Particle Swarm Optimization Model for Dynamic Supply Chain Inventory Optimization involving Lead Time

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Abstract

Efficient and effective management of inventory throughout the supply chain significantly improves the ultimate service provided to the customer. Efficient inventory management is a complex process which entails the management of the inventory in the entire supply chain and getting the final solution as optimal leading to minimum total supply chain cost. The dynamic nature of the excess stock level and shortage level over all the periods is a serious issue when implementation is considered. In addition, the complexity of the problem increases when more number of distribution centers and agents are involved. Moreover, the supply chain cost increases because of the influence of lead times for supplying the stocks . A better optimization methodology would consider all these factors in the prediction of the optimal stock levels to be maintained in order to minimize the total supply chain cost. In this paper, an optimization methodology is proposed that utilizes the Particle Swarm Optimization algorithm, one of the best optimization algorithms to overcome the impasse in maintaining the optimal stock levels in each member of the supply chain.

Keywords: *Supply chain management, supply chain cost, Inventory optimization, Particle swarm optimization (PSO)*

1. Introduction

Dynamic changes of demand patterns, global competition, shorter product life cycles, and product varieties and environmental standards cause remarkable changes in the market environment forcing the manufacturing enterprises to deliver their best in order to strive [1]. Decrease in lead times and expenses, enrichment of customer service levels and advanced product quality are the characteristics that determine the competitiveness of a company in the contemporary market place [2]. The above mentioned factors have made the business enterprises to contemplate more along their supply chains for gaining competitive advantage

The effective management of the supply chain has become unavoidable these days due to the firm increase in customer service levels [3]. The supply chain cost was immensely influenced by the overload or shortage of inventories. Thus inventory optimization has transpired into one of the most recent topics as far as supply chain management is considered [4], [5], [6].

The supply chain cost can be minimized by maintaining optimal stock levels in each supply chain member. In our paper, a methodology is developed for prediction analysis using Particle Swarm Optimization algorithm, so that the analysis paves the way for minimizing the supply chain cost..

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2. Particle Swarm Optimization

In 1995, Kennedy and Eberhartin, inspired by the choreography of a bird flock, first proposed the Particle Swarm Optimization (PSO). In comparison with the evolutionary algorithm, PSO, relatively recently devised population-based stochastic global optimization algorithm has many similarities and the robust performance of the proposed method over a variety of difficult optimization problems has been proved [9]. In accordance with PSO, either the best local or the best global individual affects the behavior of each individual in order to help it fly through a hyperspace [7].

In PSO, the potential solutions, called particles follow the current optimum particles to fly through the problem space. Every particle represents a candidate solution to the optimization problem. The best position visited by the particle and the position of the best particle in the particle's neighborhood influence its position.

Particles would retain part of their previous state using their memory. The particles still remember the best positions they ever had even as there are no restrictions for particles to know the positions of other particles in the multidimensional spaces. An initial random velocity and two randomly weighted influences: individuality (the tendency to return to the particle's best previous position), and sociality (the tendency to move towards the neighborhood's best previous position) form each particle's movement .PSO uses individual and group experiences to search the optimal solutions. Nevertheless, previous solutions may not provide the solution of the optimization problem. The optimal solution is deformed by adjusting certain parameters and putting random variables. The ability pf the particles to remember the best position that they have seen is an advantage of PSO. An evaluation function that is to be optimized evaluates the fitness values of all the particles [8].

3. Prediction analysis using Particle Swarm Optimization algorithm

Supply chain model is broadly divided into four stages in which the optimization is going to be done. The supply chain model is illustrated in the figure 1.

