Performance Optimization of a Leagility Inspired Supply Chain Model: A CFGTSA Algorithm based Approach

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Abstract

Lean and agile principles have grown interest in the past few decades. The industrial sectors throughout the world are upgrading to these principles to enhance their performance, since they have proven to be efficient in handling supply chains. However, the present market trend demanded a more robust strategy inheriting the salient features of both lean and agile principles. Inspired by these, the leagility principle has been emerged encapsulating, features of lean and agile. The present work proposes a leagile supply chain based model, for the manufacturing industries. The paper accentuates the various aspects of leagile supply chain modeling and implementation, and proposes a new Hybrid Chaos-based Fast Genetic Tabu Simulated Annealing (CFGTSA) algorithm to solve the complex scheduling problem prevailing in leagile environment. The proposed CFGTSA algorithm has been compared to GA, SA, TS, and Hybrid Tabu SA algorithms to reveal its efficacy in handling the complex scheduling problems.

Key Words: CFGTSA, GA, SA, TS, leagile, supply chain

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1. Introduction

Globalization in 21^{ST} century has imposed the modern manufacturing enterprises towards tough competitions. The tremendous industrial growth in past few decades has completely revolutionized their older manufacturing strategies, giving emergence to the modern concepts of lean, agile, and nowadays leagile manufacturing. These new strategies enable the enterprises to survive in the existing environment of fierce competitions laid down by their competitors. The requirement of faster delivery within the due date, ability of being flexible to the fluctuation of demand, and to meet the customer expectations were some of the prime motivations that has provoked the manufacturing enterprises to look for the available best alternatives, and implement it in their daily manufacturing practices. The emerging concepts of lean, agile, and leagile are the outcomes of the difficulties faced by the enterprises during the last few decades. The supply chain model which used to be basically the “Push” system earlier are now being converted to the “Pull” system, in order to be responsive to the customer demand, meanwhile maximizing the overall profit (Hoekstra *et al.*, 1992). There have been a lot of changes in the modern supply chain as compared to the conventional ones. The modern supply chain aims towards the full customer satisfaction, while simultaneously making sufficient profit for the enterprises. The lean, agile, and leagile principles play an important role in enhancing the performances of these supply chains. Lean and agile principles were behind the prime motivation for these supply chains in past years. But day by day increasing and fluctuating market demand, increasing product variety, and desire to make more profit led to the development of a new concept of leagality, which is an integration of the lean and agile principles. Recent advancements have shown that leagile principle has immense potential to counteract the existing complexity of the market scenario.

Therefore, leagile principles are nowadays attracting the manufacturing enterprises, and researchers are aiming to find its prominent benefits in all industrial sectors.

The present paper emphasizes on the importance of the leagile principles in the existing market environment. The paper deal with the various aspect of the leagile supply chain modeling, and also focuses on the role of the modern optimization methods in enhancing the performance of the supply chain. The paper considers a complex sequencing test problem scenario commonly faced in manufacturing industries, and proposes a hybrid Chaos-based Fast Genetic Tabu Simulated Annealing (CFGTSA) algorithm to solve the complexity of the problem. The proposed algorithm inherits the prominent features of the Genetic Algorithm (GA), Tabu Search (TS), and Simulated Annealing (SA) algorithms along with the chaotic theory. The paper aims to minimize the overall lead time and waiting time, and maximize the output during scheduling the parts, which is an essential criterion of the leagile principle. The minimization of waiting time signifies that it follows the lean philosophy, which describes time as a waste, whereas overall reduction of lead time follows the agile principle, which makes the supply chain flexible to the demand fluctuations. The paper shows that optimization tools can be of significant importance where the leagile strategy has been adopted, and can contribute in their performance enhancement. The result has been compared with other random optimization methods such as GA, SA, TS, and hybrid Tabu SA (HTSA) to show the efficacy of the proposed CFGTSA algorithm. The comparison signifies that the proposed algorithm is relevant in handling the scheduling complexities in a better manner among the other conventional methods.

The paper is organized as follows. Section 2 gives a general idea of the past research work carried out in the area of modern supply chain modeling inspired by lean, agile, and leagile principles. Section 3 discusses the broader prospect of these principles in modern supply chain. Section 4 discusses a test problem and gives an overview of CFGTSA algorithm. Section 5 deals with results and discussion, and highlights the relevance of the optimization methods in context of leagility. And, finally section 6 concludes the paper along with the future suggestions.

2. Literature Review

In past few decades the research interest has been drawn towards the issues pertaining to lean and agile concepts worldwide. The supply chain guided by the principles of lean and agile appeared in late 80s. Various researchers have worked on these issues. The concept of lean originated from the JIT and Kaizen theory. JIT simply means that you get what you need, where and when you need it whereas, the Kaizen theory advocates the continuous improvement. The concept of lean became popular from the Toyota Production System (TPS) which emphasized on the elimination of the waste (Ohno, 1988). Hayes *et al.* (1994) pointed out that lean is all about producing using less of everything, i.e. less inventory, less time, less space etc. Bunce *et al*. (1996) pointed out that the lean and agile paradigms have become the necessity for the manufacturing enterprises in this 21st century. The prominent features of lean led to its implementation in diverse field of the manufacturing environments. A large amount of research papers were published in last few decades revealing its salient features. Some of the work carried out in the area of lean are by Lang *et al.* (1995), Lamming (1996), Erridge *et al.* (1998), Ivezic *et al.* (1999), McIvor (2001), Arbulu *et al.* (2004) etc. However, the increasing competence in the market due to increased product variety, requirement of shorter product development and lead times, etc. forced the manufacturing enterprises to find an alternative to the lean system that can enable them to survive in the changing market scenario. This brought the emergence of the new concept of agile manufacturing. The industries started shifting their conventional supply chain model to agile supply chain model. But it was pointed out that lean was the prerequisite for the agility (Richards, 1996). A conceptual model was developed for agile manufacturing system by Gunasekaran (1999). The market sensitivity of the agile supply chain was pointed out by Christopher *et al.* (2000). Christopher *et al.* (2001) further explained that the market scenario where the demand is volatile and the customer requirement for variety is high, a much higher level of agility is required. Power *et al.* (2001) focused on the critical success factors in the agile supply chain management. They took an industrial survey to find the factors that affected the agile supply chain, and concluded that the factors separate the agile supply chain in two categories; more agile, and less agile. Maskell (2001) pointed out the benefits associated with agile supply chain and Hoek *et al.* (2001) measured the capabilities of the agile supply chain. These researches have shown that agile supply chain was capable of handling the increased range of product variety, specialized and fragmented customers, and markets.

