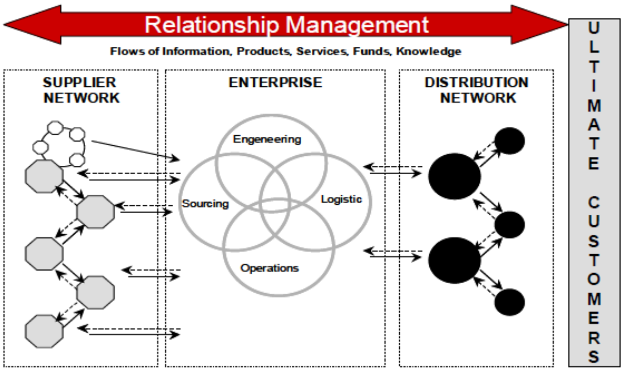

Figure 2: Supply Chain or Supply Chain Network

Organizations can be part of numerous supply chains. Danfoss for example, is part of a supply chain for district heating components, district-heating stations, and HVAC components. On the other hand, Alfa Laval can find Danfoss to be a supplier in one supply chain, a partner in another (developing components for their substations), a competitor in the fourth supply chain of stations, and as a customer in the heat exchangers supply chain.

Depending on how complex the supply network is, [6] has defined three types of supply chains: 1. Direct supply chain, which consists of a company, a supplier, and a customer. 2. Extended supply chain, which includes suppliers of the immediate supplier, as well as customers of the immediate customer. 3. Ultimate supply chain, which includes all the organizations involved in all the upstream and downstream flows.

II. BACTERIA FORAGING OPTIMIZATION (BFO)

Bacterial Foraging Optimization Algorithm (BFOA) is proposed by Kevin Passino (2002) [7], is a new comer to the family of nature inspired optimization algorithms. Application of group foraging strategy of a swarm of *E.* coli bacteria in multi-optimal function optimization is the key idea of this new algorithm. Bacteria search for nutrients is a manner to maximize energy obtained per unit time. Individual bacterium also communicates with others by sending signals. A bacterium takes foraging decisions after considering two previous factors. The process, in which a bacterium moves by taking small steps while searching for nutrients, is called chemotaxis. The key idea of BFOA is mimicking chemotactic movement of virtual bacteria in the problem search space.

p -	Dimension of the search space,
S -	Total number of bacteria in the population,
Nc -	The number of chemotactic steps,
Ns -	The swimming length.
Nre -	The number of reproduction steps,
Ned -	The number of elimination-dispersal events,
Ped -	Elimination-dispersal probability,
C(i) -	The size of the step taken in the random direction specified by the tumble.

Foraging theory is based on the assumption that animals search for and obtain nutrients in a way that maximizes their energy intake *E* per unit time *T* spent foraging. Hence, they try to maximize a function like E/T (or they maximize their long-term average rate of energy intake). Maximization of such a function provides nutrient sources to survive and additional time for other important activities (e.g., fighting, fleeing, mating, reproducing, sleeping, or shelter building). Shelter building and mate finding activities sometimes bear similarities to foraging. Clearly, foraging is very different for different species. Herbivores generally find food easily but must eat a lot of it. Carnivores generally find it difficult to locate food but do not have to eat as much since their food is of high energy value. The “environment” establishes the pattern of nutrients that are available (e.g., via what other organisms are nutrients available, geological constraints such as rivers and mountains and weather patterns) and it places constraints on obtaining that food (e.g., small portions of food may be separated by large distances). During foraging there can be risks due to predators, the prey may be mobile so it must be chased and the physiological characteristics of the forager constrain its capabilities and ultimate success. Bacterial Foraging optimization theory is explained by following steps:

1. Chemotaxis
2. Swarming
3. Reproduction and
4. Eliminational-Dispersal

Chemotaxis - This process simulates the movement of an E.coli cell through swimming and tumbling via flagella. Biologically an E.coli bacterium can move in two different ways. It can swim for a period of time in the same direction or it may tumble and alternate between these two modes of operation for the entire lifetime. Suppose $\theta^i(j,k,l)$ represents *i*th bacterium at *j*th chemotactic, *k*th reproductive and *l*th elimination-dispersal step. *C*(*i*) is the size of the step taken in the random direction specified by the tumble (run length unit). Then in computational chemotaxis the movement of the bacterium may be represented by equation-

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i).\Delta(i)}} \quad (1)$$

Where Δ indicates a vector in the random direction whose elements lie in [-1, 1].

