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MODIFIED GENETIC ALGORITHM FOR INVENTORY OPTIMIZATION IN A SERIAL SUPPLY CHAIN

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Abstract -Inventory management is considered the pillar of supply chain management as inventories accounts for about 30% of the value of the product. The performance study is conducted on a single-product serial supply chain operating with a base-stock policy .The main focus of this study is to propose a modified GA which can optimize the inventory (i.e. base stock) levels in the supply chain so as to minimize the total supply chain in the serial supply chain. In this study the single gene random crossover technique is introduced, whose mechanism acts to stabilize the results of the existing normal GA and hence the new modified GA algorithm is made. The study includes the comparison of both the existing normal and modified GA's and it is shown that the modified GA gives more optimal solutions with higher accuracy and reliability. The existing and modified GA is made to run in four different settings, with five different demand sets and the average values are taken and compared and through the data it is shown that the new modification brought gives better results and it is observed that there is a stabilization introduced by this mechanism.

Keywords: Genetic Algorithm, Metaheuristics, Supply chain, inventory control, mathematical simulations

1. INTRODUCTION:

There is an ever increasing demand of products and their consumption these days. Challenges faced by the companies are increasing day by day and this has put down pressure on industrial output and supply chain. A proper supply chain management system is of grave importance. A Supply chain management (SCM) refers to the active streamlining of a company's supply-side activities to maximize customer value and product satisfaction and gain a competitive

Advantage in the marketplace. SCM's immense scope has led to many researches and new areas previously not addressed by researchers. There has been a drastic shoot in the research papers and study done on SCM over the years. Beamon, B.M., Chen, V.C.P., (2001) suggested that virtually every manufacturing or service enterprise in the world may be classified as a supply chain (SC) - an organization that supplies products (or services) to customers via a chain of facilities comprising functional stages.

For a manufacturer who outsources many parts, a proper supply chain management system can reduce the cost and complexity of the manufacturing process drastically. It involves comprehending or even eliminating superfluous steps, modernizing conventional methods and techniques, reorienting perspectives to aid the efficiency of a process. SCM enables the analysts and management of a company reach at a credible supply chain forecasting. It interconnects and controls the production, shipment and distribution of a product thereby trimming down the excess costs and increases delivery speed.

Business logistics management refers to the activities like production, distribution etc. within the boundaries of a single organization, while supply chain management includes suppliers, manufacturers, and retailers that distribute the product who work together and the coordination of their actions to the manufacture a product and deliver it to the customer.

Over the years, the supply chain management techniques have evolved and were able to curb inflation to a great extent

Inventory is the heart of any organization as improper inventory management adds up to the total product cost. This work analyses the problems in maintaining the inventory level (base stock). The aim of this paper is to optimize the inventory so as to minimize the supply chain cost. The inventory level at each installation say for example retailer is to be maintained at a particular level at all times called the base stock level. Each installation has its own base stock policy and proper maintenance of the inventory is a necessity. Proper control, analysis and monitoring should be done at all times to replenish the stock at each installation. Due to the dynamic nature of the supply chain a simulation best represents the situation, helps understand and analyze the challenges. A four stage serial supply chain system is used and the base stock levels at each installation are done using simulation. Total supply chain cost is intended to be minimized by using a modified Genetic Algorithm (GA) to obtain the optimal base stock levels.

2. LITERATURE REVIEW:

Many researchers have proposed different methods and frameworks to understand, support and analyze supply chains. Supply chain performances can be measured in the following ways:

– Analytical methods, such as queuing theory

– Monte Carlo methods, such as simulation or emulation

– Physical experimentations, such as lab platforms or industrial pilot implementations

Analytical methods are impractical as it is difficult to build a mathematical model corresponding to a realistic case due to the dynamic behavior of the supply chain. Simulation is a powerful virtual tool that enables analysis and experimentation with the existing supply chain processes using different possible virtual supply chain settings to investigate the supply chain performance thereby reducing money and time which would have been spent if the experiment was conducted physically. Lee and Billington (1993) devised a supply chain model for Hewlett-Packard (HP) to (1) manage material flows in their supply chains; (2) assess inventory investment; and (3) evaluate alternatives.