Though, the lean and agile concepts established their efficacy in their respective fields, the present era demanded a more robust strategy inheriting the salient features of both of these strategies. The demand by the enterprises to find a strategy that inhibits the prominent features of lean and agile principles led researchers to find the alternative to these principles. Naylor *et al.* (1999) gave the concept of leagility by integrating lean and agile principles in total supply chain. Leagile supply chain separates the lean and agile principles through a decoupling point (Hoekstra *et al.* 1992). The aim of the leagile supply chain remains to postpone the products as far as to the customer end, in order to efficiently handle the demand uncertainties. Various advantages have been pointed out by Hoek (1998) regarding postponement strategy, such as reduced total inventory, greater flexibility in multiplicity of production, easy forecasting, and mass customization. The importance and applicability of the leagile supply chain has been pointed out by many authors in recent years. Jones *et al.* (2000), Christopher *et al.* (2000), Towill *et al.* (2002), etc. outlined the applicability of the leagile principles in modern manufacturing environment. The growing interest of the leagile supply chain implementation in vast fields of manufacturing environment can be found from the work of Naim *et al.* (1999), Bruce *et al.* (2004), and Csillag (2004). They pointed out the applications of the leagile principles in the textile, and telecommunication industries.

The proposed work explores the various aspects of leagile supply chain modeling and suggests its application in modern manufacturing environment. During recent years, the efficient supply chain modeling has been of major concern for the enterprises as this can be seen from the works of Bruce (1999), Angerhofer *et al.* (2000), Gjerdrum *et al.* (2001), Agarwal *et al.* (2005), Chan *et al.* (2005), etc. The present paper proposes a leagile based supply chain model for a manufacturing production plant and suggests that the similar supply chain model can be implemented to the other industrial sectors with minor modifications in the supply chain model. The present work also proposes a new hybrid CFGTSA algorithm to solve the complex scheduling problem prevailing under the considered scenario. The efficacy of the algorithm has been shown by comparing it with other random search methods. The next section discusses the leagile supply chain modeling in detailed.

3. Leagile Supply Chain Model

In the present scenario the manufacturing enterprises are facing much difficulty in properly managing their supply chains. The reason behind it is clear, that the increased competence have driven them to go for the more efficient supply chain modeling. The supply chain of any enterprise is based on relationship between the suppliers, customers, sales, and production. But the market demand uncertainty affects the performance, and behavior of the supply chain, resulting in loss of sales or loss of profit. This uncertainty and the resulting instability in the production schedules, affect the relationships with the suppliers from whom the company purchases raw materials and component parts. The traditional way of driving the supply chain by the demand forecast often gets misguided, and results in problems of shortage or excess of inventory. This has enforced the manufacturing enterprises to find the alternatives to overcome these uncertainties. The emergence of lean, agile, and leagile supply chain are the outcome of these facts only.

The lean concepts were founded late in 1940s but widely came into existence when the Toyota production system (Ohno, 1988) was revealed. Lean focuses on the elimination of muda (waste). It emphasizes on utilization of less time, less space, less inventory, and even less money to produce products. It basically focuses on the elimination of seven types of wastes that are overproduction, waiting, transportation, inventory, motion, defective units, and over-processing. The implementation of lean supply chain in an organization causes improvement in terms of increased flexibility, reduced cost, high inventory turns, shorter lead time, and defect prevention. These benefits attracted the enterprises to upgrade their supply chain according to the lean principles. Though, the lean supply chain reduced their cost of production, but the supply chain model failed to be flexible to the demand. This motivated the development of the agile supply chain model, which emerged as the alternative to the lean supply. But the lean concept remained the prerequisite for the agile supply chain. The requirement for the enterprises to become highly responsive to the fluctuations of demand, in terms of volume and variety, rapid response to the customers, and desire of becoming market winners, motivated them to shift from the lean to agile strategies. Agile supply chain is basically guided by four principles (Goldman, 1995); (a) deliver the value to the customers, (b) become adaptable to changes, (c) give value to human knowledge and skills, and (d) formation of virtual enterprises. Successful implementation of agile manufacturing system in an organisation requires enterprise level integration that includes design integration, process planning, and scheduling.The delicacies inherited in agile supply chain enabled the manufacturing enterprises to handle the demand uncertainty, and product variety more efficiently. However, the gradually increasing complexity in the market scenario demanded a more vigorous methodology that inherits the salient features of both the lean as well as the agile principles. Thus, the strategic integration of lean and agile principles gave birth to the leagile principles. However, the concept of Leagility does not underestimate the importance of lean and agile principles under certain conditions.

The leagile principle (Naylor, 1999) combines the lean and agile principles through a decoupling point that separates the production line into two parts at the point of product differentiation. The main objective of lean inspired supply chain is to produce a limited number of products efficiently, while agile supply chain focuses on simultaneously producing a larger variety of interrelated products. Lean supply also values long term supplier partnerships whereas; agile supply focuses on short term partnerships with suppliers after the point of product differentiation. Both the chains are intimately connected to the supply chain strategy by the appropriate positioning of the decoupling point. The pictorial representation of the leagile supply chain is shown in Figure 1. The decoupling point separating both the strategies in a leagile supply chain is defined as, the point separating the part of the supply chain oriented towards customer orders from the part of it based on planning. It also acts as a point at which strategic stock is held as a buffer between unpredictable customer orders and product variety, and level production output. The most important issue of the leagile supply chain is the positioning of the decoupling point. The supply chain inspired by the leagile principles, aims towards the positioning of the decoupling point as far as from the supplier end, i.e. near the user end, so that the total lead time incurred to deliver the product can be minimized. It also adds flexibility to withstand the demand uncertainty. Thus, leagile supply chain advocates the product generalization up to the decoupling point, and then suggests for the finalization, as per the customer demand. This concept of delayed product differentiation results in total reduced inventory, greater flexibility in multiplicity of production, easy forecasting, and mass customization. The leagile supply chain has proven to be efficient, and gaining much popularity these days.

[Include Figure 1 about here]

The leagility inspired supply chain models are gaining the attention of the manufactures from different fields because of its abovementioned benefits. The growing interest in the field of implementations of the leagile supply chain can be found from the examples of Cloth industries (Bruce *et al.* 2004), and Telecommunication industries (Csillag *et al.* 2004). The leagility concepts in theses industries have helped them to revive in this era. The UK cloth industry was facing major problems in recent years, which can be envisioned from the lost jobs and losses incurred by them (Bruce *et al.* 2004). But the implementation of the leagile supply chain has now increased their profits, and the scenario is becoming much better these days. Even nowadays the warehousing inheriting the lean and agile concepts (Warehousing Forum, 2004) are emerging. As the warehousing in supply chain plays an important role, the incorporation of the lean and agile concepts enhances the efficiency of the enterprises to provide adequate and reliable deliveries of the products to their customers. This also facilitates them to accomplish their customer demands in time, and enable them to remain flexible to the demand fluctuations.