Swarming - An interesting group behavior has been observed for several motile species of bacteria including E.coli and S. Typhimurium, where intricate and stablespatio-temporal patterns (swarms) are formed in semisolidnutrient medium. A group of E.coli cells arrange themselves in a traveling ring by moving up the nutrient gradient when placed amidst a semisolid matrix with a single nutrient chemo-effecter. The cells when stimulated by a high level of succinate, release an attractant aspartate, which helps them to aggregate into groups and thus move as concentric patterns of swarms with high bacterial density.

Reproduction - The least healthy bacteria eventually die when each of the healthier bacteria (which yielding lower value of the objective function) asexually split into two bacteria, which are then placed in the same location. This keeps the swarm size constant.

Elimination and Dispersal - Gradual or sudden changes in the local environment where bacterium population lives may occur due to various reasons. Events can occur such that all the bacteria in a region are killed or a group is dispersed into a new part of the environment. For example, a significant local rise of temperature may kill a group of bacteria that are currently in a region with high concentration of nutrient gradients. Events can take place in such fashion that all the bacteria in a region are killed or a group is dispersed into a new location. Over long periods of time, such events had spread various types of bacteria into every part of our environment from our intestines to hot springs and underground environments. To simulate this phenomenon info some bacteria are liquidated at random with a very small probability while the new replacements are randomly initialized over the search space. Elimination and dispersal events have the effect of possibly destroying chemotactic progress, but they also have the effect of assisting in chemotaxis, since dispersal may place the bacteria near good food sources. From a broad perspective, elimination and dispersal are parts of the population-level long-distance motile behavior.

Algorithm -

Step 1: Initialize the parameters S, Nc, Ns, Nre, Ned, Ped and the C (i),(i=1,2,…,S). Choose the initial value for the θ^i, i=1, 2….S. These must be done in areas where an optimum value is likely to exist. They are randomly distributed across the domain of the optimization space. After computation of θ is completed, the value of P (position of each member in the population of the S bacteria) is updated automatically and termination test is done for maximum number of specified iterations.

Step 2: Elimination-Dispersal loop: $l = l+1$

Step 3: Reproduction loop: $k = k+1$

Step 4: Chemo taxis loop: $j = j+1$

For i= 1, 2,….,S take a chemo tactic step for bacterium 'i' as follows:

(i) Compute cost $J(i,j,k,l)$.

(ii) Let $J(i,j,k,l)=J(i,j,k,l)+Jcc(\theta^i(j,k,l),P(j,k,l))$

(iii) Let $Jlast = J(i,j,k,l)$ to save this value since find better cost via a run

(iv) Tumble: Generate a random vector $\Delta^i \epsilon R^p$ with each element $\Delta^i m$, m= 1, 2,….,p a random number on [-1,1]. Where R is a real number.

(v) Move let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i).\Delta(i)}}$$

(vi) Compute $J(i,j+1,k,l)$

(vii) Swim.

Let m=0 (counter for swim length)

While m<Ns

Let m=m+1

If $J(i,j+1,k,l)<Jlast$(if there is improvement), let $Jlast = J(i,j+1,k,l)$ and let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i).\Delta(i)}}$$

and use this θ^i ($j+1,k,l$) to compute the new $J(i,j+1,k,l)$.

Else, let m=Ns. End of while statement

(viii) Go to next bacterium ($i+1$) if i<S

Step 5: If j<Nc go to step 3. In this case, continue chemo taxis, since the life of the bacteria is not over.

Step 6: Reproduction

For the given k and l, and for each i=1,2,….,S, let $J^i_{health} = \sum_{j=1}^{Nc+1} J(i,j,k,l)$ be the health of bacterium i. Sort bacteria and chemo tactic parameter C(i) in order of ascending cost *Jhealth.*

The Sr bacterium with the highest *Jhealth* values die and the other Sr bacteria with the best values split.

