Design of Genetic Algorithm Based Supply Chain Inventory Optimization with Lead Time

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Summary:

Inventory management is considered to be a very important area in Supply chain management. Efficient and effective management of inventory throughout the supply chain significantly improves the ultimate service provided to the customer. Hence, to ensure minimal cost for the supply chain, the determination of the inventory to be held at various levels in a supply chain is unavoidable. Minimizing the total supply chain cost refers to the reduction of holding and shortage cost in the entire supply chain. Efficient inventory management is a complex process which entails the management of the inventory in the whole supply chain. The dynamic nature of the excess stock level and shortage level over all the periods is a serious issue when implementation is considered. The complexity of the problem increases when more number of products, 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, these issues of inventory management have been focused and a novel approach based on Genetic Algorithm has been proposed in which the most probable excess stock level and shortage level required for inventory optimization in the supply chain is distinctively determined so as to achieve minimum total supply chain cost.

Keywords:

Inventory control, lead time, Inventory Optimization, Genetic Algorithm, supply chain cost.

1. Introduction

Global competition, shorter product life cycles, dynamic changes of demand patterns and product varieties and environmental standards cause remarkable changes in the market scenario thereby thrusting 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 [11]. The above mentioned factors have made the business enterprises to contemplate about their supply chains. An ensemble of organizations providing products and services to the market may be called as a supply chain. A supply chain can also be described as a collection of numerous entities that work in unison towards 1) obtaining raw materials, (2) converting these raw materials into precise end products, and (3) delivering the end products to retailers [19].

A huge problem that a majority of the supply chains aiming to reduce the supply chains costs besides improving customer service levels face is that of the administration of the dynamic demand [10]. A variety of process that aid the planning, implementation, control, ,manufacturing and the delivery processes originating from the raw material reserve to the point of utilization of the end product [6], are considered to be an integral part of the supply chain managements. Shorter product lifecycles that lead to higher demand uncertainty and their effect on global markets accordingly increase the supply chain complexity, resulting in severe problems in the management of the supply chain [11, 8]. The four problems from the operational perspective namely: inventory management and control; production, planning and scheduling; information sharing, coordination, monitoring; and operation tools need attention and focus in effectively managing a supply chain[9].

The effective management of the supply chain has become unavoidable these days due to the firm increase in customer service levels [5]. 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 [3], [15], [17].

Inventory optimization application organizes the latest techniques and technologies, thereby assisting the enhancement of inventory control and its management across an extended supply network. Some of the design objectives of inventory optimization are to optimize inventory strategies, thereby enhancing customer service, reducing lead times and costs and meeting market demand [3], [15], [17]. The design and management of the storage policies and procedures for raw materials,

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work-in-process inventories, and typically, final products [19] are illustrated by the inventory control. The costs and lead times can be reduced and the responsiveness to the changing customer demands can be significantly improved and subsequently inventory can be optimized by the effective handling of the supply chain [8].

The inventory and supply chain managers are mainly concerned about the estimation of the exact amount of inventory at each point in the supply chain free of excesses and shortages. Owing to the fact that shortage of inventory yields to lost sales, whereas excess of inventory may result in unnecessary storage costs, the precise estimation of optimal inventory is indispensable [20]. In other words, there is a cost involved in manufacturing any product in the factory as well as in holding any product in the distribution center and agent shop. More the products manufactured or held, higher will be the holding cost. Meanwhile, there is possibility for the shortage of products. For the shortage of each product there will be a shortage cost. Holding excess stock levels as well as the occurrence of shortage for products lead to the increase in the supply chain cost.

In this paper, we have developed a novel and efficient approach using Genetic Algorithm to solve this complexity. This paper supplements the previous study on supply chain inventory optimization without lead time considerations[34]. As the lead time plays vital role in the increase of supply chain cost, the complexity in predicting the optimal stock levels increases. In order to minimize the total supply chain cost, the proposed approach clearly determines the most probable excess stock level and shortage level that are required for inventory optimization in the supply chain. In practice, the dynamic nature of the excess stock level and shortage level over all the periods is the typical problem occurring in inventory management. The proposed approach of genetic algorithm predicts the emerging excess/shortage stock levels of the future by considering the stock levels of the past years, which is an essential information for supply chain inventory optimization as well as total supply chain cost minimization.