Inspired by these results the present work highlights the importance and implementation of leagility principles in other industrial sectors. The paper proposes a generalized leagile supply chain model that can be implemented in most of the industrial sectors. The model presented has been constructed as per the problem environment considered in this paper, but does not limit to that only. The proposed model has been shown in Figure 2. The similar supply chain model can be implemented in other industrial sectors with minor modifications. The proposed supply chain model considers a manufacturing environment where they are producing variety of products. The detailed description of the manufacturing scenario undertaken will be described in the next section. According to the proposed model it is suggested that rather than going for specific product manufacturing, the product generalization is aimed. The generic parts are produced, and at the assembly section as per the market demand, they are assembled according to the specific product demand, along with the components supplied by the external suppliers. This adds additional flexibility to the manufacturing enterprises to cope with demand uncertainty. After the assembly, the products are sent to the warehouses from where it is further delivered to desired destinations. The warehousing system follows the modern lean and agile concepts, rather than the conventional way to store and deliver the products. To manage the overseas demand, there is a provision of direct shipment from the assembly section (McCullen *et al.* 2001). It avoids the delay incurred during transporting to the warehouse, and then to the overseas. However, the local and some of the outstation demands are fulfilled by the warehouses, through the distribution centres. The demand and material information is regulated continuously to remain updated with the market scenario, and the production is directed accordingly. This makes their supply chain, based on the pull system, rather than the conventional push system. Therefore, the generalized production, shifting production to the customer end, improved warehousing, and regular flow of information can completely revolutionize the scenario of any enterprise, leading to increased profit, greater flexibility, and make them more robust to the demand uncertainties. Hence, the proposed leagile supply chain model can be really efficient in the modern complex market environment. The next section discusses in detail about the problem environment and the role of the optimization method in enhancing the performance of leagile based supply chain.

[Include Figure 2 about here]

4. Problem Formulation

The desire to become the market winner has left all the enterprises in a highly competitive era. Today enterprises are trying hard, and putting all efforts to sustain in this situation. The greatest risk that the manufacturing industries are facing nowadays is of demand uncertainty. However, in this tough situation the lean, agile, and leagile principles are really proving to be of great importance for these modern enterprises. The ability of these principles to enable the enterprises to achieve the prime objectives of reduced production time, proper utilization of resources, handling demand uncertainty, and minimizing wastes helps them to carry on in the market. The leagile principles emphasizes on the product generalization, which enables the industries to go for the generic product as far as in their supply chain, so that the chances of the product to be outdated becomes minimal. It focuses on adoption of the lean principles upstream in the supply chain till the decoupling point. At that point based on the customer and material information, the supply chain shifts to follow, the agile principles further downstream the supply chain. This unique feature of leagile principle makes it, a reliable strategy for the modern enterprises. Therefore, enterprises are now practicing these strategies in their supply chain to grab a strong position in the market, and enhance their profits. Realizing these facts the present paper discusses the importance of the leagile principles in the modern supply chain. The paper also highlights the importance of the modern optimization method that acts as an important aid to achieve these goals. To show that how optimization method can be helpful for the manufacturing enterprises practicing the leagile principles, a scheduling test problem commonly faced by enterprises has been presented.

In the present work the test problem considered aims to analyze the efficacy, and robustness of the proposed CFGTSA algorithm. It also shows the ability of the algorithm to enhance the performance of the manufacturing enterprise. Since, the scheduling problem considered in the present work is commonly faced by the production plant. Hence, the solutions to these problems are of major concern for the overall success of the supply chain of any manufacturing enterprise. In the considered test problem there are total of 20 parts that are to be manufactured by passing through three major operations. Since the enterprise follows leagile principles, it manufactures various generic products, and the final products are produced by assembling these 20 parts, and some other parts provided by their suppliers according to the existing demand. Figure 3 shows the finished parts assembling process. The proposed model consists of 5 machines for each of the operation thus, total of 15 machines are available for the 3 operations. The parts are subjected for processing on the alternative machines available to them while, passing through these three operations. The final products are produced by assembling these small parts as per the demand of the desired final product. In the proposed problem it has been assumed that each product is assembled from of the five different parts, and few other parts supplied by external resources or suppliers. The lean principles are practiced during the entire production stage focusing on reduction of wastes, and agile principle is followed during assembling stage to tackle the demand uncertainty thus, fulfilling the needs of the leagility principles. Some of the assumptions considered before starting the sequencing of the parts can be stated as follows:

i. All the component parts can be processed for these three operations only in the order of:

   Operation 1 ⟶ Operation 2 ⟶ Operation 3

ii. Simultaneously five parts can be assigned at a time.

iii. The scheduling of the other parts can start only when one of the machines available for operation 1 is free.

[Include Figure 3 about here]

However, for all the three major operations there are alternative machines available for each part. For each operation there are 5 machines, but each part doesn't have access to all the alternatives, due to the capacity limitation of the machines, and the shape and size of the parts to be produced. The alternatives available and corresponding processing time for the parts is shown in Table 1. From table it can be seen that there are 5 machines for each operation, and the parts are required to pass through these all three operations in same sequential manner hence, at a time only five parts can be assigned. As soon as the machine becomes available the next parts are scheduled on the machines, based on the alternatives available for them. Therefore, the next part has to wait, until the machine on which it has been scheduled is free, this adds a waiting time.

[Include Table 1 about here]

The prime objectives considered in the proposed work are to minimize the waiting time while scheduling the parts, maximize output, and to reduce the overall lead time satisfying the constraints. The CFGTSA algorithm helps to minimize this waiting time in order to reduce the wastage of time, obeying the lean principles. It also minimizes the overall lead time, which is important from agile point of view. The prominent features of the CFGTSA algorithm helps in obtaining a feasible sequence that satisfies the objectives of minimization of the waiting time, output maximization, and the overall lead time minimization. The criteria essential for evaluation of the part scheduling has been discussed below that serves as the objective functions. The objective functions discussed below are subjected to the constraints that are required to be satisfied. The constraints are discussed after the objective function formulation. The following notations have been used during the formulation of the objective functions and the constraints:

Notations:

p : Part Number, p= 1,2,3, …P, where P is the total number of parts

m : Machine Number, m=1,2,3, … M, where M is the total number of machines

o : Operation Number, o= 1,2, …, O, where O is the total number of operations

n : Number of products assembled, n = 1,2,3, …N, where N is the total number of products