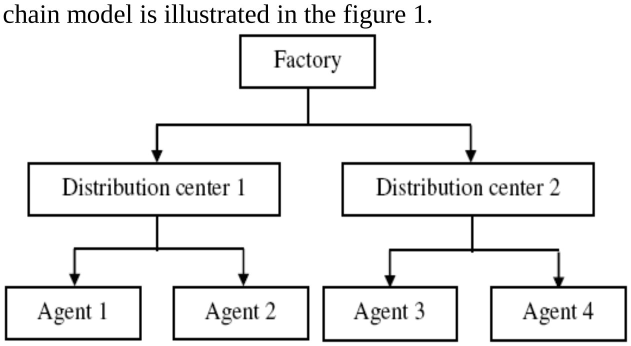

Fig. 1 : 3 stage-7 member supply chain .

As illustrated in figure 1, a factory is the parent of the chain and it is having two distribution centers Distribution center 1 and Distribution center 2. Distribution center 1 is having 2 agents Agent1 and Agent2 and Distribution center 2 is having Agent 3 and Agent 4 . The products manufactured by the factory would be supplied to the distribution centers. From the distribution centers, the stocks will be moved to the corresponding agents.

The factory is manufacturing two types of product. The database holds the information about the stock levels of the product in each of the supply chain member, lead time of products in each supply chain member . For l members from factory to end-level-Agents, there are $l-1$ lead times for a particular product and these times are collected from the past records.. Each and every dataset recorded in the database is indexed by a Transportation Identification (TID). For p periods, the TID will be $\{T_1, T_2, T_3, \Lambda\ , T_p\}$. This TID will be used as an index in mining the lead time information. Then each individual is queried into the database for obtaining the details regarding the TID and frequency of the individual. This obtained TID is queried into the database having the lead time of a particular product to a particular supply chain member. After all these queries, we have obtained the lead time of stocks as follows

$$T_s = [t_{q,1} \quad t_{q,2} \quad \Lambda \quad t_{q,l-1}]$$

Now, the particle Swarm Optimization (PSO) is utilized to predict the optimal stock levels to be maintained in the future to minimize the supply chain cost. The procedures involved in determining the optimal stock levels are illustrated in figure 2

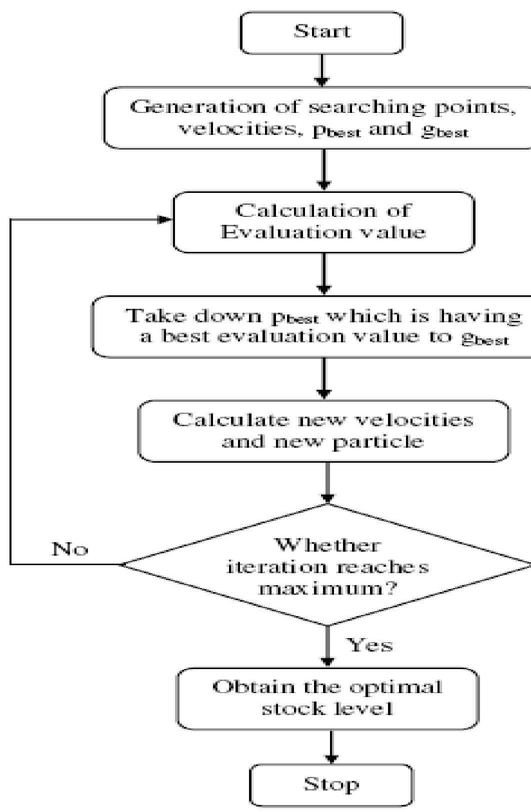

Fig. 2: Particle swarm optimization in optimizing the Base stock levels

and the methodology is outlined below.

The individuals of the population including searching points, velocities, p_{best} and g_{best} are initialized randomly but within the lower and upper bounds of the stock levels for all supply chain members, which have to be specified in advance.

