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Cross Entropy - Genetic Algorithm based Optimized Supply Chain Model

K.Abishek Kumar
Department of Information Technology
Anna University
Chennai, Tamil Nadu

ABSTRACT

Supply Chain Management (SCM) is the management of the flow of goods and services. It is a cross functional approach that involves the movement and storage of raw materials of work-in-process inventory and of finished goods from point of origin to point of consumption. The current research in supply chain management is concerned with topics related to supply chain planning and optimization. Individual suppliers, producers and marketers who are associated through a supply chain coordinate their value creating activities with one another in order to create greater value. Ever increasing demand leads to numerous supply chain planning and optimization challenges. Various solution techniques ranging from exact linear solvers to meta-heuristic and heuristic algorithms have been developed to solve such complex supply chain optimization models. Achieving quality solutions in a reasonable length of time has remained a challenge. Meta-heuristics are general-purpose algorithms that can be applied to solve a range of optimization problems. This work presents a practical supply chain planning model that can be used to optimize the cost performance of the supply chain. The modeling effort was motivated not only by theoretical considerations, but also by real world practical requirements facing an actual organization. This work proposed hybrid meta-heuristic algorithm (Genetic Algorithm-Cross Entropy method) for continuous optimization in order to provide improvements in the planning model by using combined approach.

Keywords:**—**Supply Chain Management, Supply Chain Planning, Meta-Heuristics, Genetic Algorithm, Cross-Entropy method

I. INTRODUCTION

Supply Chain Management involves supply chain planning, execution and shipping. Supply Chain Planning (SCP), an important element of company management is one of the main categories of Supply Chain Management. Supply Chain Planning is broken down into the stages of supply chain modeling, design, distribution and planning. Coordination of supply chain depends very much on how well the issues related to demand, cost, process and supply are managed.

Manufacturing firms have been driven to develop effective supply chain planning models due to increasing competitions and globalization of businesses. Various supply chain planning models have been developed in order to improve the overall performance of the supply chain. Supply chain models being developed are differentiated based on important concepts relating to modeling and analysis such as time granularity and performance measures.

In case of supply chain planning models focusing on performance measures, each and every supply chain planning model aims in improving particular aspects of the supply chain. For example Supply chain planning models have been developed in order to increase the productivity of the supply chain, to improvise the services provided by the supply chain, to provide better products for the end user and even to improve the environmental factors concerning a supply chain since the most competitive firms are not necessarily the ones which provides the best set of products and services but also the ones that have the most sustainable, resilient and efficient supply chain.

Designing a supply chain planning model that deals with production, sale, purchase and logistics is critical to the success of an organization. The need to design and analyze supply chain planning models that integrate information and supply chain decisions are increasing day by day. The importance of supply chain planning has imposed the need for decision support systems that can operate in real time to provide solutions for supply chain planning problems.

Supply chain planning models focus on increasing the quality of the end product being delivered to the customer but most often do not pay attention to the total money being spent by the organization or firm along the course of the supply chain. The profit of the organization depends on the total supply chain cost and whether this value is greater than or less than the money made by the sales of the end product. Thus total supply chain cost is an important factor that is to be considered while dealing with supply chain planning.

Globally optimal supply chain performance can only be achieved through integrated supply chain planning. The supply chain should not only focus on providing the best set of products and services, it should also be cost-effective. The incorporation of the efficient-related measures and cost-related measures into the conventional supply chain planning practices adds to the complexity of the modeling efforts due to additional variables and constraints. Complex supply chains often have nonlinear optimization problems that are difficult to solve using standard solution methods.

Global supply chains are transforming and are becoming increasingly more complex and difficult to manage. Organizations with thousands of suppliers from different regions offering hundreds of products to millions of customers require sophisticated optimization tools and techniques to minimize the cost of their complex supply chains. The objective of this work is to propose hybrid meta-heuristic algorithm such as Genetic Algorithm-Cross Entropy method to solve such complex optimization problems by using combined approach.