According to the inventory literature supply chain is a multi-echelon system which is defined as a system involving multiple steps or processes. Echelon stock in the context of an installation is the sum total of the actual on hand inventory at that installation and all other inventory in the supply chain, which is actually at a lower level installation or in transit to a lower level installation. Whereas the installation stock for an installation in the supply chain is the sum of all on orders at that installation and its on-hand inventory minus its back orders. Implementation of installation stock policy is used in many supply chains due to its simplicity.

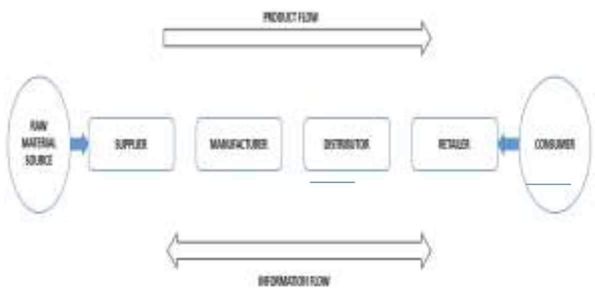
Disney et al. (1997) demonstrated the use of a simulation model of a decision support system and GA optimization procedure that can yield enhanced results to the production control function. The authors deployed GA to search for the best value of the control parameters (i.e. time to average consumption, time to adjust inventory, and time to adjust to work in progress) so that the production control system can respond to dynamic nature in the supply chain, trim out random noise in the sales pattern and be rugged to variations in production lead time. Genetic algorithm (GA) is a metaheuristics tool belonging to the class of evolutionary algorithms inspired by the celebrated theory of natural selection proposed by Charles Darwin.

Jung, J.Y. et al.(2004) used Monte Carlo simulation provides due to its flexibility to accommodate various types of uncertain parameters and their distributions. This framework has high potential for application to a wide range of large scale stochastic optimization problems.

J. S. R. Daniel and C. Rajendran (2005) proposed a genetic algorithm (GA) to determine the best base-stock levels at various installations (members/stages) in the supply chain that will minimize the total supply chain inventory-related cost. A random search procedure (RSP) and complete enumeration technique were used to test the effectiveness of the proposed GA. The authors used GA to optimize the TSCC by searching for the best set of base-stock levels at every stage in the supply chain. The present work analyses the problems in maintaining base stock levels using a simulation which best represents the dynamic nature of the supply chain, capturing the interactions and interdependencies of different installations, and their impact on the overall system performance. We propose a modified GA to optimize the TSCC by searching for the best set of base-stock levels at every installation in the supply chain

3 .DESCRIPTION OF SCM MODEL:

The focus of our study is confined to a single-product four-stage serial supply chain. The following assumptions are taken from the work done by J. S. R. Daniel and C. Rajendran (2005).



SUPPLY CHAIN MODEL

3.1 MODEL ASSUMPTIONS

- Since the area of study considered is for a single product, a single product flows through the supply chain.
- The supply chain operates under a periodic-review base-stock policy for each member in the supply chain that is a timely review structure is used.
- The order processing or information lead time is considered to be zero.
- Processing lead time and transportation lead time as a whole for each member is considered as the replenishment lead time for that member of the supply chain.
- The most downstream member, retailer faces random customer demand, which is assumed to be stationary.
- There is no lot-size or discount policy for members in the supply chain.

- Each installation in the supply chain takes up discrete integer values for their base stock level.
- Each member has their own holding and shortage costs in the supply chain, that is local or installation cost rates.
- If the demand cannot be satisfied by the on-hand inventory, then the excess demand is backlogged.
- The transportation cost is assumed to be directly proportional to the quantity shipped.
- All installations have infinite capacity.
- The most upstream member, supplier, is assumed to have infinite raw material supply.

3.2 MODEL DESCRIPTION

The supply chain model considered in this study includes four members, namely retailer, distributor, manufacturer, and supplier. All the four members add value to the product before it is delivered to the ultimate customer. The whole supply chain system works with the pull strategy and therefore the consumer puts a demand on the most downstream member, namely the retailer and as a result the product flow is from left to right, i.e. supplier to retailer. Here the supply chain is well connected and there is information flow in both directions. The most downstream member, namely retailer, places an order to the upstream member, namely the distributor as soon as the retailer's on-hand inventory is depleted due to customer demand. The inventory control mechanism used here is a periodic-review base-stock system and using this stock is replenished when necessary at each member. Base stock mechanism triggers replenishment at each member. Some of the important terms used in supply chains are given below