Determination of Evaluation function

$$f(i)=w_1.\ \log\left(1-\frac{n_{occ}(i)}{n_{tot}}\right)+\log(w_2 . t_{stock})$$

$i = 1,2,3,\Lambda\ , n$

$n_{occ}(i)$ is the number of occurrences of the particle i in the record set

n_{tot} is the total number of records that have been collected from the past or total number of data present in the record set.

n is the total number of particles for which the fitness function is calculated.

w_1 and w_2 are the weightings of the factors, stock levels, lead time of stocks in optimization, respectively and they are determined as

$$w_1 = \frac{R_1}{R_1 + R_2}$$

$$w_2 = \frac{R_2}{R_1 + R_2}$$

R_1 and R_2 are the priority levels of influence of stock levels and lead time of stocks in optimization of respectively. Increasing the priority level of a factor increases the influence of the corresponding factor in the evaluation function. Hence this R_1 and R_2 decide the amount of influence of the factors The lead time of the stocks t_{stock} is determined as follows

$$t_{stock} = \sum_{i=1}^{l-1}\sum_{q} t_{q,i}$$

For every individual, a comparison is made between its evaluation value and its p_{best} .The g_{best} indicates the most excellent evaluation value among the p_{best} . This g_{best} nothing but an index that points the best individual we have generated so far.

Subsequently the adjustment of the velocity of each particle a is as follows:

$$v_{new}(a,b) = w * v_{cnt}(a) + c_1 * r_1 * [p_{best}(a,b) - I_{cnt}(a,b)]$$
$$+ c_2 * r_2 * [g_{best}(b) - I_{cnt}(a,b)]$$

where,

$$a = 1,2,\Lambda\ \Lambda\ , N_p$$
$$b = 1,2,\Lambda\ \Lambda\ , d$$

Here, $v_{cnt}(a)$ represents current velocity of the particle, $v_{new}(a,b)$ represents new velocity of a particular parameter of a particle, r_1 and r_2 are arbitrary numbers in the interval $[0,1]$, c_1 and c_2 are acceleration constants (often chosen as 2.0), w is the inertia weight that is given as

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter$$

where,

$w_{\max}$ and $w_{\min}$ are the maximum and minimum inertia weight factors respectively that are chosen randomly in the interval $[0,1]$

$iter_{\max}$ is the maximum number of iterations

$iter$ is the current number of iteration

Such newly obtained particle should not exceed the limits. This would be checked and corrected before proceeding further as follows,

If $v_{new}(a,b) > v_{\max}(b)$, then $v_{new}(a,b) = v_{\max}(b)$

if $v_{new}(a,b) < v_{\min}(b)$, then $v_{new}(a,b) = v_{\min}(b)$

Then, as per the newly obtained velocity, the parameters of each particle is changed as follows

$$I_{new}(a,b) = I_{cnt}(a,b) + v_{new}(a,b)$$

Then the parameter of each particle is also verified whether it is beyond the lower bound and upper bound limits. If the parameter is lower than the corresponding lower bound limit then replace the new parameter by the lower bound value. If the parameter is higher than the corresponding upper bound value, then replace the new parameter by the upper bound value. For instance,

If $P_k < P_{L.B}$, then $P_k = P_{L.B.}$

Similarly, if $P_k > P_{U.B}$, then $P_k = P_{U.B.}$

This is to be done for the other parameters also.

This process will be repeated again and again until the evaluation function value is stabilizing and the algorithm has converged towards optimal solution. The latest g_{best} pointing the individual is the best individual which is having the stock levels that are to be considered and by taking necessary steps to eliminate the identified emerging excesses/ shortages at different members of the supply chain, near optimal inventory levels can be maintained and the supply chain cost can be minimized to that extent

4. Implementation Results

We have implemented the analysis based on PSO for optimal inventory control in the platform of MATLAB .As stated, we have the detailed information about the excess and the shortage stock levels in each supply chain member, the lead times of product stock levels to replenish each supply chain member as well as raw material lead time. The sample data having this information is given in the Table 1.