LT_p : Lead Time for part p processed on M machines

WT_{pm} : Waiting Time for the part p on machine m

PT_{pm} : Processing time of part p on machine m

OT_n : Total n number of products produced

S_{op} : Starting time of operation o for part p

C_{op} : Completion time of operation o for part p

4.1 Objective functions:

a. Minimization of waiting time

The scheduling of the parts in proper manner plays an important role in overall efficiency enhancement. According to the lean principles, the time has been defined as one of the wastes that need to be minimized. Hence, for the manufacturing enterprise that follows the leagile principles it is necessary to satisfy the lean principles, i.e. the waiting time needs to be reduced. The objective of the proposed work is to minimize the waiting time satisfying the constraints. The time up to which the parts are required to wait, until it is conveyed to the next operation is defined as the waiting time. It is expressed as;

$$\text{Min } \{WaitingTime\} = \sum_{p=1}^{P} \sum_{m=1}^{M} \text{WT}_{pm} \qquad \dots (1)$$

b. Minimization of lead time

The success of any supply chain to a great extent depends on how long the product takes to complete. For most of the manufacturing industries the lead time is of prime concern, as they aim towards the faster and reliable deliveries. The supply chain aiming towards the total customer satisfaction must be more responsive to the existing customer demand, and should be able to deliver their products in shorter lead times. The shorter lead time enables the manufacturing enterprise to tackle the demand uncertainty efficiently. Since in the modern scenario the demand changes at a very fast rate thus, long production time can cause loss of the profit, as the product may become outdated till it reaches the market. Therefore, the shorter lead times have become the necessity nowadays. The lead time is the total time that the product takes to complete. The present work focuses on the minimization of the lead time in order to be responsive to the demand uncertainty following the agile principles. It is expressed as;

$$\text{Min}\left\{LT_p\right\} = \sum_{p=1}^{P}\sum_{m=1}^{M}\left(PT_{pm} + WT_{pm}\right) \qquad \ldots (2)$$

c. **Maximization of output**

In the proposed work the output is the products that are manufactured by assembling the different parts. Each product has been assumed to be composed of five different parts out of the total 20 parts, and few other parts supplied by their suppliers. But for this purpose all the parts are required to be completed within the prescribed time. For this purpose the limit has been prearranged for the waiting time. If the part fails to satisfy the constraint, it will affect the output. The objective considered in this approach is represented as;

$$\text{Max}\left\{\text{Output}\right\} = \sum_{n=1}^{N} OT_n \qquad \ldots (3)$$

The abovementioned objective functions are subjected to following constraints;

4.2 Constraints

1) *Waiting time constraint*

The waiting time has certain restriction, as if exceeds predefined value it may cause disruption in assembling, leading to delayed production. Hence, waiting time is feasible only if;

$$\sum_{m=1}^{M} WT_{pm} \leq 30 \qquad \ldots (4)$$

2) *Processing Time constraint*

This constraint implies that completion time should be either positive or zero.

$$PT_{pm} \geq 0 \qquad \ldots (5)$$

3) The parts can't proceed to other operation until the previous operation is completed i.e.,

$$S_{op} \succ C_{op} \qquad \ldots (6)$$

4) The parts can't be assigned on more than one machine for the same operation.

5) The machines are subjected to continuous operation while production is in process. Hence, the waiting time incurred should be considered for the maintenance of those machines.

The next section discusses the proposed CFGTSA algorithm in detailed.

4.3 Chaos-based Fast Genetic Tabu Simulated Annealing Algorithm

The present work proposes a new hybrid Chaos-based Fast Genetic Tabu Simulated Annealing (CFGTSA) algorithm, integrating Genetic Algorithm (GA), Tabu Search (TS), Simulated Annealing (SA) algorithms, and the chaotic sequencing method. The proposed algorithm has been applied to solve the sequencing problem in the undertaken manufacturing environment. The GA, TS, and SA search methods seem to be promising and are still evolving. They have been successfully applied to solve the scheduling problem in job shops, and under different manufacturing environments. But the increased competence demanded more robust methods that can provide the optimal solutions in less time. The proposed algorithm is the extension of the work carried out by Mantawy *et al.* (1999). They have proposed the hybrid GTS algorithm integrating GA, TS, and SA algorithms. In this paper, proposed algorithm uses the perturbation methods to explore the neighborhood solution in a more efficient manner. Five different types of perturbation methods have been used to explore the search space in an efficient manner. In addition, the proposed algorithm employs the probabilistic transition rule rather than deterministic descent rule, and uses the Cauchy distribution function during annealing process.

GA inherits some drawbacks such as premature convergence, extreme reliance on crossover, and too slow mutation rate. The TS algorithm uses the tabu list, which is the short term memory of recently visited solution, in order to escape from local optima, but due to its deterministic nature it can not avoid cycling. The stochastic characteristic of SA avoids cycling but, as it does not have the memory of the recently visited solutions hence, the rate of improvement of solution is very slow. The individual drawbacks associated with each of the GA, TS, and SA methods enforced the researchers to find an alternative to these methods that can encapsulate the salient features of each individual, and converge to optimal solutions in less computational time. Motivated by these facts, the present paper deals with a Hybrid CFGTSA algorithm, to solve the scheduling problem commonly faced in the manufacturing environment. The result when compared by other random search techniques showed the superiority of the algorithm. This also clarified the fact that optimization methods can contribute towards the performance enhancement of the leagility based supply chains by reducing the overall lead time, and the waiting time which are the prime focus of lean and agile driven supply chains.

The terminologies and the design issues of the proposed CFGTSA algorithm will be discussed in the upcoming sections. The various design issues discussed are encoding scheme, initialization, fitness calculation, perturbation method, probabilistic transition rule, annealing schedule, Tabu-List, aspiration, rejection, and stopping criteria. The parameters of the algorithm are discussed as follows:

Notations:

TP	:	Transition probability (Cauchy Function)
ΔF	:	Change in fitness value
F	:	Fitness Value
$F(Sol_p)$	:	Fitness value of the perturbed solution
$F(Sol)$	:	Fitness value of the current solution
X	:	GA population member
TL	:	Tabu List
T	:	Temperature
T_0	:	Initial Temperature
k	:	Number of Iteration in which the temperature is to be reduced
C_p	:	Control parameter of the cooling schedule
C_p^k	:	Control parameter at k^{th} number of generation

4.3.1 Solution encoding: Solution encoding plays an important role in GA, and SA implementation. In the proposed work the operation oriented encoding scheme has been used. According to this scheme the first row of each solution represents the parts number, while further rows represent machines allocated for the three operations, where subsequent processing has to be done.

2	3	1	5	12	7	18	11	4	19	13	16	8	17	6	20	9	14	10	15
2	4	5	1	1	2	3	1	5	1	4	5	1	3	2	5	4	2	1	5
3	3	2	4	5	1	4	4	2	1	2	5	2	5	4	1	2	4	5	4
5	1	2	3	3	2	4	1	3	3	5	3	4	2	2	1	2	3	2	3

4.3.2 Initialization: In the proposed work the random initialization has been performed, as it is believed that randomly generated solution initiates a more effective search. But later on chaotic sequence generation has been adopted throughout.