The remainder of the paper is organized as follows; Section 2 gives a brief review of relevant researches on inventory optimization. Section 3 gives the fundamentals of Genetic algorithm. The proposed approach of the genetic algorithm is presented in Section 4 and conclusions are summed up in Section 5.

2. Related Works

A fresh genetic algorithm (GA) approach for the integrated inventory distribution problem (IIDP) has been projected by Abdel et al. [33]. They have developed a genetic representation and have utilized a randomized version of a formerly developed construction heuristic in order to produce the initial random population.

In [8] Pupong et al., have put forth an optimization tool that works on basis of a multi-matrix real-coded Generic Algorithm (MRGA) and aids in reduction of total costs associated within supply chain logistics. They have incorporated procedures that ensure feasible solutions such as the chromosome initialization procedure, crossover and mutation operations. They have evaluated the algorithm with the aid of three sizes of benchmarking dataset of logistic chain network that are conventionally faced by most global manufacturing companies.

A technique to utilize in supply-chain management that supports the decision-making process for purchases of direct goods has been projected by Scott et al. [20]. RFQs have been constructed on basis of the projections for future prices and demand and the quotes that optimize the level of inventory each day besides minimizing the cost have been accepted. The problem was represented as a Markov decision process (MDP) that allows for the calculation of the utility of actions to be based on the utilities of substantial future states. The optimal quote requests and accepts at each state in the MDP were determined with the aid of Dynamic programming.

A supply chain management agent comprising of predictive, optimizing, and adaptive components called the TacTex-06 has been put forth by David et al. [6]. TacTex-06 functions by making predictions regarding the future of the economy, such as the prices that will be proffered by component suppliers and the degree of customer demand, and then strategizing its future actions so as to ensure maximum profit.

Beamon et al. [19] have presented a study and evaluations of the performance measures employed in supply chain models and have also displayed a framework for the beneficial selection of performance measurement systems for manufacturing supply chains. Three kinds of performance measures have been recognized as mandatory constituents in any supply chain performance measurement system. New flexibility measures have been also created for the supply chains.

The accomplishment of Beam-ACO in supply-chain management has been proposed by Caldeira et al. [28]. Beam-ACO has been used to optimize the supplying and logistic agents of a supply chain. A standard ACO algorithm has aided in the optimization of the distributed system. The application of Beam-ACO has enhanced the local and global results of the supply chain.

A beneficial industry case applying genetic algorithms (GA) has been proposed by Kesheng et al. [29]. The case has made use of GAs for the optimization of the total cost of a multiple sourcing supply chain system. The system has been exemplified by a multiple sourcing model with stochastic demand. A mathematical model has been implemented to portray the stochastic inventory with the many to many demand and transportation parameters as well as price uncertainty factors

A genetic algorithm which has been approved by Chih-Yao Lo [30] to deal with the production-inventory problem with backlog in the real situations, with time-varied demand and imperfect production due to the defects in production disruption with exponential distribution. Besides optimizing the number of production cycles to generate a (R,Q) inventory policy, an aggregative production plan can also be produced to minimize the total inventory cost on basis of the reproduction interval searching in a given time horizon.

In [31] Barlas et al., have developed a System Dynamics simulation model of a typical retail supply chain. The intent of their simulation exercise was to build up inventory policies that enhance the retailer's revenue and reduce costs at the same instant. Besides, the research was also intended towards studying the implications of different diversification strategies

A supply chain model functioning under periodic review base-stock inventory system to assist the manufacturing managers at HP to administer material in their supply chains has been introduced by Lee et al. [32]. The inventory levels across supply chain members were obtained with the aid of a search routine.

3. Genetic Algorithm

Genetic algorithm is a randomized search methodology having its roots in the natural selection process. Initially the neighborhood search operators (crossover and mutation) are applied to the preliminary set of solutions to acquire generation of new solutions. Solutions are chosen randomly from the existing set of solutions where the selection probability and the solution’s objective function value are proportional to each other and eventually the aforesaid operators are applied on the chosen solutions. Genetic algorithms have aided in the successful implementation of solutions for a wide variety of combinatorial problems.