II. LITERATURE SURVEY

Some of the articles by illustrious scholars on Supply Chain Planning models and Meta-Heuristic algorithms are studied and discussed below.

Zheng et.al [1] presented a practical supply chain planning model which is used to balance the performance of the supply chain in terms of time granularity. A nonlinear mathematical model was developed in an integrated manner to determine production and distribution decisions by making use of knowledge exchange in supply chain planning. Real data from a garment manufacturing industry was utilized.

Subramanian et.al [2] proposed a study that utilized optimization techniques like Genetic Algorithm in order to minimize the total cost of the supply chain. This study developed a total supply chain costing model in view of adding value to the business. The model developed was taken into use at the case company.

Lauri [3] examined mathematical modeling as a means to improve profitability. It focused on studying supply chain cost drivers and their impacts on cost reduction in manufacturing industries, since the role of supply chain management is significant in such an industry due to capital intensive and their high volume of business..

Behnam et.al [4] evaluated and compared the performance of three meta-heuristic algorithms (Genetic Algorithm, Simulated Annealing and Cross Entropy method) for solving the proposed practical supply chain planning model. The numerical results showed the superiority of the Cross Entropy method over Genetic Algorithm and Simulated Annealing in terms of supply chain cost, emissions performance and computation time.

Almazan et.al [5] demonstrated the accurate performance of the Cross Entropy method for solving continuous multi-extremal optimization problems, both constrained and unconstrained. The Cross Entropy method has been successfully applied to a large number of problems in combinatorial optimization. This study numerically showed that Cross Entropy method found the optimal solution quickly when compared to other meta-heuristic algorithms.

Nguyen et.al [6] utilized the techniques of meta-heuristic algorithms like Firefly Algorithm, Particle Swarm Optimization and Genetic Algorithm in order to optimize the parameters of TSK fuzzy logic system so as to find the optimal fuzzy logic system for sea water level prediction. This study also compared the performance of the three meta-heuristic algorithms and arrived at the conclusion that Firefly Algorithm provided the best results for the proposed problem.

Fernandes et.al [7] gave on overview on hybrid meta-heuristic algorithms which has proved to be very powerful search algorithms. A good combination of different meta-heuristic algorithms can provide a more efficient result while dealing with large-scale problems..

Christian et.al [8] discussed the reasons as to why the field of hybrid meta-heuristic algorithms has risen over time and concluded that it was due to the fact that focus of research in optimization shifted from algorithm-oriented point of view to problem-oriented point of view.

Based on various taxonomies, Conesa-Munoz et.al [9] presented a classification and characterization of hybridization approaches to fit optimization problems. It focused on determining the meta-heuristic algorithms best for optimization problems and the techniques to combine those meta-heuristic algorithms with their counterparts in order to achieve better results.

Talbi [10] proposed the methods of combining meta-heuristics with other complementary meta-heuristic algorithms and described the major role played by these hybrid meta-heuristic algorithms in improving supply chain optimization.

Jakob et.al [11] proposed a hybrid meta-heuristic algorithm combining the techniques of Ant Colony Optimization and Constraint Programming in solving combinatorial optimization problems and verified that the combined meta-heuristic approach provided better results than the results obtained when the problem was solved using the individual algorithms on their own.

III. HYBRID META-HEURISTICS

Supply chain planning models are used to resolve the issues faced by complex supply chains in terms of productivity, cost, efficiency, sustainability. Various supply chain planning models have been designed and developed with the view of improving the overall performance of the supply chain.

3.1 Architecture of Supply Chain Planning Model

A supply chain of an industry begins right from the suppliers and goes all the way up to the retailers compressing the activities of the suppliers, manufacturers, storage units, transportation, distribution centers and retailers. Coordination among the supply chain members is a crucial factor in improving the performance of the supply chain, as a result of which various supply chain planning models have been designed and developed.