4.3.3 Neighborhood generation (Perturbation): Perturbation controls the searching capacity and convergence trend of the algorithm. The proposed algorithm considers four new perturbation methods (Caponetto *et al.* 2003), i.e. Logistic Map Based heuristic perturbation method, Tent Map Based heuristic perturbation method, Sinusoidal Integrator Based heuristic perturbation method, and Gauss Map Based heuristic perturbation method, along with a hybrid perturbation termed as, Chaotic Function based perturbation method. These perturbation methods make use of Heuristic Based perturbation method, where, N bits of initial solution is selected randomly and thereafter all possible permutation of selected bits is generated. Finally the best one is selected as final solution, for further calculation. The procedure of the hybrid perturbation is described below:

Step 1: Randomly select a chaotic sequence strategy among aforementioned five strategies.

Step 2: Perform Step 1 to Step 3 as mentioned in Logistic Map Based Heuristic Perturbation Method stated below:

- *Logistic Map Based Heuristic Perturbation Method (LMHPM):*

In this method (Parker *et al.* 1989) logistic map based chaotic sequence is used to generate random numbers. It is one of the simplest dynamic systems evidencing chaotic behavior. The Logistic Map equation is expressed as follow;

$$X_{k+1} = \mu X_k (1 - X_k) \quad \dots (6)$$

Where, μ is tuning parameter. In the proposed work $\mu = 4$ and $X_0 = 0.2027$.

$$N_{k+1} = I \times X_{k+1} \quad \dots (7)$$

Where, I = number of bits in the solution, N_{k+1} = number of Bits selected at $k+1^{th}$ generation, X_k = Random number generated at k^{th} generation.

Step 1: Pick up N different bits (from the set of random number generated by the selected chaotic sequence strategy).

Step 2: From the exiting alternative, change the operating machine corresponding to selected operations in the step 1.

Step 3: Considering all possible permutation of first row of selected bits and, select the best neighborhood for further calculation

4.3.4 Probabilistic transition rule: During the fitness function evaluation the new solution is accepted if it gives better value, otherwise it is accepted only if the transition probability is higher than the uniform random number. In this algorithm, the Cauchy function (TP) has been used instead of the Boltzmann function during the annealing process. The next inferior iteration solution is selected only if, TP >R where

R is a random number. For each perturbed solution, inferior in comparison with candidate solution; the transition probability can be calculated as

$$\mathrm{TP} = \frac{\mathrm{T(k)}}{T^2(k) + (\Delta \mathrm{F})^2} \qquad \text{… (8)}$$

Where, T (k) = annealing temperature at the k^{th} iteration.

$$\Delta F = F(Sol) - F(Sol_p) \qquad \text{… (9)}$$

F (*Sol)* = Fitness value of initially generated solution '*Sol'*.

F (Sol_p) = Fitness value of perturbed solution which is inferior in compare to candidate solution '*Sol'* at temperature (T).

4.3.5 Annealing schedule: Cooling schedule determines the value of annealing temperature and the transition probability during each iteration. The following cooling schedule is followed:

$$T(k) = \frac{T_0}{1 + \ln k} \qquad \text{… (10)}$$

Where, T_0= Initial temperature; T (k) = Temperature at k^{th} iteration

4.3.6 Tabu-List: Tabu list is used to check whether the pre-treated solution is again visited or not during the each step of algorithm, and thus, helps in restricting the algorithm to revisit the pre-visited solutions. This feature of hybrid CFGTSA algorithm helps the searching procedure to converge toward the global optima in minimum number of iterations, and significantly reduces the computational time of the algorithm.

4.3.7 Aspiration

This tabu search variable denoted by '*A*' restricts the search from being trapped in a solution surrounded by the tabu neighbors. At any instant, if the search gets trapped into the solution surrounded by only tabu solutions, then the solution whose objective function is greater than aspiration is chosen for further exploration.

4.3.8 Reject

The pretreated solutions are often rejected on the basis of probability consideration. Rejection gets increased by 1 whenever, a solution is not selected through the probability consideration. After a certain limit of rejection, it is assumed that there is no superior solution existing in the neighborhood, and the search has reached a near optimal / optimal solution.

4.3.9 Stopping criteria

In order to stop the searching procedure from roaming into the solution space, following stopping criteria has been adopted.

(a) *Number of iterations*: During experimentation, it was found that as the number of iteration increases, equivalent temperature falls to a minimum level. Any further reduction in temperature would not be useful, because at low temperature the possibility of accepting inferior solution is very small and results obtained are virtually indistinguishable from the optimal solution.

(b) *Variable reject*: When reject counter attains predetermined fixed value then it means that, no optimal or near optimal solution has been visited during the last few steps. Therefore, the probability of obtaining better solution is small and hence, the searching procedure is stopped.

The steps of the proposed CFGTSA algorithm are described below:

STEP 1: Initialize the parameters of GA, TS, and SA i.e. $T= T_0= 500$, $TL =0$, $Cp= Cp^k$, Reject = 0.

STEP 2: Generate initial population by generating a set of feasible solutions

STEP 3: Evaluate the fitness value of each population

STEP 4: Generate a new solution from the existing solution. If the perturbated solution is a feasible one then move to next step otherwise regenerate the solution till feasible solution is obtained.

STEP 5: Apply GA parameters to generate a new set of populations as follows;

- Copy the best solution from the current to the new population
- Generate new neighbor members in the present population using TS algorithm
- Apply the crossover operator (Single point crossover) to complete the members of the new population (chaotic sequences are used to choose the points to perform crossover)
- Apply the mutation operator (Swap mutation) to the new population (Chaotic sequences are used to select the points from where the bit is to be swapped).

STEP 6: If $SOL_p \in TL$, then go to STEP 7 else go to STEP 8

STEP 7: If $F(Sol_p) \geq A$, then go to STEP 8 else go to STEP 4

STEP 8: Compute $\Delta F = F(Sol_p) - F(Sol)$. If $\Delta F \geq 0$ then go to STEP 9 else, go to STEP 13.

STEP 9: Assign Sol = Sol_p, Reject $\longleftarrow$ 0, Go to STEP 10

STEP 10: Compute the Transition Probability (TP) and generate random number R between (0, 1). If (TP ≤ R) then go to STEP 14 else go to STEP 11.

STEP 11: Assign Sol = Sol_p. Include Sol_p in the Tabu list. A $\longleftarrow$ F (Sol_p)

STEP 12: Reject = Reject + 1; If Reject ≥ 3 go to step 16 else go to STEP 13

STEP 13: Calculate the new temperature of SA algorithm cooling schedule

- Calculate the new temperature $C_p^k = C_p (\beta)^k$, where $0 < \beta < 1$

STEP 14: Apply SA algorithm to test the members of the new population.

- If $F_i \leq F_j$, then accept the population member, and go to STEP 15, else if $\frac{\exp[X_i - X_j]}{C_p} \geq R(0,1)$ set $X_i = X_j$, then go to STEP 13 where, X_i and X_j are GA population members and F_i , and F_j are their corresponding fitness value.

STEP 15: Make the current population to be the new population

STEP 16: STOP, if the stopping criterion is satisfied. The solution is the optimal/near optimal.

