The relevance of Outsourcing and Leagile strategies in performance optimization of an Integrated Process Planning and Scheduling Model

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Abstract

Over the past few years the grown global competition has enforced the manufacturing industries to upgrade their old production strategies with the modern day approaches. As a result of which, recent interest has been developed towards finding an appropriate policy that could enable them to compete with others, and facilitate them to emerge as a market winner. Keeping in mind the abovementioned facts, in this paper the authors have proposed an integrated process planning and scheduling model inheriting the salient features of outsourcing, and leagile principles to compete in the existing market scenario. The paper also proposes a model based on leagile principles, where the integrated planning management has been practiced. In the present work a scheduling problem has been considered and overall minimization of makespan has been aimed. The paper shows the relevance of both the strategies in performance enhancement of the industries, in terms of their reduced makespan. The authors have also proposed a new hybrid Enhanced Swift Converging Simulated Annealing (ESCSA) algorithm, to solve the complex real time scheduling problems. The proposed algorithm inherits the prominent features of the Genetic Algorithm (GA), Simulated Annealing (SA), and the Fuzzy Logic Controller (FLC). The ESCSA algorithm reduces the makespan significantly in less computational time and number of iterations. The efficacy of the proposed algorithm has been shown by comparing the results with GA, SA, Tabu, and hybrid Tabu-SA optimization methods.

Key Words: Process planning, scheduling, outsourcing, leagile, ESCSA, FLC.

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1. Introduction

The tremendous industrial growth in the past decade has changed the market scenario, enforcing the industries to strive hard to thrive in this competitive era. The aged production strategies (branch and bound (Potts and Wassenhove, 1985), integer linear programming (Christopher *et al.*, 1992), etc.) on which the industries were relying is no longer valid to endure the pressure of the modern scenario. The challenges to handle the varying lot sizes, reduced lead time, increased product variety have forced the manufacturing industries with no other alternatives than to modify their strategies as per the contemporary market environment. They have now realized the importance of the organized planning and scheduling practices. Therefore, enterprises are aiming to meet their customer expectations in more efficient manner by changing their planning and scheduling strategies with the modern day approaches. The major concern that they are targeting these days is to deliver the products within the due dates, and reduce the lead time as much as possible to counteract the fluctuations in demand. In order to meet the above mentioned goals the manufacturing industries are encouraged to adopt the strategy in which the integration of the process planning and scheduling has been emphasized. Traditionally, the process planning and scheduling were handled separately but, it resulted in deadlocks, incompetent resource utilization, and inefficient scheduling. This enforced them to go for the integration of both the strategies, which simultaneously overcomes the drawbacks inherited in it if they were considered separately. In the proposed work the integration of the process planning and scheduling has been focused encapsulating the outsourcing strategy. Inheriting outsourcing allows a manufacturing enterprise to focus on its core competencies, reduce its investment in non-core activities, control upon the specialized expertise of its partners, and to build strategic flexibility along with, reduction of manufacturing cost, capital investment, and uncertainty by the risk pooling effect leading to the performance optimization of the enterprises. The present research also discusses the significance of the leagile concept in enhancing the performance of manufacturing industries where the process planning and scheduling has been integrated. The schematic representation of the integrated process planning and scheduling model inheriting outsourcing has been shown in Figure 1.

<<Insert Figure 1 about here>>

Integrated process planning and scheduling (IPPS) problems inherited with outsourcing, are well known non-deterministic polynomial complex problems. It is a well known fact that the process planning in an industry deals with the efficient process plan generation inheriting the features of part designs specifications, and availability of the machine characteristics and their mutual relationship. Whereas, the scheduling part is responsible for the allocation of the available resources, as well as the overall management of the flow of production order. Realizing the abovementioned facts, the authors have integrated the process planning and scheduling, along with a newly emerging concept of outsourcing. Conventionally, manufacturers were processing the internal production of the entire product. Nowadays, outsourcing is increasingly popular with the production of a number of sub-assemblies to their partners. The authors have also suggested the benefits of the leagile strategy in enhancing the production and making the manufacturing industries robust to the market fluctuations. Leagile principle helps in tackling the demand uncertainties, product varieties, and enables fast and reliable product deliveries. The present work discusses about the various aspects of the leagile concept and its relevance in the performance optimization.