- **On hand inventory** refers to the current inventory level in each installation of the supply chain.
- **On order inventory** refers to the inventory that has been ordered by the installation but has not been delivered yet.
- **Backlog** refers to the quantity of the pending commodity to be delivered to the downstream member.
- **Inventory position** is the sum of on hand inventory and on order inventory minus current backlog.
- **Lead time** refers to the time required for the upstream member to fulfil the order requirement of the downstream member.
- **Replenishment order** refers to the order given by a downstream member to the upstream member when the inventory level at the downstream member falls below the base stock level prespecified to that member.
- There exists local holding and shortage cost rates. The sum of such cost incurred by all members in the chain is referred to as **TOTAL SUPPLY CHAIN COST (TSCC)**.
- **Replenishment lead time** refers to the time taken by the immediate upstream member or other upstream members to deliver the supplies to a downstream member.

The replenishment lead time can vary between the maximum and the minimum replenishment lead times. This is because if a replenishment order is given by a downstream member to the immediate upstream member, the order can be fulfilled only if the immediate upstream member has adequate supplies. Otherwise the immediate upstream member has to order the deficient supply plus the replenishment to its next upstream member. The minimum replenishment lead time is the time taken by the immediate upstream member to deliver supplies to the downstream member. The maximum replenishment lead time however is the time taken by most upstream member to deliver supplies to the downstream member if the immediate upstream member lacks the supplies to fulfil the order given by the downstream member

3.3 Simulation of a given base stock setting with respect to TSCC

A simulation is done on the supply chain studied here in order to analyse and study the performance of the supply chain with respect to every base stock setting. The simulation is prepared using the erratum proposed by J. S. R. Daniel and C. Rajendran (2005).The performance of the latter is measured using TSCC. The supply chain is simulated for a certain set of customer demands generated from a uniform distribution for a specified run length over which static TSCC values are taken. Since a serial supply chain is used, the supply chain can be viewed as a set of firms arranged in series. A sequence of events takes place at each member i, where i denotes the position of each member, i.e. 1 to N. N denotes the total number of members involved in the supply chain.

4. NOTATIONS AND TERMINOLOGIES USED IN THE MODIFIED GA:

GEN: number of generations

N: number of members/installations in the supply chain

n : number of chromosomes

parentpop : parent population

Bi: base-stock level at installation, i

BiUL: upper limit of Bi.

BiLL : lower limit of Bi

fj : fitness value for the jth chromosomes

Pj: probability of selecting a chromosome j.

r : a uniform random number between 0 and 1

CR: crossover rate

MR: mutation rate

intpop : intermediate population

childpop : child population

secondpop: secondary population

5. MECHANICS OF THE PROPOSED GENETIC ALGORITHM

5.1 Chromosome representation:

GA works on a population of solutions to the given problem. Each individual in the population is called a chromosome. In the current study the problem is to optimize the installation base-stock levels across all members in the supply chain to reduce TSCC. The chromosome is represented as a phenotype, i.e. the actual values of the base-stock levels are used to code all the genes in a chromosome. The chromosome length (len) is set equal to the number of installations (N). For example, there are four installations in the supply chain, thus the length of the chromosome and number of genes is set to four.

5.2 Generation of initial population:

The initial base stock levels created in this study are selected randomly within the range i.e, every base stock level is bound within the upper and lower limits (B_i^{UL} , B_i^{LL}). These limits are computed by taking into account the customer demand, minimum replenishment lead time, and maximum replenishment lead time with respect to the corresponding member.

Thus Upper limit and lower limits are given by:

B_i^{UL} = (maximum demand per unit time at member i) x (maximum replenishment leadtime w.r.t member i)

B_i^{LL} = (minimum demand per unit time at member i) x (minimum replenishment leadtime w.r.t member i)

For example, the maximum customer demand is 60 and minimum is 20, i.e., customer demand varies in the range [60,20] per unit time. Consider setting 1 (table !!!!!), we see that the maximum replenishment lead time for the member 1, that is the retailer is 13 days (1+3+5+4 days). While the minimum replenishment leadtime is 1 days. So by following the equation for B_i^{UL} and B_i^{LL}, it can be computed to 60*13=780 and 20*1=20, thus the basestock should be within the limits [780,20] for member 1. Similarly we can compute for the rest of the members.