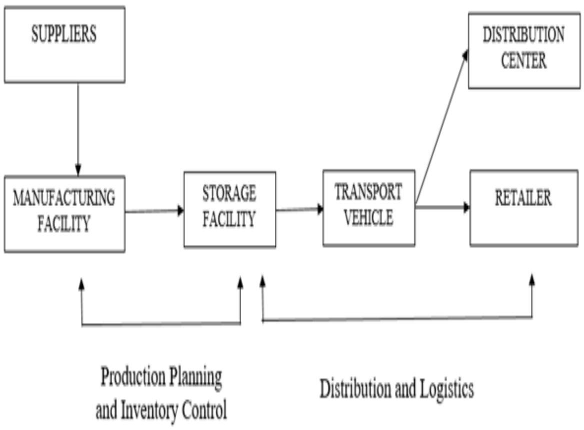

Fig.1 Sectors of industry and supply chain

3.2 Mathematical Optimization Model

Supply chain planning and optimization is a relatively complex process. This work specifically deals with the planning for minimization of total cost. The supply chain planning model for a three-month period from January to March is proposed.

The various costs taken into consideration are

- Raw materials cost
- Machinery and Equipment cost
- Staff and labor cost
- Cost for installation of machines
- Office Furniture cost
- Pre-operative expenses
- Electricity charges
- Water charges
- Fuel cost
- Rent
- Advertisement & Publicity cost
- Postage & Stationery cost
- Repair & Maintenance cost
- Transport cost
- Telephone bills
- Miscellaneous charges

The data collected from a real world garment industry is listed as follows

Table 1: Raw Material Cost

S. NO	ITEM	QUANTITY (UNIT)	RATE/ITEM (Rs)
1	Cotton fabric shirts (m)	16500	80
2	Blended fabric (m)	10000	150
3	Trims & Embellishments (nos)	7500	15
4	Sewing threads (m)	15000	80
5	Packing material (nos)	15000	3

Table 2: Machinery & Equipment cost

S.NO	MACHINE	QUANTITY(NOS)	RATE /ITEM (Rs)
1	Single needle lock stitch machine	50	23650
2	Cloth cutting machine	1	50000
3	Safety stitching machine	1	50000
4	Double needle lock stitch machine	2	75000
5	Button hole making machine	1	145000
6	Button stitching machine	1	75000
7	Hot fusing press	1	65000
8	Washing machine	1	145000
9	Hydro extractor	1	70000
10	Tumbler dryer	1	140000
11	Flat bed steam iron press	4	75000
12	Embroidery machine	1	45000
13	Generator set	1	100000
14	Wash room trolleys	4	10000

Table 3: Staff and Labor cost

S.NO	PERSONNEL	NOS	RATE/PERSON (Rs)
1	Marketing manager	1	10000
2	Sales representative	1	6000
3	Accounts officer	1	5000
4	Clerk	2	3500
5	Electrician	1	3500
6	Watchman	2	3000
7	Production manager	1	10000
8	Cutting master	1	8000
9	Skilled workers	55	3500
10	Pressman	4	3000
11	Unskilled workers	6	3000

Table 4: Other costs

S.NO	COST TYPE	COST(Rs)
UTILITY EXPENSES		
1	Installation of machines	217500
2	Office furniture	40000
3	Pre-operative expenses	30000
OTHER CONTINGENT EXPENSES		
4	Electricity	24000
5	Water charges	2000
6	Fuel for generator	5000
7	Rent	24000
8	Advertisement & Publicity	3000
9	Postage & Stationery	1000
10	Repair & Maintenance	2000
11	Transport charges	5000
12	Telephone bills	2000
13	Miscellaneous charges	2000

The expenses are divided into two categories

1. Recurring Expenses
2. Fixed Expenses

3.2.1 Recurring Expenses

Recurring expenses are those expenses which are incurred by a company on a regular basis. These expenses are essential for running the business. Among the different costs considered, the recurring expenses are

- Raw materials cost
- Staff and labor cost
- Electricity charges
- Water charges
- Fuel cost
- Rent
- Advertisement & Publicity cost