5. Results and Discussion

The leagile supply chains adopted in the recent years have shown to be one of the best available alternatives, to handle the modern complexities of the market environment. The present work highlights the various issues of the leagile supply chain modeling, and suggests its applications in diverse field of manufacturing environment. Through the extensive literature review it has been found that GA, TS, and SA methods have their individual drawback that limits their applications under different circumstances. Encouraged by this, the present work also proposes a new Hybrid CFGTSA algorithm, to handle the problems of the manufacturing enterprises, prevailing under the vulnerable market scenario. The relative comparison with the GA, SA, TS, and HTSA algorithms shows that, the proposed algorithm has better chance of escaping from the local minima. It also converges to the optimal/near optimal solution in less computational time.

The present work deals with a scheduling problem of the different parts manufactured in a production plant. There are total 20 parts that are to be scheduled for the three major operations, in same sequential manner. The overall objective of the proposed work is to reduce the waiting time and lead time incurred during their production, satisfying all the constraints. The CFGTSA algorithm is applied to find out an efficient schedule. The crossover rate and mutation rate were considered to be 0.5 and 0.01 respectively whereas; the temperature for SA was initialized to 500ºC. The sequencing schedule obtained by the proposed algorithm along with those obtained from GA, SA, TS, and HTSA is presented in Table 2. The Gantt chart representing the detailed schedule has been shown in Figure 4. Table 3 shows the comparative results of the waiting time, lead time and the output obtained by the proposed CFGTSA algorithm and the other optimization methods. The comparative plot of the waiting time has been shown in Figure 5. The convergence plot has been shown in Figure 6. The average comparative percentage improvements in the result by the proposed CFGTSA algorithm with others, considering all the objectives is presented in Table 4. From the results it can be visualized that the proposed CFGTSA algorithm surpasses all the other optimization methods in terms of optimality, number of iterations, and the computational time. These results signify that the proposed algorithm can be of prime importance in enhancing the performance of leagility inspired supply chains. As the leagile supply chain aims in accomplishment of the lean and the agile requirements, the proposed algorithm stands on the expectations. The reduction of the waiting time fulfills the requirements of the lean strategy of reducing waste as time is defined as one of the wastes in lean principles. The overall reduction in the lead time accomplishes the requirement of agility. This reduction in lead time prevents the manufacturing enterprises from the risk of their products to get outdated. Thus, it enhances the flexibility to withstand the market demand fluctuations. Therefore, the result shows the importance of the optimization method from the leagility point of view.

[Insert Table 2 about here]

[Insert Table 3 about here]

[Insert Table 4 about here]

[Insert Figure 4 about here]

[Insert Figure 5 about here]

[Insert Figure 6 about here]

6. Conclusion

The proposed work deals with the issues related to the supply chain modeling and suggest its extension to most of the industrial sectors. The paper outlines the major benefits associated with the leagile supply chain implementation in industries. The paper also suggests a generalized supply chain model driven by the leagile principles for the manufacturing production plants. The significance of the modern optimization methods in performance enhancement, of these supply chain models has also been highlighted in this paper. To show the relevance of optimization techniques, the paper proposes a new hybrid Chaos-based Fast Genetic Tabu Simulated Annealing (CFGTSA) algorithm, to solve the scheduling problem. The results obtained by the proposed algorithm has been authenticated, and proven to be better by comparing it with the GA, SA, TS, and HTSA algorithms. The result discloses the superiority of the proposed algorithm in efficiently handling such complex problems of the production plants.

Though, the results obtained by the proposed CFGTSA algorithm are found to be superior than the most conventional optimization techniques, the future work needs to be carried out to test its efficiency on more computationally complex problems. The proposed algorithm needs to be tested on real time computationally complex problems that are difficult to be solved by the conventional optimization techniques. The work can be further extended aiming the tuning of the various parameters used in the algorithm to have more accuracy, and reduced computational time. To the best of the knowledge of the authors, the leagile supply chain model has been extended to only textile, telecommunication, and few other industrial sectors. The prominent feature of the leagility demands its application in most of the industrial sectors. Therefore, the research work needs to be propelled in the direction of devising the industry specific leagile supply chain models. This will help the industrial sectors to maximize their profits, and satisfy their customer demands in a more efficient manner.

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Table 1: Parts Alternatives and Processing Time Corresponding to the Operations

Parts (P)	Operation I		Operation II		Operation III	
No.	M/C (m)	PT_{pm}	M/C (m)	PT_{pm}	M/C (m)	PT_{pm}
1	M12	30	M22	15	M35	30
	M15	30	M24	30		
2	M12	30	M25	15	M32	30
	M14	30			M33	30
3	M11	45	M22	30	M34	45
	M15	45	M23	15	M35	45
4	M12	30	M21	30	M31	30
	M13	45			M35	45
5	M11	30	M22	30	M32	30
	M15	30	M24	15	M35	30
6	M12	30	M23	30	M33	45
	M13	45	M25	30	M34	30
7	M14	30	M23	15	M31	45
			M25	30	M34	45
8	M11	45	M21	30	M35	30
	M15	30	M24	15		
9	M12	30	M22	15	M31	45
	M15	30	M23	15	M32	30
10	M11	30	M21	30	M32	30
	M14	30	M25	15	M35	30
11	M13	45	M21	30	M31	45
	M14	45	M24	30	M34	30
12	M11	30	M22	15	M33	30
	M12	30	M25	30	M35	30
13	M14	30	M23	15	M32	30
	M15	30	M24	30	M33	45
14	M11	45	M21	30	M31	30
	M13	30	M24	30		
15	M12	30	M23	30	M34	30
16	M13	30	M22	30	M33	30
					M35	30
17	M11	30	M25	15	M32	30
	M14	45			M33	30
18	M11	30	M23	30	M34	30
	M12	30	M25	30		
19	M13	30	M21	30	M31	30
			M24	30	M34	45
20	M14	30	M21	30	M33	30
	M15	45	M24	15	M35	30

Table 2: Optimal Part Sequences

Scheduling methodology	Part Sequences																			
GA	5	2	6	9	11	15	3	7	16	14	20	1	19	18	10	17	13	12	8	4
SA	2	6	7	12	5	3	4	10	16	11	19	13	14	18	1	20	17	15	8	9
TS	15	17	14	4	20	1	9	11	7	16	6	13	19	5	3	10	2	12	8	18
HTSA	5	2	6	4	7	13	14	11	16	20	19	3	9	17	18	1	10	12	8	15
CFGTSA	5	2	6	9	7	1	4	11	16	20	14	3	19	18	8	10	17	12	13	15

Table 3: Computational Results

Scheduling Methods	Number of Iterations	Waiting Time (Minutes)	Lead Time	Output (Parts/Shift)
GA	640	330	225	17
SA	780	255	225	18
TS	610	210	225	19
Hybrid TSA	632	105	210	20
CFGTSA	584	90	195	20