The robustness of the Genetic algorithms as search techniques have been theoretically and empirically proved [23]. The artificial individual is the basic element of a GA. An artificial individual consists of a chromosome and a fitness value, similar to a natural individual. The individual's likelihood for survival and mating is determined by the fitness function [21]. In accordance with the Darwin’s principle, individuals superior to their competitors, are more likely to promote their genes to the next generations. In accordance with this concept, in Genetic Algorithms, we encode a set of parameters mapped into a potential solution, named chromosome, to the optimization problem [22]. The population of candidate solutions is obtained through the process of selection, recombination, and mutation performed in an iterative manner. [24].

Chromosomes refer to the random population of encoded candidate solutions with which the Genetic algorithms initiate with [23]. Then the set (called a population) of possible solutions (called chromosomes) are generated [27]. A function assigns a degree of fitness to each chromosome in every generation in order to use the best individual during the evolutionary process [26]. In accordance to the objective, the fitness function evaluates the individuals [24]. Each chromosome is evaluated using a fitness function and a fitness value is assigned. Then, three different operators- selection, crossover and mutation- are applied to update the population. A generation refers to an iteration of these three operators [25]. The promising areas of the search space are focused in the selection step.

The selection process typically keeps solutions with high fitness values in the population and rejects individuals of low quality [24]. Hence, this provides a means for the chromosomes with better fitness to form the mating pool (MP) [27].

After the process of Selection, the crossover is performed. In the crossover operation, two new children are formed by exchanging the genetic information between two parent chromosomes (say C1 and C2 which are selected from the selection process) [27]. A crossover point is chosen at random by the crossover operator. At this point, two parent chromosomes break and then exchange the chromosome parts after that point. Consequently, the partial features of two chromosomes are combined to generate two off springs. The chromosome cloning takes place when a pair of chromosomes does not cross over, thus creating off springs that are exact copies of each parent [26].The ultimate step in each generation is the mutation of individuals through the alteration of parts of their genes [24]. Mutation alters a minute portion of a chromosome and thus institutes variability into the population of the subsequent generation [27]. Mutation, a rarity in nature, denotes the alteration in the gene and assists us in avoiding loss of genetic diversity [24]. Its chief intent is to ensure that the search algorithm is not bound on a local optimum [26].

4. Inventory Optimization Analysis Using GA

The proposed method uses the Genetic Algorithm to study the stock level that needs essential inventory control. In practice, the supply chain is of length , means having number of members in supply chain such as factory, distribution centers, suppliers, retailers and so on. Here, for instance we are going to use a three stage supply chain that is illustrated in the figure 1. Our exemplary supply chain consists of a three stage supply chain having seven members and it is depicted in the figure 1.

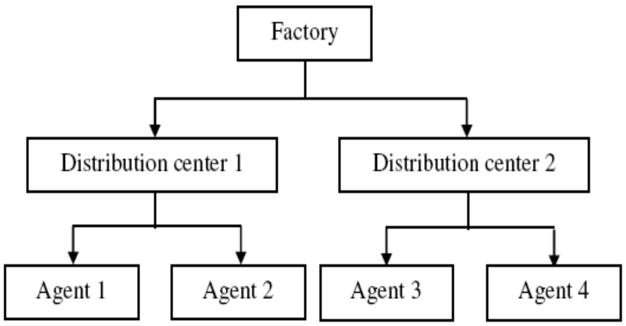

Figure 1: 3 stage-7 member supply chain

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, each having two agents. So, in aggregate there are four agents, Agent1 and Agent2 for Distribution center 1 and Agent 3 and Agent 4 for Distribution center 2. From the distribution center, the stocks will be moved to the corresponding agents. The methodology adopted is intended to determine the specific product that needs to be concentrated on and the amount of stock levels of the product that has to be maintained by the different members of the supply chain. Also, the methodology analyses whether the stock level of the particular product at each member of the supply chain needs to be in abundance in order to avoid shortage of the product or needs to be held minimal in order to minimize the holding cost.

The factory is manufacturing one type 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 members from factory to end-level-Agents, there are 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 periods, the TID will be . 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

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

The methodology flow is illustrated in the figure 2 would analyze the past records very effectively and thus facilitate efficient inventory management with the contribution of Genetic Algorithm.