- Postage & Stationery cost
- Repair & Maintenance cost
- Transport cost
- Telephone bills
- Miscellaneous charges

3.2.2 Fixed Expenses

Unlike recurring expenses, fixed expenses are those expenses which are incurred by a company once in a while. These expenses are fixed and do not reoccur for a very long period of time. Among the different costs considered, the fixed expenses are

- Machinery and Equipment cost
- Cost for installation of machines
- Office Furniture cost
- Pre-operative expenses

3.2.3 Objective Function

A total of 95 decision variables representing the recurring and fixed expenses are considered and are denoted as follows

Table 5: Recurring expenses

VARIABLES	JAN	FEB	MARCH
Cotton fabric shirts(C)	x(1)	x(27)	x(53)
Blended fabric(B)	x(2)	x(28)	x(54)
Trims& Embellishments(T)	x(3)	x(29)	x(55)
Sewing thread(S)	x(4)	x(30)	x(56)
Packing material(P)	x(5)	x(31)	x(57)
Marketing manager(Mm)	x(6)	x(32)	x(58)
Sales representative(Sr)	x(7)	x(33)	x(59)
Accounts officer(O)	x(8)	x(34)	x(60)
Clerk(Cl)	x(9)	x(35)	x(61)
Electrician (E)	x(10)	x(36)	x(62)
Watchman(Pw)	x(11)	x(37)	x(63)
Production manager(Pm)	x(12)	x(38)	x(64)
Cutting master(Cm)	x(13)	x(39)	x(65)
Skilled workers(Sw)	x(14)	x(40)	x(66)
Pressman(Pr)	x(15)	x(41)	x(67)
Unskilled workers(Uw)	x(16)	x(42)	x(68)
Electricity(El)	x(17)	x(43)	x(69)
Water charges(W)	x(18)	x(44)	x(70)
Fuel for generator(F)	x(19)	x(45)	x(71)
Rent(R)	x(20)	x(46)	x(72)
Advertisement& Publicity(Ad)	x(21)	x(47)	x(73)
Postage& Stationery(Ps)	x(22)	x(48)	x(74)
Repair& Maintenance(Rm)	x(23)	x(49)	x(75)
Transport charges(Tc)	x(24)	x(50)	x(76)
Telephone bills(Tb)	x(25)	x(51)	x(77)
Miscellaneous charges(M)	x(26)	x(52)	x(78)

Table 6: Fixed expenses

Single needle lock stitch machine (Sn)	x(79)
Cloth cutting machine(C)	x(80)
Safety stitching machine(Ss)	x(81)
Double needle lock stitch machine(Dn)	x(82)
Button hole making machine(Bh)	x(83)
Button stitching machine(Bs)	x(84)
Hot fusing press(Hf)	x(85)
Washing machine(Wm)	x(86)
Hydro extractor(He)	x(87)
Tumbler dryer(Td)	x(88)
Flat bed steam iron press(Fb)	x(89)
Embroidery machine(Em)	x(90)
Generator set(G)	x(91)
Wash room Trolleys(Tr)	x(92)

Installation of machines(I)	x(93)
Office Furniture(Of)	x(94)
Pre-operative expenses(Pe)	x(95)

The total cost of the supply chain is given as

Recurring Expenses (for 3 months) =

$$\sum_{t=1}^{3} 80\, C_t + \sum_{t=1}^{3} 150\, B_t + \sum_{t=1}^{3} 15\, T_t + \sum_{t=1}^{3} 80\, S_t + \sum_{t=1}^{3} 3\, P_t + \sum_{t=1}^{3} 10000\, Mm_t + \sum_{t=1}^{3} 6000\, Sr_t + \sum_{t=1}^{3} 50000\, O_t + \sum_{t=1}^{3} 3500\, Cl_t + \sum_{t=1}^{3} 3500\, E_t + \sum_{t=1}^{3} 3000\, Pw_t + \sum_{t=1}^{3} 10000\, Pm_t + \sum_{t=1}^{3} 8000\, Cm_t + \sum_{t=1}^{3} 3500\, Sw_t + \sum_{t=1}^{3} 3500\, Pr_t + \sum_{t=1}^{3} 3000\, Uw_t + \sum_{t=1}^{3} 1 Wt_t + \sum_{t=1}^{3} 1\, El_t + \sum_{t=1}^{3} 1\, Ft_t + \sum_{t=1}^{3} 1\, Rt_t + \sum_{t=1}^{3} 1\, Ad_t + \sum_{t=1}^{3} 1\, Ps_t + \sum_{t=1}^{3} 1\, Rm_t + \sum_{t=1}^{3} 1\, Tc_t + \sum_{t=1}^{3} 1\, Tb_t + \sum_{t=1}^{3} 1\, M_t$$