Step 7: If k<Nre, go to step 2. In this case we have not reached the number of specified reproduction steps

Step 8: Elimination-Dispersal

For i=1,2,…..,S with probability Ped, eliminate and disperse each bacterium. Eliminate a bacterium and disperse one to a random location on the optimization domain. If l <Ned, then go to step 1, otherwise end.

III. PROPOSED WORK

Various researchers proposed different techniques to optimize supply chain management system for maximizing profit using different techniques [8-13]. In this section we have discussed our proposed methodology for optimization in SCM scenario using BFO.Each production house needs a supply chain to make the goods in reach of customers. For this purpose, warehouses and distribution centres are maintained which increase the running cost. Supply chain Management is a process of integrating and utilizing suppliers, manufacturers, warehouses and retailers, so that goods are produced and delivered at the right quantities and at the right time while minimizing costs as well as satisfying customer requirements. Each manufacturer or distributor has some subset of the supply chain that it must manage and run profitably and efficiently to survive and grow. Managing the entire supply chain becomes a key factor for the successful business. The model was mathematically represented considering the capacity, inventory balancing and demand constraints at various stages of the supply chain. The mathematical formulation was solved using genetic algorithm initially but since GA falls in local minima so we have improved the method by another evolutionary optimisation algorithm. The industry under study has the following details. The problem is to capture the dynamics of a single product being manufactured out of 3 different components.

- Suppliers - 3
- Manufacturing plants - 2
- Distribution centres - 3
- Retailer - 6

Every nonlinear problem has been formulated mathematically to identify the dependent and nondependent variables. Like in our case cost is the dependent parameter which depends upon several factors formulated in mathematical expressions below. The supply chain management is targeted to reduce the running cost and expressed as:

Total Operating cost = TOC = TC + SC + MC + DC (2)

Where,

TC = transportation cost =

$$\sum_c \sum_s \sum_p (a_{c,s,p} \times T_{c,s,p}) + \sum_p \sum_d b_{p,d} \times TPD \quad (3)$$

SC=Supplier cost =

$$\sum_c \sum_s \sum_p (CS_{c,s} \times a_{c,s,p}) \quad (4)$$

MC=Manufacturer cost =

$$\sum_p (M_p \times \sum_d b_{p,d}) + \sum_p (IC_p \times \sum_c I_{c,p}) \quad (5)$$

DC=Distribution cost =

$$\sum_d \sum_r (C_{d,r} \times TCD_{d,r}) + \sum_d (IC_d \times I_d) \quad (6)$$

where,

c - Components

s - Suppliers

p - Plant

r - Retailer

d – Distribution center

a,b,c - Variables

TSP - Cost of transportation of component from supplier to plant per unit

TPD - Cost of transportation of component from plant to distribution centre

CS – Cost of making a component by the supplier

M p – Cost of manufacturing of plant per unit

ICp – Cost of carrying inventory of plant per unit IC,

P – Inventory of component at plant

TCDd,r – Cost of transportation from distribution centre to retailer zone per unit

ICD – Cost of inventory of distribution centre per unit

ID – Inventory at distribution centre

Profit from the above can be calculated as:

$$Profit = (Demand \times Selling\ Price) - TC \quad (7)$$

To get the maximum profit we need to minimise the total running cost by solving the equations from 4.1 to 4.5. These equations have constraint of maximum and minimum limit too. So, the total cost variable must be set within that range. To fulfil these requirements, we replaced the GA optimisation method with the bacterial foraging optimisation (BFO) algorithm. The basic structure and algorithm of BFO is discussed in previous chapter.

The BFO is based on the foraging behaviour of bacteria. These bacteria can be considered as the possible case of getting the optimal set of dependent variables in our case. The position of a bacteria is defined by those dependent variables. Our dependent variables are Transportation Cost Limits of All 3 Components from All 3 Suppliers to Plant1 and plant 2 Per Unit, the variable a for plant 1 and plant 2 and the PD value. These will be 109 in total number. In other words, we need to tune these 109 values to get the maximum profit for a fox number of plants, distribution centres and manufacturing centres. The relation between BFO method and supply chain management can be shown by the figure 3.