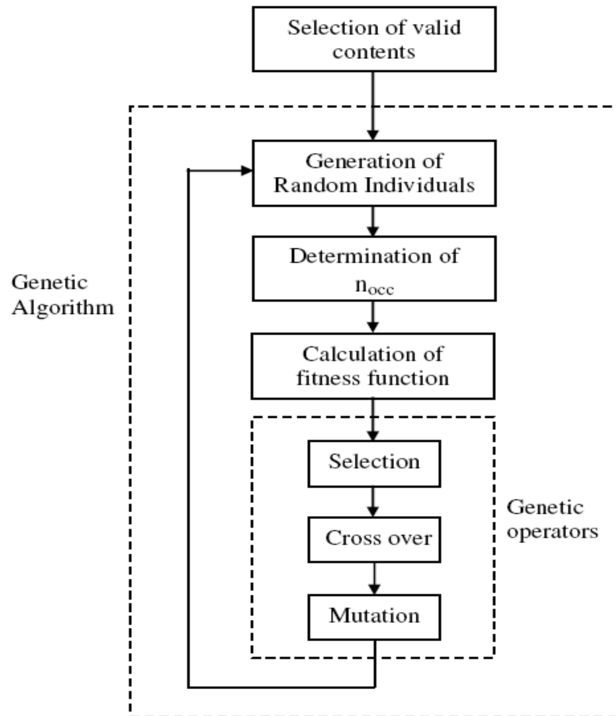

Figure 2: Genetic Algorithm flow for the proposed inventory management analysis

Table 1: The dataset for the analysis taken from the past periods

Factory (F)	Distribution Center1 (D1)	Distribution Center2 (D2)	Agent1 (A1)	Agent 2 (A2)	Agent 3 (A3)	Agent4 (A4)
2000	500	-300	30	120	-130	200

The record set having positive values represents excess stock levels of the product and the negative values represent shortage level of the product.. Then the data set is subjected to Genetic Algorithm and the various steps performed in the genetic algorithm model for our objective work are discussed below.

4.1 Generation of Individuals

Each individual constitutes a gene and is generated with random values. Here, the chromosome of seven genes where the random values occupy each gene is generated along with the product representation. A random individual generated for the genetic operation is illustrated in the figure 3.

Chromosome1

2000	200	-400	600	-800	-300	600

Chromosome2

6000	- 100	-500	700	- 300	600	-700

Figure 3: random individual generated for the genetic operation

These kinds of chromosomes are generated for the genetic operation. Initially, only two chromosomes will be generated. The chromosomes thus generated is then applied to find its number of occurrences in the database content by using a function

The function will give the number of occurrences of the particular amount of stock level for the three members that are going to be used further in the fitness function.

4.2 Evaluation of Fitness function

Fitness functions ensure that the evolution is toward optimization by calculating the fitness value for each individual in the population. The fitness value evaluates the performance of each individual in the population.

$$f(a) = w_1\left(1 - \frac{P(occ)}{T(periods)}\right) + \log(w_2 . t_{stock})$$

$$a = 1,2,3\cdots\cdots, m$$

where,

$P(occ)$,is the number of counts of past records that occurs throughout the period.

T(Periods) is the total number of records of inventory values obtained after clustering.

m is the total number of chromosomes 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

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

The fitness function is carried out for each chromosome and the chromosomes are sorted on the basis of the result of the fitness function.

In the fitness function, the ratio ($P(occ)$ / T(Periods)) plays the role of finding the probability of occurrence of a particular chromosome; and [1-($P(occ)$ / T(Periods))] will ensure minimum value corresponding to the maximum probability; (t_{stock}) is structured to choose the stock record with as minimum lead time as possible.

So, the fitness function is structured to retain the minimum value corresponding to the various chromosomes being evaluated iteration after iteration and this in turn ensures that the fitness function evolution is towards optimization.

4.3 Genetic operations

Once fitness calculation is done , Genetic operations are performed. Selection, Crossover and Mutation comprise Genetic operations.