Fixed Expenses = 23650(Sn) + 50000(C) + 50000(Ss) + 75000(Dn) + 145000(Bh) + 75000(Bs) + 65000(Hf) + 145000(Wm) + 70000(He) + 140000(Td) + 75000(Fb) + 45000(Em) + 100000(G) + 10000(Tr) + 1(I) + 1(Of) + 1(Pe)

Thus the total cost is given as

Total Cost = Recurring Expenses + Fixed Expenses

Total Cost =

$$\sum_{t=1}^{3} 80\, C_t + \sum_{t=1}^{3} 150\, B_t + \sum_{t=1}^{3} 15\, T_t + \sum_{t=1}^{3} 80\, S_t + \sum_{t=1}^{3} 3\, P_t + \sum_{t=1}^{3} 10000\, Mm_t + \sum_{t=1}^{3} 6000\, Sr_t + \sum_{t=1}^{3} 50000\, O_t + \sum_{t=1}^{3} 3500\, Cl_t + \sum_{t=1}^{3} 3500\, E_t + \sum_{t=1}^{3} 3000\, Pw_t + \sum_{t=1}^{3} 10000\, Pm_t + \sum_{t=1}^{3} 8000\, Cm_t + \sum_{t=1}^{3} 3500\, Sw_t + \sum_{t=1}^{3} 3500\, Pr_t + \sum_{t=1}^{3} 3000\, Uw_t + \sum_{t=1}^{3} 1 Wt_t + \sum_{t=1}^{3} 1\, El_t + \sum_{t=1}^{3} 1\, Ft_t + \sum_{t=1}^{3} 1\, Rt_t + \sum_{t=1}^{3} 1\, Ad_t + \sum_{t=1}^{3} 1\, Ps_t + \sum_{t=1}^{3} 1\, Rm_t + \sum_{t=1}^{3} 1\, Tc_t + \sum_{t=1}^{3} 1\, Tb_t + \sum_{t=1}^{3} 1\, M_t + 23650(Sn) + 50000(C) + 50000(Ss) + 75000(Dn) + 145000(Bh) + 75000(Bs) + 65000(Hf) + 145000(Wm) + 70000(He) + 140000(Td) + 75000(Fb) + 45000(Em) + 100000(G) + 10000(Tr) + 1(I) + 1(Of) + 1(Pe)$$

3.3 Hybrid Meta-Heuristic: Genetic Algorithm & Cross-Entropy method

Since the optimization of complex supply chain becomes an NP Hard problem, hybrid meta-heuristic algorithm is proposed for solving it. The hybrid meta-heuristic algorithm developed combines the following two meta-heuristic algorithms.

- Genetic Algorithm [GA]
- Cross-Entropy [CE] Method

Genetic Algorithm [GA] is the most popular meta-heuristic algorithm for solving large-scale and/or non-linear optimization problems whereas Cross-Entropy [CE] Method is one of the more recent meta-heuristic algorithm with application in solving complex optimization problems.