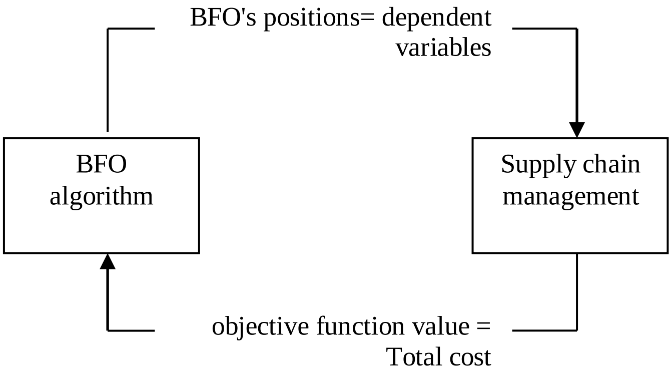

Figure 3: Representation of equilibrium of BFO optimisation and supply chain management

The minimum cost value from that is observed and positions for that bacteria is updated further using BFO mathematical formulation. The new position of each bacteria is again fed into the objective function and minimum cost for bacteria in this iteration is saved again. The minimum of these iterations is analysed and this process goes on till last iteration and minimum cost of all iterations are recorded and corresponding bacteria positions are recorded as the final values of dependent variables or in other words transportation cost for all components from plant A to B, a and PD. The significance of BFO terminology with our application is tabulated in table 1. Figure 8 at last of paper shows work flow diagram of our proposed methodology.

Table 1: Significance of BFO terminology in supply chain management

BFO terms	**Supply chain management**
Bacteria Position	Values of all dependent variables
Dimension for optimisation/ number of variables to be tuned	Total number of dependent variables which is 109 in our case
Update in the position of bacteria	Change is dependent variables values to achieve the minimum total cost

A step by step algorithm for the proposed work is given as:

STEP1. Initialize the node population random positions and directions of bacteria.

STEP2. Load the all the data from the file data.m in which target industry data is saved.

STEP3. Create an objective function which can calculate total cost using equations 4.1-4.5

STEP4. Initialize random positions and directions of bacteria in BFO which must be equal to 109 (number of tuning variables)

STEP5. Consider the searching space dimension as number of membership function values to be tuned which is 109 in our case.

STEP6. Initialize the chemotactic, swarming, reproduction and dispersion steps. The initial step size of bacteria is taken as 0.005.

STEP7. In each chemotactic step, for every bacteria fitness function is and position of bacteria is updated by position updating formula. It is

$$new\ pos = old\ pos + step\ size \times \frac{direction}{\sqrt{direction * direction'}}$$

STEP8. In swarming step the previous fitness function output is compared with the next position output of same bacteria. If found less then position of bacteria is updated again by formula given in step 5.

STEP9. The present position of bacteria is termed as current values of membership functions.

STEP10.The chemotactic and swarming loop continues till all initialized steps are completed. In each loop BFO updates the direction of bacteria and move the bacteria into the direction of fast convergence.

STEP11.Reproduction steps take place for bacteria with high fitness function values.

STEP12.To disperse or kill the weak bacteria, a probability of 0.25 is defined as the deciding probability. If random probability is higher than it, bacteria is dispersed or vice versa.

STEP13.Result will be positions of bacteria with minimum fitness function output. These positions are membership function's tuned variables for supply chain management.

IV. RESULTS

WeIn our case we need to reduce the total running cost of supply chain, so the objective function value which is total cost must be reduced with each BFO iteration and settle to a minimum value which doesn't change further. This is called convergence, earlier and lesser is the convergence point, better is the optimisation. Figure 5.1 and 5.2 shows the optimisation curve for BFO and GA respectively. The convergence value settled in BFO is 668690 whereas with GA it is 715950. An improvement of 7% has been achieved by BFO over GA. The cost is reduced by 7% by BFO as shown in table 2.

Table 2: Comparison of BFO and GA in supply chain management industry

	BFO	**GA**	**Improvement**
Total Cost	668690 INR	715950 INR	7%
Profit	469310 INR	422050 INR	11.20%

Similarly for the different demand and selling price listed in table 3 for which profit is calculated is also more in case of BFO than GA. 11.20 % more profit is achieved in BFO than GA.