4.3.1. Selection:

The selection operation is the initial genetic operation which is responsible for the selection of the fittest chromosome for further genetic operations. This is done by offering ranks based on the calculated fitness to each of the prevailing chromosome. On the basis of this ranking, best chromosomes are selected for further proceedings. The chromosome generating value as minimum as possible will be selected by the fitness function and will be subjected further to the genetic operations, crossover and mutation.

4.3.2. Crossover:

Among the numerous crossover operators in practice, for our complex operation, we have chosen two point crossover. From the matting pool, two chromosomes are subjected for the two point crossover. The crossover operation performed in our analysis is pictured in the figure 4.

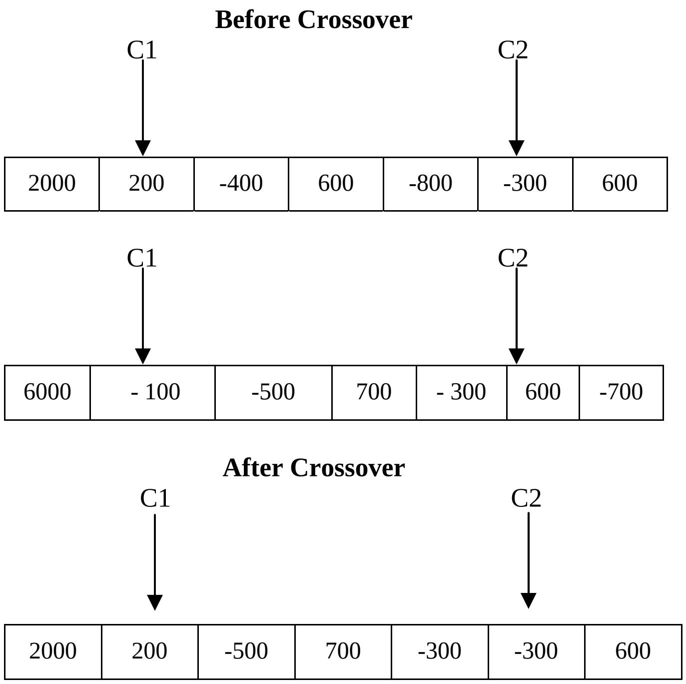

Figure 4: Chromosomes are subjected to Two point crossover operation

As soon as the crossover operation is completed, the genes of the two chromosomes present within the two crossover points get interchanged. The genes before the crossover point C1 and the genes beyond the crossover point C2 remain unaltered even after the crossover operation.

4.3.3. Mutation:

The crossover operation is succeeded by the final stage of genetic operation known as Mutation. In the mutation, a new chromosome is obtained. This chromosome is totally new from the parent chromosome. The concept behind this is the child chromosome thus obtained will be fitter than the parent chromosome. The performance of mutation operation is illustrated in the figure 5.

In figure 5 we have chosen four mutation points Mp1, Mp2, Mp3 and Mp4. The mutation is done on the particular gene present at the Mutation point points. This pointing of gene is done randomly. Hence, the four mutation points may point any of the seven genes.

The mutation operation provides new chromosomes that do not resemble the initially generated chromosomes. After obtaining the new chromosome, another random chromosome will be generated. Then again the process repeats for a particular number of iteration while the two chromosomes that are going to be subjected for the process is decided by the result of the fitness function. Each number of iteration will give a best chromosome and this is will be considered to find an optimal solution for the inventory control. When the number of iterations is increased then the obtained solution moves very closer to the accurate solution and as long as minimization of the fitness function is still possible, the iteration continues till such a time that no improvement in the fitness function value is noticeable. Eventually with the help of the Genetic algorithm, the best stock level to be maintained in the members of the supply chain could be predicted from the past records and so that the loss due to the holding of excess stock level and shortage level can be reduced in the upcoming days.

5. Results and Discussion

The approach we have suggested for the optimization of inventory level and thereby efficient supply chain management has been implemented in the platform of MATLAB (MATLAB 7.4). The database consists of the records of stock levels held by each member of the supply chain for every period. In our implementation we have utilized a single product which is in circulation in the seven member supply chain network we have considered. The sample database which consists of the past records is shown in Table 2 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

Table 2: A sample data set along with its stock levels in each member of the supply chain

TI	*F*	*D1*	*D2*	*A1*	*A2*	*A3*	*A4*
1	-407	379	-981	-864	-391	999	-196
2	-146	-604	443	746	-561	-734	445
3	-962	-524	-685	-254	205	446	-469
4	-834	266	969	965	735	244	-752
5	-449	-282	577	-926	-414	-200	-743
6	540	-830	-835	882	-379	768	-635

In the database we have tabulated in Table 2, the fields are related with the stock levels that were held by the respective seven members of the supply chain network.