Due to the complexity prevailing in the modern scenario the authors have proposed a new hybrid Enhanced Swift Convergence Simulated Annealing (ESCSA) algorithm to solve the complex problem. The proposed ESCSA algorithm inherits the salient features of Genetic Algorithm (GA), Simulated Annealing (SA), and a Fuzzy Logic Controller (FLC). The proposed algorithm combines the elements of directed and stochastic search, and maintains the balance between the exploitation and exploration of the search space. It inherits the efficacy associated with simple GA and SA and does away from some of their demerits such as premature convergence, extreme reliance on crossover and too slow mutation rate. The proposed algorithm encompasses a Cauchy distribution function in the selection step and the fuzzy logic controller (FLC) for the selection of appropriate mutation ratio in order to escape the local minima in an effective manner. These implementations further enhance the effectiveness of the algorithm in escaping from the local minima as well as reduce the computational time.

The paper is organized as follows. Section 2 deals with the survey of the literatures that have been referred while carrying out this research work. The various literatures dealing with the process planning, scheduling, outsourcing, leagile principles, etc. have been discussed. Section 3 emphasizes on the leagile principles and its significance in performance optimization of the manufacturing enterprises. The detailed description of the problem and its modeling has been discussed in section 4. The overviews of the proposed ESCSA algorithm have been presented in section 5.

Section 6 deals with the computational results and discussions. And, finally the conclusions along with the future suggestion have been presented in section 7.

2. Literature Review

Various researchers have resolved the issues pertaining to the process planning and scheduling. But most of them have handled the issues of process planning and scheduling independently. The process plan selection problem for an automated manufacturing system has been discussed by Kusiak and Finke (1998).They formulated a graph theoretical formulation, and integer programming formulation aiming towards the minimization of the manufacturing cost, number of tools, and supplementary devices. However, due to the computational complexity they addressed the problem later by constructing two heuristic algorithms. Khoshnevis and Chen (1990) generated an efficient process plan and schedule with the help of various dispatching rules. Their approach seems simple, and is easy to implement but it lacks of forward planning that may lead to the poor schedule generation. Bhaskaaran (1990) addressed the process plan selection problem by formulating an intransigent cost model to cover the objectives, such as minimization of total time, number of steps, and dissimilarity between the process plans. There are several research papers dealing with the scheduling problems. In static scheduling environment, a rescheduling policy has been studied by Yamamoto and Nof (1985). Hall and Sriskandrajah (1996) presented a survey of scheduling problems with blocking and no-wait. They pointed out the computational complexity existing in scheduling problems and suggested heuristics for several deterministic problems. Cai *et al.* (2003) studied the stochastic scheduling for minimizing the expected weighted flow time using preemptive repeat machine breakdowns model.

The research papers dealing with the integrated process planning and scheduling problems, and outsourcing are very few in numbers. Some of the researchers such as Zhang and Mechant (1993), Zhang and Millur (1994), Tonshoff *et al.* (1989), Tiwari and Vidyarthi (1998), etc. have worked on the integrated process planning and scheduling problems. These researchers highlighted the difference between the integration and interfacing issues. They pointed out that integration is addressed at the task level whereas the interfacing is achieved at the result level. An integrated process planning and scheduling (IPPS) model for the multi-plant supply chain (MSC), which behaves like a single company through strong coordination, and cooperation toward mutual goals has been discussed by Moon *et al.* (2002). Boër *et al*. (2004) have proposed the planning and scheduling module mainly focusing on the short term duration in order to respond quickly to market needs and changes in a flexible manner. There are some papers that deal with the concept of outsourcing in this scenario. The scheduling problem for a job shop considering the outsourcing and due dates as constraints have been discussed by Park *et al.* (2000). They addressed the total job shop scheduling problem, by solving a series of smaller sub-problems. Advance planning and scheduling (APS) problem in which each customer order has a due date and outsourcing is available, has been discussed by Moon *et al.* (2002). The theory of extended enterprises promotes the use of external resources without owning them, which is very close to outsourcing concept. The theory of extended enterprises has been discussed by some of the researchers (Browne *et al.* (1995), Jagdev and Browne (1998), Mark Davis (1999), which aims towards the reduction of life cycle of material processing, increase in speed to compete in the market, and creation of effective organizations and systems.