B_1^{UL}= 60*13 = 780 | B_1^{LL} = 20*1 = 20 (Retailer)

B_2^{UL}= 60*12 = 720 | B_2^{LL} = 20*3 = 60 (Distributor)

B_3^{UL}= 60*9 = 540 | B_2^{LL} = 20*5 = 100 (Manufacturer)

B_4^{UL}= 60*4 = 240 | B_4^{LL} = 20*4 = 80 (Supplier)

Since the B_i^{UL} and B_i^{LL} values are determined for all supply chain members, a base stock is generated in the range [B_i^{UL}, B_i^{LL}] for i=1 to N in every chromosome. The parents generated form the initial parent population.

5.3 Evaluation of chromosomes:

Every chromosome in the parent population is evaluated through simulation and the respective objective function (TSCCj) value is obtained through simulation of the supply chain. Fitness value is calculated for the jth chromosome by using the formula fj = 1/(1+TSCCj) where j=1 to n.

In the current study the simulation is done as per the existing study, so that comparisons can be drawn out easily.(for details, refer erratum (Daniel,J.S.R and Rajendran, 2005))

5.4 Roulette wheel selection of chromosomes:

In this study, roulette wheel selection is used at two places. First to select chromosomes to the mating pool and the second to select chromosomes to the secondary population. The procedure employed is the same at both the places. It is explained here with an example for ease of understanding. Consider number of chromosome equal to 4, and we have got fitness values as f1=0.2,f2=0.3,f3=0.4 and f4=0.6. Now selection is made by roulette wheel procedure (see Goldberg, 1989).Accordingly the probability Pj is obtained by calculating (fk/Σu=1 to n f'j).

Thus the Pj value of all the chromosomes in the population are calculated. Then the cumulative probabilities of these chromosomes are also calculated, in the present example P1=0.13,P2=0.2,P3=0.26,P4=0.40 and the cumulative probabilities of selecting chromosomes 1,2,3,4 are 0.13, 0.33, 0.59,1, respectively. In order to choose n chromosomes to the mating pool, uniform random numbers are generated between 0 and 1 and it is to be noted that no two identical chromosomes should be copied into the mating pool/secondary population, otherwise this would lead to premature convergence.

5.5 Crossover operation:

A single point crossover was done in the existing study and the first two chromosomes in the mating pool were selected for crossover operation when the the random number generated by uniform sampling was less than or equal to the CR, otherwise both chromosomes were inserted into the intermediate population intpop (see Daniel, J.S.R and Rajendran, 2005 and Goldberg, 1989, for detailed explanation of the mechanism)

In this mechanism, we introduced a technique where the child chromosomes are subjected to fitness test. And the fittest two chromosomes are subjected to further crossover called the Single gene random crossover.In SGRC, a uniform random number, r is sampled and the operation is done when r is less than or equal to CR.

In the operation, two random numbers indicating the positions of the gene in chromosomes is sampled and then the two gene values are interchanged at these random positions in the two chromosomes selected for this operation. Now the Fitness of the second child chromosomes is undertaken and then the best value among the first and second child population is copied to the new secondary population.

The fitness, probability and cumulative probability of the secondary population is taken. The secondary population is subjected to a roulette wheel randomisation process in accordance with the cumulative probabilities and uniform random number r. Then the values in secondary population are subjected to mutation and the values are copied to the intermediate population.

5.7 Mutation operation:

A gene-wise mutation is employed in this study because every gene in a chromosome represents the base-stock level of the corresponding member .All genes in intpop are mutated with the probability of MR, by sampling a uniform random number, r. If r is less than or equal to MR, then the value of the gene is altered as given below:

$B_I^{NEW} = B_I^{OLD}(1\text{-}X) + B_I^{OLD} \times 2 \times X \times r$

Where r is a uniform random number and x denotes the fraction of B_I^{OLD}. In this study x is set to 0.2. Also since Bi is a positive integer and bound by $[B_i^{UL}, B_i^{LL}]$, therefore if B_I^{NEW} is greater than B_i^{UL} then B_I^{NEW} is set to B_I^{OLD} and this logic is applied for the lower bound as well.

5.8 Survival of chromosomes to next generation:

We now have n chromosomes in the intpop and n chromosomes in parentpop. The best n chromosomes, among the 2n chromosomes in intpop and parentpop among them is chosen with respect to the fitness value and these n best chromosomes are copied into the next generations parent population

6. ALGORITHM

Step1: Start the initial generation, i.e,GEN=0;

Step2: Generate the initial population with the number of chromosomes equal to population size, and each gene representing the basestock level at the member (i), in the supply chain. The basestock level at every member (i) is set in the range (B_i^{UL} , B_i^{LL}) in every chromosome. The initial population is sent to parent population.