Similarly, different sets of stock levels are held by the database.
As per the proposed analysis based on GA, we have generated 2 random initial chromosome as shown in the Fig. 6.

F	*D1*	*D2*	*A1*	*A2*	*A3*	*A4*
855	61	215	863	24	75	-757
854	-154	145	-241	-215	415	845

Fig. 6: Random inventory generated initially for the GA based analysis

and they will be subjected to genetic operations like Fitness evaluation, Selection, Crossover and Mutation. An iteration involving all these processes was carried out so as to obtain the initial best chromosome.

Table 3: Sample data from Database which is having lead times for stocks

TI	*T1*	*T2*	*T3*	*T4*	*T5*	*T6*
1	28	27	19	9	19	19
2	35	33	16	4	24	15
3	38	38	20	8	10	18
4	25	25	9	21	22	13
5	45	40	15	4	16	11
6	36	43	7	13	21	3

Table 3 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.
In table 3, 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 A1;
T6 is the lead time involved for movements of the product from D2 to A2;
The methodology that uses Genetic algorithm presented is aimed at establishing the most probable surplus stock level and shortage level along with the consideration of lead time involved in supplying the stocks that are required for inventory optimization in the supply chain such that the total supply chain cost is minimal. The Fitness function is structured to choose the most emerging pattern of inventory levels at different members of the supply chain with minimum lead time. The simulation run on a huge database of 5000 past records showing Fitness function improvement at different levels of iteration is as follows:
Simulation Result showing Fitness function improvement with w1 = 0.6250; w2= 0.3750
For iteration 20: fitness = 4.7787
For iteration 50; fitness = 4.6456;
Improvement: 3%
For iteration 70; fitness = 4.3849;
Improvement: 6%
For iteration 100; fitness = 3.8220;
Improvement: 15%
As for deciding the total number of iterations required, the criteria followed is that as long as minimization of the fitness function is still possible, then the iteration continues till such a time that no improvement in the fitness function value is noticeable. After a certain number of iterations, if the fitness function value is not improving from the previous iterations, then this is an indication that the fitness 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 best chromosome we have obtained as result after satisfying the above mentioned convergence criteria is' $[697\ \ -906\ \ 304\ \ 257\ \ 849\ \ -444\ \ -845]$', and its database format is depicted in the Fig. 7.

F	*D1*	*D2*	*A1*	*A2*	*A3*	*A4*
697	-906	304	257	849	-444	-845

Fig. 7: The final best chromosome obtained from the analysis

The final chromosome we have obtained from the GA based analysis shown in the figure 7 is the inventory level that has the potential to cause maximum increase of supply chain cost. By taking necessary steps to eliminate the identified emerging excesses/ shortages at different members of the supply chain, the supply chain cost can be minimized to that extent. Thus by following the predicted stock levels, we can avoid the increase of supply chain cost.

6. Conclusion

Inventory management is an important component of supply chain management. The members of the supply chain are responsible for minimizing the costs of a supply chain by managing inventory levels in a number of production and distribution operations associated with different chain stages. 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 methodology that uses Genetic algorithm presented that is aimed at reducing the total supply chain cost as it undoubtedly established the most probable surplus stock level and shortage level along with the consideration of lead time involved in supplying the stocks that are required for inventory optimization in the supply chain such that the total supply chain cost is minimal. The proposed approach was implemented and its performance was evaluated using MATLAB 7.4. The performance of Genetic Algorithm was well as predicted. By following the proposed genetic algorithm based approach for inventory management, we determined the products due to which the members of the supply chain incurred extra holding or shortage cost in the whole supply chain. The proposed approach of inventory management has achieved the objectives which are the minimization of total supply chain cost as well as lead time and the determination of the products due to which the respective supply chain members endured either additional holding cost or shortage cost with lead time consideration which is a vital information for supply chain inventory optimization.

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