Table 3: Demand and selling price of components to calculate the profit

Demand	[100,25,50,80,90,60]
Selling Price	[2000,2500,2750,3000,3200,3500]

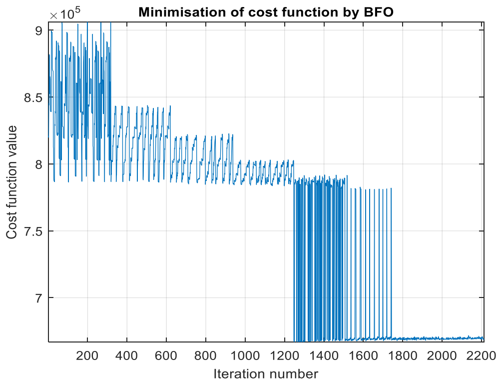

Figure 4: BFO Optimisation curve for target supply chain industry.

The final tuned values of all dependent variables are also plotted as bar graph in figure 5. These values don't have any specific comparison pattern as the maximum and minimum limit varies. But after an analysis it is notified that in BFO for a particular dependent variable out of 4, the change is uniform. These are not varying much whereas for GA the values for a variable itself are rapidly changing. So it can be concluded that uniform travelling cost, variable a and PD values results in lower total cost in supply chain.

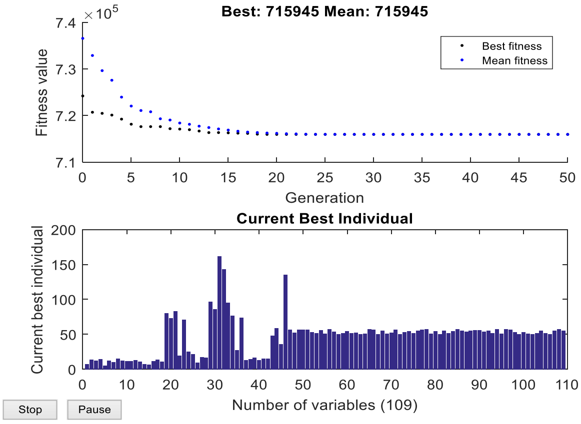

Figure 5: GA Optimisation curve for target supply chain industry.

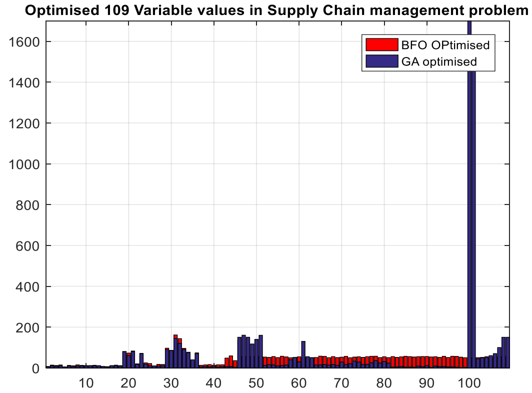

Figure 6: Comparison of tuned dependent variables of supply chain by BFO and GA

A comparison bar plot in total cost and profit as calculated by BFO tuned final variable values and GA tuned final values is shown in figure 7.

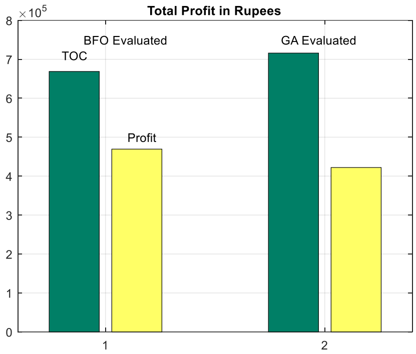

Figure 7: Total cost and profit comparison as calculated by using BFO and GA optimisation for targeted industry data

V. CONCLUSION

In this work, the optimal solution of the job-shop scheduling problem is obtained by using the non-linear optimisation technique like Bacterial foraging optimisation (BFO) and genetic algorithm (GA). GA was used previously in the literature for this work. We have applied both method on same industry data with same constraints and found BFO has reduced the total cost of running the supply chain by 7% and profit is increased by 12%. The major advantage of using these algorithms is that even though the number of possible sequences for 20 operations is very high, an optimal solution is obtained within few minutes while running on a standard PC. The effectiveness of these algorithms is tested through computer simulation for various real life problems and is found to be very effective. The results obtained shows that the BFO is improving the results of GA and this approach not only satisfies the customer's requirements and capacity restraints, but also offers a near minimum cost. The best individual of each generation is steadily converging to a near optimal solution with the process of generations. Finally supply chain network was analysed and optimized the component and products distribution with optimal total cost of supply chain.