Table 4: Average comparative percentage improvement by CFGTSA with other methods

Scheduling Methods	% Improvement in overall results
GA	46.68
SA	38.75
TABU	32.81
Hybrid TSA	8.9

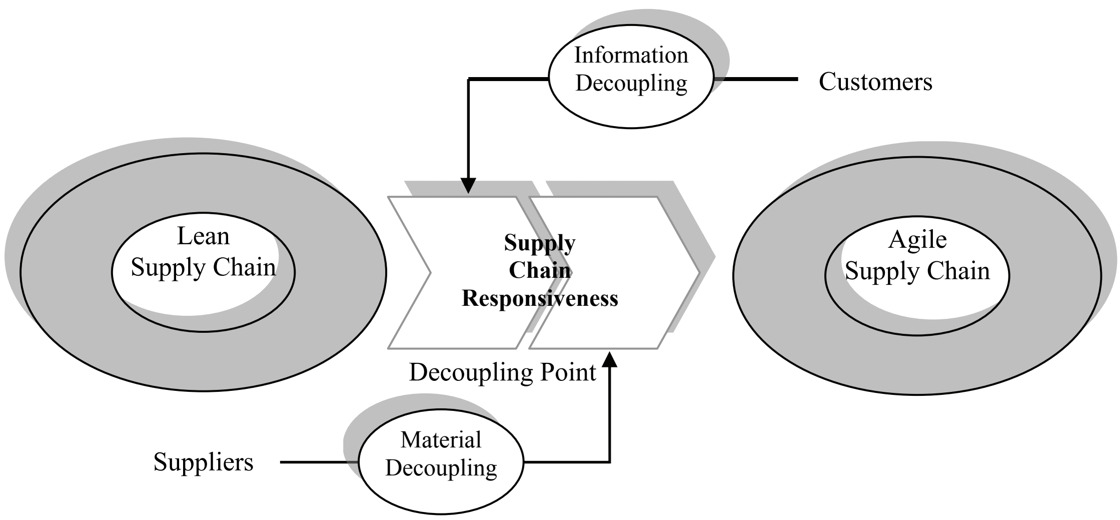

Figure 1: Leagile Supply Chain Model

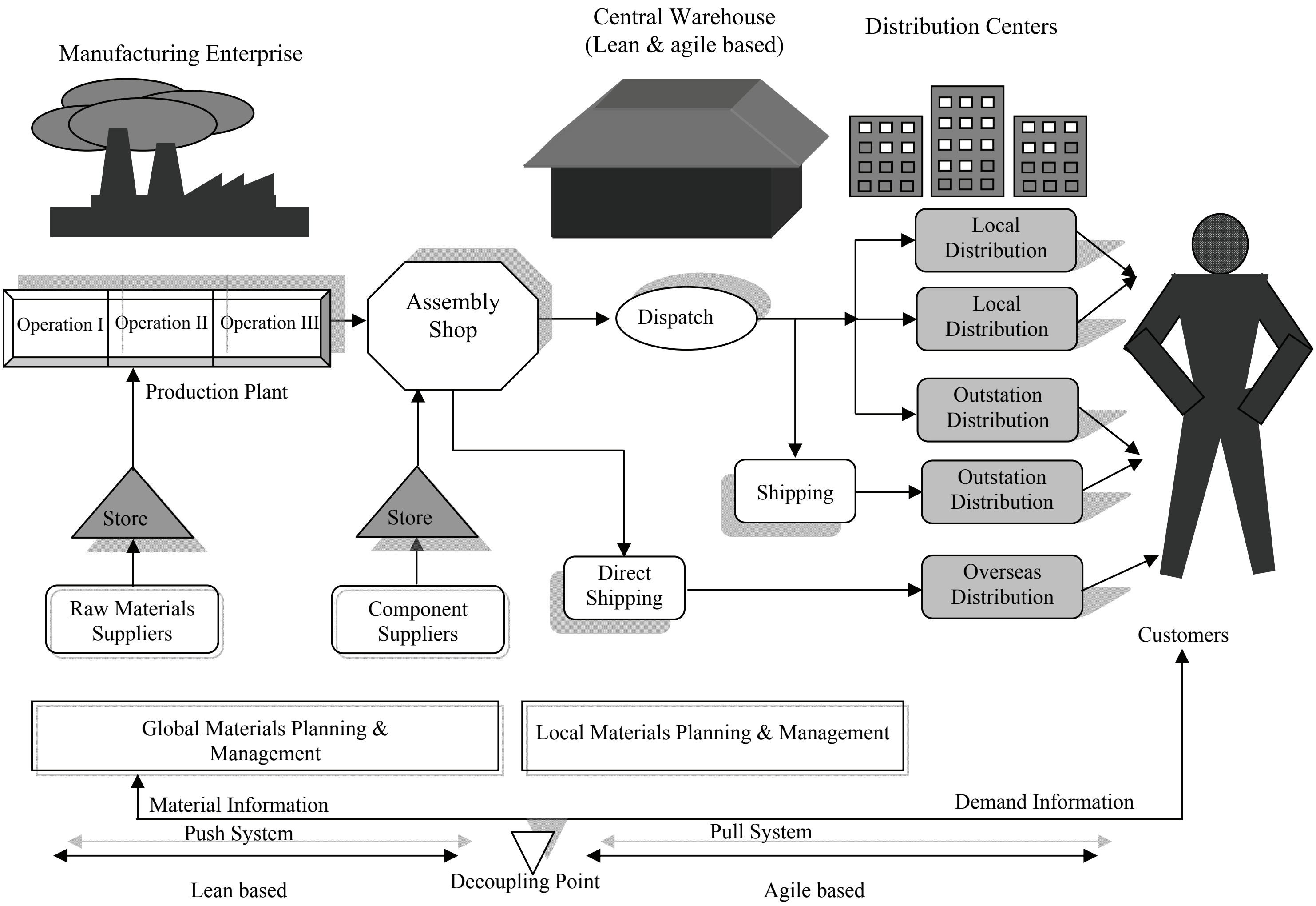

Figure 2: Modern Leagile based Supply Chain Organization in Industry