Step3: Subject the chromosomes in the parent population to simulation of the supply chain and hence obtain the TSCC value and compute the fitness value F_j for every j^{th} chromosome.

Step4: Use roulette-wheel selection procedure to copy the chromosomes from the parent population into the mating pool. Ensure that no two successive chromosomes selected are the same.

Step5: Subject two successive chromosomes in mating pool to single point crossover operation. Do this operation when the random number sampled is less than or equal to CR. Copy all chromosome from the mating pool to child population childpop. This includes both the crossover subjected and non-crossover subjected chromosomes.

Step6: Evaluate the fitness of the childpop and then arrange the childpop in accordance with the fitness values.

Step7: Employee the Single Gene Random Crossover (SGRC) operation on the fittest chromosomes in the childpop when the random number r, is less than or equal to CR.

Step8: Copy the values in the matpool and childpop into secondpop and the select the best values from it and copy those chromosomes into the interpop.

Step9: Subject the chromosomes in the intepop to roulette wheel randomisation procedure in accordance with the chromosomes cumulative probabilities.

Step10: Subject the chromosomes in the interpop to gene-wise mutation process, with a probability MR.

Step11: Subject the mutated interpop to supply chain simulation and obtain the fitness value corresponding to every chromosome.

Step12: Copy the the fittest values from the parentpop and interpop (equal to population size) based on fitness value to form the next generation of the parentpop.

Step13: Increment the Generation.

GEN=GEN+1

If GEN is less than or equal to 500, then return to step, step 4

Else go to step 14.

Step14: End the process. The fittest chromosome from 500 generation constitute the solution to the problem. Record the data.

7. EXPERIMENT DESIGN FOR COMPARISON AND PERFORMANCE ANALYSIS

Supply chain in the current study is a single product four-stage serial supply chain which has retailer, distributor, manufacturer and supplier as its members. Four different supply chain settings are selected for performance analysis, optimization and comparison of the normal and modified GA. The setting includes the holding cost rates, shortage cost rate, and lead times which are considered to analyze the effectiveness of the proposed GA search algorithm in real world problems. It is seen that, the Holding and shortage costs are in a decreasing manner when going upstream in the serial supply chain and this is because of the assumption that more value is added downstream in the supply chain. This supply chain setting is envisaged so as to make the supply chain model more realistic and generic in nature. (For details see, Daniel, J.S.R and Rajendran, 2005)

Five random customer demand sets are generated in the range [60, 20] per unit time. Every member in the supply chain operates with a specified base stock level. Simulation experiments are carried out for 1200 days and the TSCC and Fitness values are noted.

In the course of this study we will be considering the Fitness value as the base value for comparing the existing and modified GA's. The existing GA and modified GA is simulated for the four supply chain settings considered.

The population size for both the mechanisms is set at 20.We consider two crossover and mutation rates, namely CR=0.5, MR=0.15 and CR=0.75, MR=0.20 and the initial base stock values of all chromosomes are the same, this is done so that there is no discrimination in the starting points of the search process.

But the uniform random numbers sampled for checking with CR and MR are random in nature and thus for every demand set , five runs of simulation are done thus the average value of fitness and base stock levels of these five runs are taken.

Both the existing and modified GA's are run and the above said data is recorded for both. For example, setting 1 is selected and its values is used for the simulation and we get the 5 set each data value for each demand set considered.

Supply chain setting : 1	Member 1	Member 2	Member 3	Member 4
Holding cost (h_i)	8	4	2	1
Shortage cost (b_i)	24	12	6	3
Leadtime (LT_i)	1	3	5	4

Table 1

Supply chain setting : 2	Member 1	Member 2	Member 3	Member 4
Holding cost (h_i)	5	4	3	1
Shortage cost (b_i)	10	8	6	2
Leadtime (LT_i)	1	3	5	4

Table 2

Supply chain setting : 3	Member 1	Member 2	Member 3	Member 4
Holding cost (h_i)	8	4	2	1
Shortage cost (b_i)	24	12	6	3
Leadtime (LT_i)	2	3	6	4

Table 3

Supply chain setting : 4	Member 1	Member 2	Member 3	Member 4
Holding cost (h_i)	5	4	3	1
Shortage cost (b_i)	10	8	6	2
Leadtime (LT_i)	2	3	6	4

Table 4

Now the average of all base stock levels and fitness value of each demand set is taken. Now note down the average value of fitness and base stock levels. Now take the average of this averaged value and compare the data. Also plot the graphs and compare the variation in base stock and fitness values for every data recorded. This is done to see the consistency and variation of the existing and modified GA's and to compare them to reach a conclusion.