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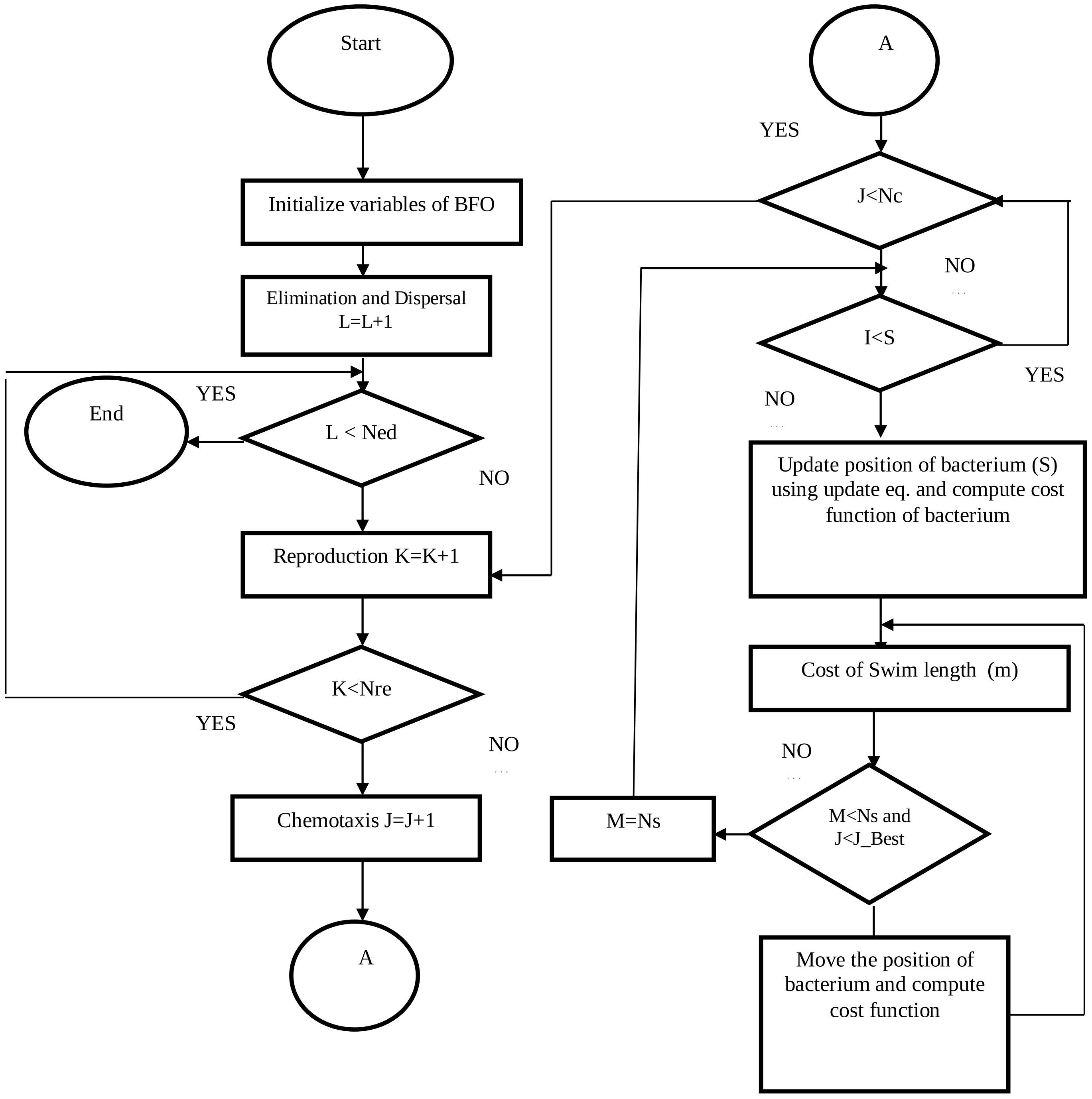

Figure 8: Flow chart of proposed supply chain management algorithm using BFO