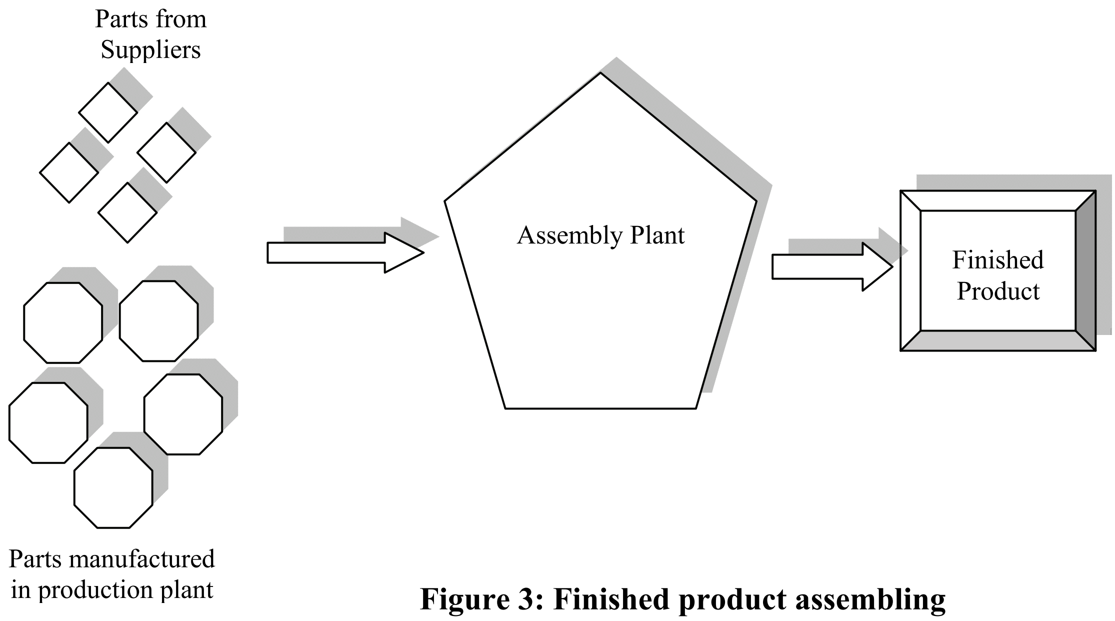

Figure 3: Finished product assembling

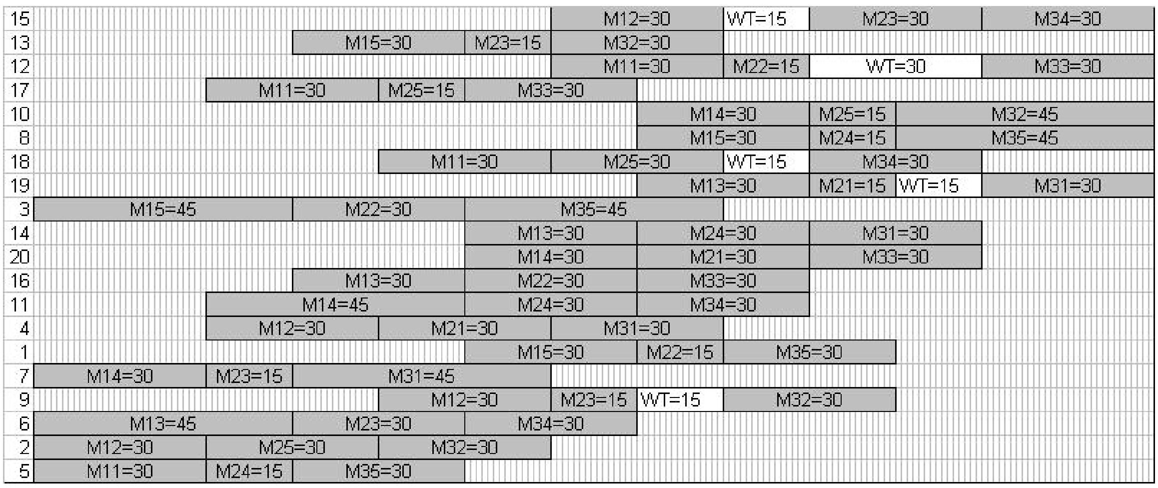

Figure 4: Gantt chart representation of the schedule obtained by CFGTSA

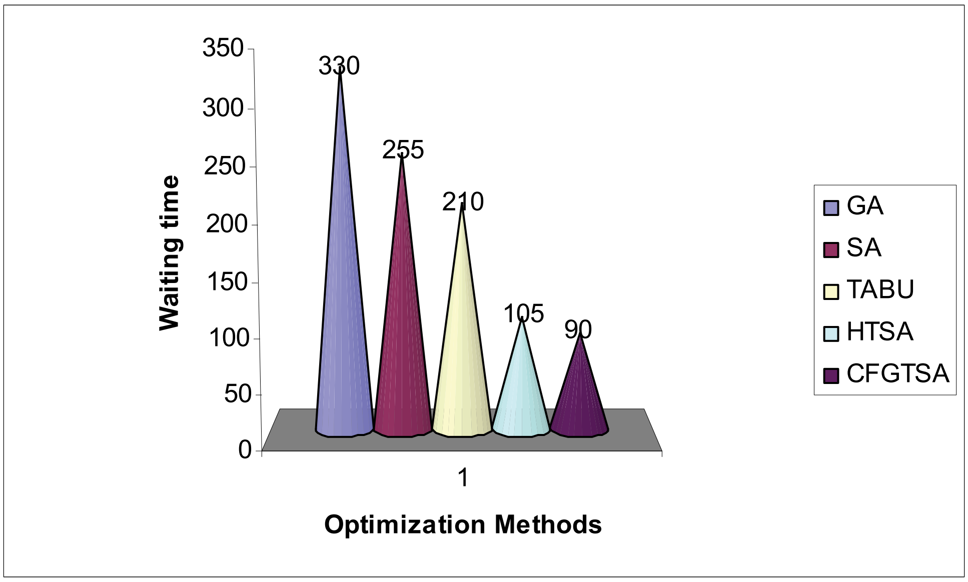

Figure 5: Comparative plot of waiting time

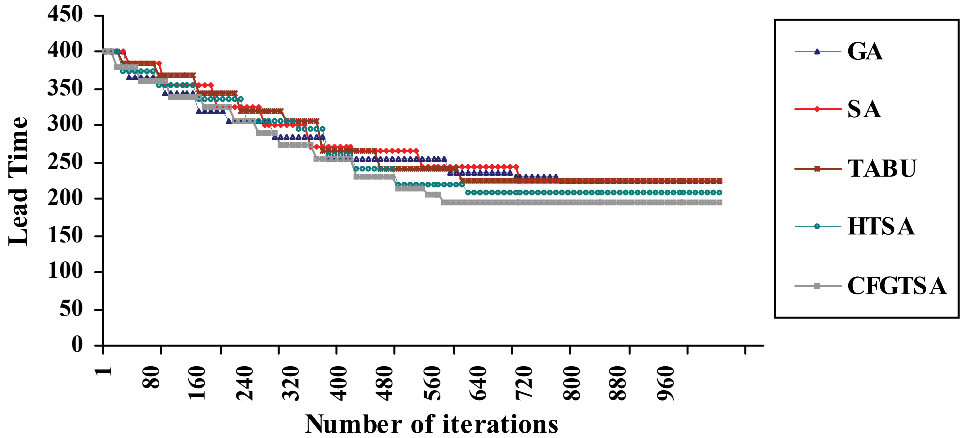

Figure 6: Comparative convergence plot with CFGTSA