Now the existing and modified GA is also run for 30 times in a single demand set with random initial chromosome (base stock) values and the average of the fitness and base stock values is noted and compared against its setting data.

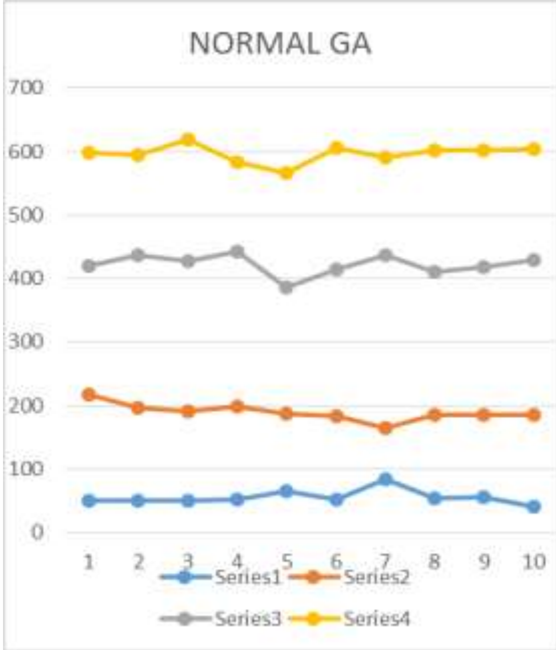
8. RESULTS AND DISCUSSION

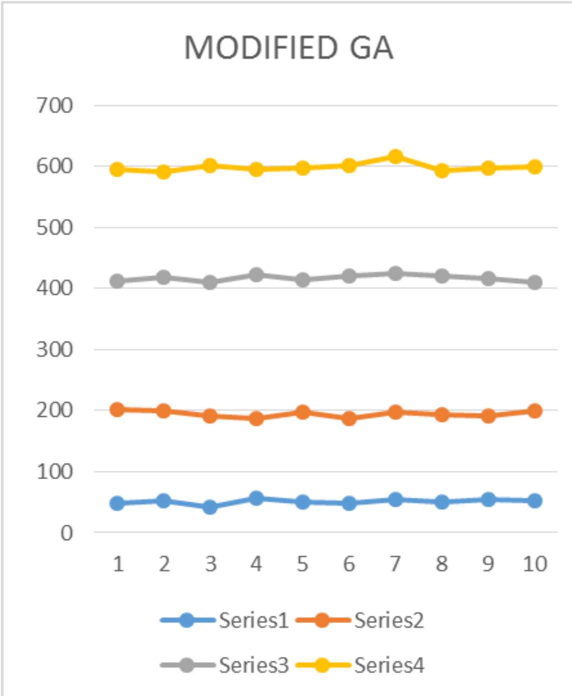
The performance of the supply chain is studied through the simulation and base stock levels are optimized by implementing the proposed GA. Considering the four supply chain settings, their respective base stock levels are optimized by using both the methodologies namely the existing and modified GA's.

The graph below shows how both the GA's have functioned, when the simulation was run at setting 1, demand set 1 and CR=0.5,MR=0.15

From both the graphs it can be observed that, in the modified GA the RL, DL, ML, SL are more stabilized in nature than its counterpart's in the normal GA graph. Thus this makes us to conclude that Modified GA is more consistent and that even a single run of the process gives reliable and optimized base stock level. All settings have shown consistency with the above said conclusion.

Setting 1 with CR 0.5, MR 0.15 and CR 0.75, MR 0.20 was simulated with five different demand sets each run 10 times to take the average values of fitness and base stock was done. This is done to keep the variance occurring due to randomness in probability distribution low.