3.3.1 Genetic Algorithm (GA)

Genetic Algorithm is a sub-class of evolutionary algorithms. GA begins with a population of potential solutions, called individuals, and iteratively modifies those individuals using different operators in order to achieve improvements. At each step, it produces the children for the next generation by selecting individuals from the current population to play the role of parents. The selection process gives preference to the fittest individuals so that they can pass the quality genes to the next generation. A fitness function is used to evaluate the potential solutions and a fitter solution is evaluated based on the problem, be it maximization or minimization. A new population of solutions is created using genetic operators. The genetic operators used are Selection, Crossover and Mutation.

This process is stopped when a termination criterion is met or after a certain number of iterations.

Algorithm: Genetic Algorithm

Input: population, crossover probability, mutation probability, max_iterations
Output: Best individual found

1. iteration ← 0
2. Initialize population
3. Evaluate Population

4. while iteration < max_iterations do
5. Parents ← Select parents from population
6. Offspring ← Crossover the parents with the chosen crossover probability
7. Offspring ← Mutate the offspring with the chosen mutation probability
8. Evaluate Offspring
9. Replace the old population with the new population
10. iteration ← iteration + 1
11. end

3.3.2 Cross-Entropy (CE) Method

Cross-Entropy Method is used for solving NP-hard combinatorial optimization problems but was initially used for estimating the probability of rare events.

CE has three main phases:
1. Generate random samples from a normal distribution with mean m and standard deviation s (N(m, s)).
2. Select the best samples.
3. Update mean and standard deviation according to the individuals with better fitness.

In this method, the mean tends to locate itself over the point with the best results, while standard deviation becomes smaller and smaller, until both values are focused on the area of the best solutions found in the domain. The variation of the values of mean and standard deviation depends upon the learning rate which can take values from 0.6 to 0.9. The update of means and standard deviation is done by combining the actual values of mean and standard deviation with the mean and standard deviation of the best samples selected in an iteration.

The updating scheme is a major contribution of Cross-Entropy. The process of CE continues until a termination criterion is met.

Algorithm: Cross Entropy method

Input: population, learning rate, max_iterations
Output: Best individual found
1. M ← Initialize Means vector
2. S ← Initialize standard deviations vector
3. iteration ← 0
4. while iteration < max_iterations do
5. Generate samples to create the initial population
6. Evaluate population
7. Samples ← Select the best individuals from population
8. M ← Update the Mean using the mean of Samples and learning rate
9. S ← Update the standard deviation using the standard deviation of Samples and learning rate
10. iteration ← iteration + 1
11. end

3.3.3 Hybrid: Genetic Algorithm (GA) & Cross-Entropy (CE) Method

Hybridization of Genetic Algorithm and Cross Entropy Method is proposed to obtain good performance for resolving the specified problem of optimization, and the combination of them can improve the results obtained on their own. One of the problems of population-based algorithms like Genetic Algorithm is their bad exploitation abilities. On the other side, Cross Entropy Method has a high exploitation ability.

In the process of hybridization, Cross Entropy Method is used to cover the lack of exploitation of Genetic Algorithm, focusing the search of solutions in the area where the best individuals have appeared and Genetic Algorithm is responsible for the exploration of the search. Thus, the proposed hybrid method aims to take advantage of the exploration ability of a GA and the exploitation ability of a CE in optimization.

First, the population is divided into two sub-populations. Each sub-population is used in a different way. One sub-population undergoes the process of Genetic Algorithm and the other sub-population undergoes the process of Cross Entropy Method.

• GA sub-population: Genetic Algorithm operators like Selection, crossover and mutation are applied to this sub-population in order to create new individuals.

• CE sub-population: New individuals are randomly generated using a normal distribution with mean M and standard deviation S, N (M, S), updated iteratively.

Then, the total population size is the sum of the number of individuals in each sub-population. In addition, elitism is applied, in which case if the best individual found so far is not present in the generation, it is inserted, replacing the worst one. The individuals created as a result of Genetic Algorithm contribute the exploration of the search space, while the individuals created using Cross Entropy Method takes care of exploitation. When both sub-populations are joined into a new one, individuals can be in both of them in the next generation, contributing to the improvement of the best solutions found.