Table 1: A sample data set along with its stock levels in each member of the supply chain

TI	PI	F	D1	D2	A1	A2	A3	A4
1	1	232	424	247	-298	-115	365	561
2	2	-415	488	-912	979	-492	-722	205
3	1	369	-686	-468	-807	183	-386	-228
4	2	459	289	-522	-316	130	-854	468
5	1	-663	944	856	451	-763	657	484
6	2	-768	-937	-768	242	369	-890	289

The Table 1 is having the product ID, the Transportation ID, the stock levels which are in excess or in shortage at each supply chain member. Negative values represent shortage of stock levels and positive values represent the excess of stock levels. The transportation ID mentioned in table is working as an index in extracting the lead times for stocks and raw material lead times. Table2 depicts the sample data which is having the transportation ID and the lead times for stocks. For seven member supply chain, six lead times can be obtained.

Table 2: Sample data from Database which is having lead times for stocks

TI	PI	T1	T2	T3	T4	T5	T6
1	1	18	22	9	19	18	17
2	2	26	33	16	14	24	15
3	1	28	38	10	17	10	18
4	2	20	22	9	21	21	13
5	1	38	40	25	21	16	11
6	2	33	41	17	13	21	19

Table 2 depicts the sample data which is having the transportation ID and the lead times for stocks. For seven member supply chain, six lead times can be obtained.

T1 is the lead time involved for movements of the product from F to D1;

T2 is the lead time involved for movements of the product from F to D2;

T3 is the lead time involved for movements of the product from D1 to A1;

T4 is the lead time involved for movements of the product from D1 to A2;

T5 is the lead time involved for movements of the product from D2 to A3;

T6 is the lead time involved for movements of the product from D2 to A4;

As initialization step of the PSO process, the random individuals and their corresponding velocities are generated.

Table 3: Initial random individuals

PI	F	D1	D2	A1	A2	A3	A4
1	255	61	215	463	24	75	-457
2	354	-154	145	-241	-215	415	645

For PSO based analysis, we have to generate random individuals having eight numbers of particles representing product ID and seven supply chain members. Table 3 describes two random individuals.

Similarly, Table 4represents random velocities which correspond to each particle of the individual.

Table 4: Initial Random velocities corresponding to each particle of the individual

PI	F	D1	D2	A1	A2	A3	A4
1	0.1298	0.1298	0.1298	0.1298	0.1298	0.1298	0.1298
2	0.0376	0.0376	0.0376	0.0376	0.0376	0.0376	0.0376

The simulation run on a huge database of 5000 past records showing evaluation function improvement at different levels of iteration is as follows:

Simulation Result showing evaluation function improvement with w1 = 0.6250; w2= 0.375

For iteration 50: evaluation function = 5.6845;

For iteration 60; evaluation function = 5.5450;
Improvement: 2%

For iteration 70; evaluation function = 5.4749;
Improvement: 5%

For iteration 100; evaluation function = 4.7220;
Improvement: 10%

As for deciding the total number of iterations required, the criteria followed is that as long as minimization of the Evaluation function is still possible, then the iteration continues till such a time that no improvement in the Evaluation function value is noticeable. After a certain number of iterations, if the evaluation function value is not improving from the previous iterations, then this is an indication that the evaluation function value is stabilizing and the algorithm has converged towards optimal solution. For greater accuracy, the number of iterations should be sufficiently increased and run on the most frequently updated large database of past records

The final individual obtained after satisfying the above mentioned convergence criteria isgiven in Table 5.

Table 5: database format of Final Individual

PI	F	D1	D2	A1	A2	A3	A4
1	-202	-280	-321	198	282	64	-125

The final individual thus obtained represents a product ID and excess or shortage stock levels at each of the seven members providing essential information for supply chain inventory optimization.

5. Conclusions

Inventory management is an important component of supply chain management. As the lead time plays vital role in the increase of supply chain cost, the complexity in predicting the optimal stock levels increases. We have proposed an innovative and efficient approach based on Particle Swarm optimization algorithm using MATLAB that is aimed at reducing the total supply chain cost by predicting the most probable surplus stock level and shortage level in each member of the supply chain for the forthcoming period.

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