GRAPH 1&2

LEGEND:

SERIES NAME	REPRESENTATION
1	**RETAILER LINE (RL)**
2	**DISTRIBUTOR LINE (DL)**
3	**MANUFACTURER LINE (ML)**
4	**SUPPLIER LINE (SL)**

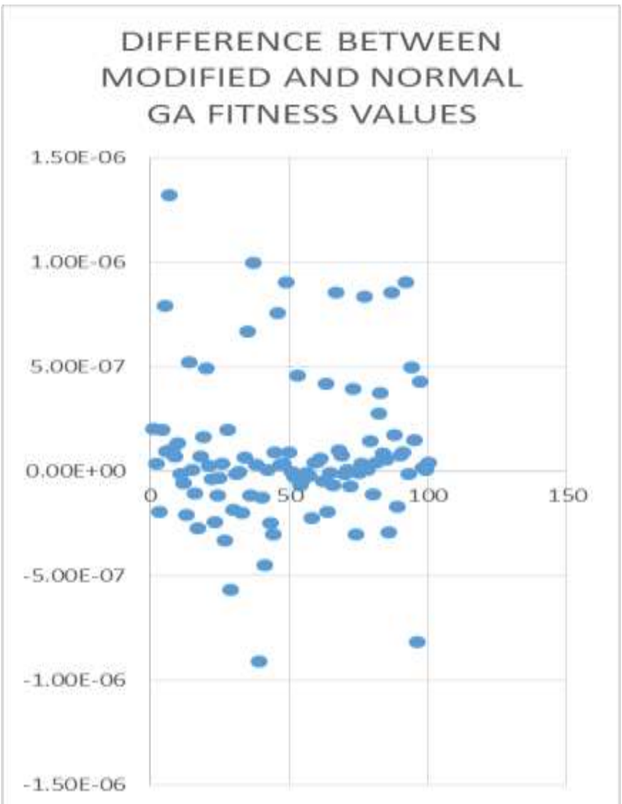
X AXIS	Y AXIS
BASESTOCK LEVEL	POSITION(NUMBER OF TIMES)

It was seen from the data for setting 1 that, the modified GA has given more optimized and higher values of fitness in every CR, MR combination with 8 out of 10 data set showing consistently higher values for modified GA than the existing normal GA.

The test was conducted with the same starting point for both the algorithms to run, i.e., the initial base stock values in the chromosomes were the same for every test conducted and only the uniformly sampled numbers were random.

To shed of this randomness we conducted the simulation 10 times in a single demand set. It can be seen that the lower fitness values shown by the modified GA in the 3 data sets namely 7, 9, 12 at the 9th, 9th & 6th positions were negligibly small, the difference being 0.00000057, 9.10E-07, 8.16E-07 respectively and it can be concluded that this is due to the random probability distribution of the sampled number r.

In the graph 3, we have plotted the difference between Modified GA fitness value and existing Normal GA fitness value for 100 fitness value comparisons and it can be seen that 60% of the differences are above the zero line and all other negative values are close to the zero line with most of it having differences in E-08 & E-09 range and only 3% having difference in the range [-5.0E-07, -1.0E-07].



Graph 3

X-AXIS	Y-AXIS
FITNESS VALUE	NUMBER OF COMPARISON

The above results again show us that the fitness value of the modified GA is always better than the existing normal GA. It is also seen that better values of fitness and consistency is obtained when the CR is 0.75 and MR is 0.20, this is attributed to the fact that the starting base stock values of chromosomes returned poorer fitness values and thus the global search component, here the CR had to be increased to attain better and optimized fitness values.

Also, the initial base stock level of every chromosome was set randomly and a single demand set was run for 30 times and all five demand sets were simulated and the average of every single demand set is plotted with the CR 0.75, MR 0.20, since this CR, MR combination showed better test results than the other combination.

From the observations from all settings and CR, MR combinations we can conclude that the new modification has brought significant increase in the fitness values and also the most important observation about the quality of the modified GA over the existing GA is that the former has showed that the results shown by it are consistent and reliable over varying demand sets, random probability values and even the random initialization of chromosome values.

We see that the modified GA is attaining a stability in the base stock values it returns over multiple runs/iterations and this stabilization factor is achieved in the modified GA due to the introduction of Single gene random crossover of child population and roulette wheel randomization before copying values for mutation operation.

9. CONCLUSION:

This stabilization of the New Modified Genetic Algorithm gives it more credibility to work and solve real world problems with much more accuracy. It can be applied to various other problems in which inventory levels have to be tightly controlled. This stability, consistency, reliability and better optimality gives this algorithm a chance for further research to be conducted on it, so that it is improved to achieve the global optimal solution with cent percent accuracy, which generally meta-heuristic approaches lack.

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