Algorithm: Hybrid: Genetic Algorithm & Cross Entropy method

Input: population, crossover probability, mutation probability, learning rate, max_iterations
Output: Best individual found
1. iteration ← 0
2. Initialize population
3. M ← Initialize Means vector
4. S ← Initialize Standard Deviation vector
5. Evaluate population
6. while iteration < max_iterations do
7. POP_GA ← Select individuals from initial population for GA
8. POP_CE ← Select individuals from initial population for CE
9. Offspring_GA ← Crossover the GA inidividuals with the chosen crossover probability
10. Offspring_GA ← Mutate the GA offspring with the chosen mutation probability
11. Offspring_CE ← Generate CE offspring using mean and standard deviation
12. M ← Update the Mean of CE offspring using learning rate
13. S ← Update the Standard deviation of CE offspring using learning rate
14. New offspring ← OffspringGA + OffspringCE
15. Evaluate offspring
16. Add the best individual found to new population if it is not in the population
17. iteration ← iteration + 1
18. end

IV. RESULTS AND DISCUSSION

The performance of the proposed hybrid algorithm Genetic Algorithm-Cross Entropy method embedded with the concept of elitism is compared with the performance of the algorithms on their own to show that the results obtained by the hybrid algorithm solved the lacks (lack of exploitation and lack of exploration) that the original algorithms had on their own.

Table 7: Performance analysis of the GA&CE hybrid algorithm

ALGO	TIME (S)	COST COMPONENTS (RS)		
		Total Cost	Production Cost	Net Profit
GA	5.8145	20,47,950	9,48,300	1,09,76,700
CE	2.5935	44,59,438	25,97,208	93,27,792
GA & CE	3.0065	20,26,974	5,95,324	1,13,29,676

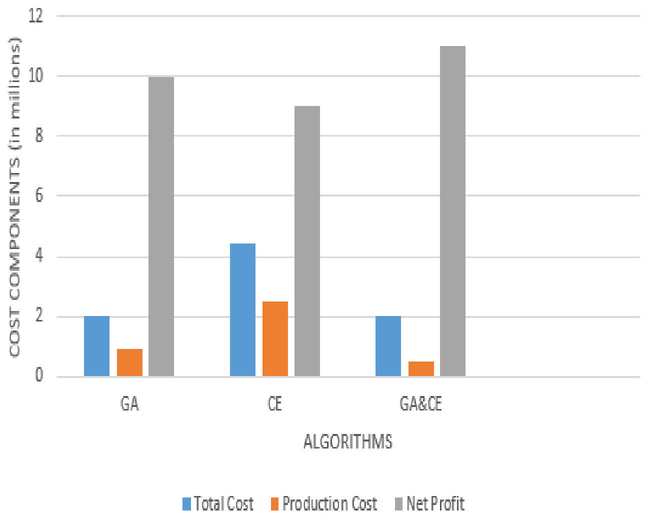

Fig.2 Comparison of the hybrid algorithm with GA and CE

V. CONCLUSION AND FUTURE WORK

Hybrid meta-heuristics which is a combination of two meta-heuristic algorithms seems to work better than individual meta-heuristics for solving optimization models. The most important factor that determines the successfulness of a search algorithm is the balance between exploitation and exploration. Exploitation refers to making good use of already found solutions whereas exploration refers to the search of new solutions in order to avoid getting trapped in a local optima. Hybridization of the meta-heuristic algorithm like Cross Entropy method which has strong exploitation ability with other meta-heuristic algorithms like Genetic Algorithm which has strong exploration ability provides new insights in the context of supply chain planning optimization. Thus the supply chain planning model developed optimizes the total cost of the supply chain by making use of hybrid meta-heuristic algorithm such as Genetic Algorithm-Cross Entropy method.

The proposed hybrid meta-heuristic algorithms can further be improved by means of tuning the parameters that would result in increasing the accuracy of the algorithm and also different meta-heuristic algorithms could be combined and evaluated to check if their performance is better than the existing hybrid meta-heuristic algorithms.

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