Nowadays interest has been grown towards the implementation of the leagile strategy. There are research papers dealing with the lean and agile paradigms separately but only few literatures are available on the leagile supply chain. Bunce and Gould (1996) pointed out that lean and agile paradigm has become the necessity for the success of any supply chain in twenty first century. Therefore integration of both the strategies led to the development of the leagile principles. Leagile principles were first implemented by Naylor *et al.* (1999). They defined leagility by combining the agility and leanness in one supply chain through the strategic use of the decoupling point. The lean and agile supply chains are separated by the decoupling point. Number of researchers including Stratton and Warburton (2003), Prince and Kay (2003), Mason-Jones (2000), Naim *et al.* (1999), etc. have pointed out the relevance of decoupling point. Rudberg and Wikner (2004) defined the mass customization in terms of the COPD which is also very similar to the term decoupling point used in leagile supply chains. Wikner and Rudberg (2005) explained that customer order decoupling point (COPD) emphasizes on separation of production performed on speculation from commitment to customer orders. Van Hoek (1997), Zapfel (1998), etc. were some of the researchers who pointed out the benefits associated with COPD. The aim of the leagile strategy is to place the decoupling point as far as from the supplier end, i.e. near the user end, so that the total lead time required to deliver the products to customers can be minimized. This concludes that the product is made in standard form as far as possible and converted to final customized product after the decoupling point, in order to cope with the demand uncertainty. Christopher and Towill (2000) highlighted the concept of delaying the product differentiation. Chan *and* Zhang *al.* (2001) have suggested a model for the agile manufacturing system. Van Hoek (1998) have pointed out the various advantages regarding postponement strategy, such as reduced total inventory, greater flexibility in multiplicity of production, easy forecasting, and mass customization. These prominent features of the leagile strategy inspired the authors to implement it in the process planning and scheduling problem environment.

The integrated process planning and scheduling problems have been solved by various researchers using many heuristics. Palmer (1996) proposed the integrated process planning and scheduling model for a manufacturing unit and solved the problem through the simulated annealing based approach. Zhang *et al.* (1994), Rai *et al.* (2002), etc have formulated process plan problem using fuzzy approach considering setup costs, process steps, machining times and machining costs. In order to reduce the dissimilarity among the process plans selection they first generated alternative optimal process plan for each part type and later merged the plans. A genetic algorithm approach to solve the process planning problem for a job shop was attempted by Zhang *et al.* (1997). Kolisch and Hess (2000) solved these types of problems using three approaches; a biased random sampling method and rest of the two approaches are Tabu-search based large-step optimization techniques. Chan *et al.* (2001) attempted the multi-agent based approach for the integrated process planning and scheduling problem. Kumar *et al.* (2003) utilized the ant colony approach to resolve the issues related to the job shop scheduling. Literature review reveals that researchers have aimed to minimize the makespan assuming the fixed machines for different operation sequences or vice-versa without the consideration of the outsourcing strategy.

In the present work an attempt has been made to resolve the complexity prevailing in the process planning and scheduling problems by considering the concept of outsourcing. The work also focuses on incorporation of leagile principles in the manufacturing industries to make them robust to the demand fluctuations. The paper emphasizes on the various aspects of leagile supply chain modeling, and building up an efficient model that can handle multiple customer orders involving the outsourcing strategy in an environment where, there are alternative operation sequences, alternative machines for different operations and precedence relationships between the operations. The present work utilizes a new hybrid Enhanced Swift Converging Simulated Annealing (ESCSA) algorithm to solve the scheduling problem. The algorithm encapsulates the prominent features of both GA and SA. The fuzzy logic controller (Kim *et al.,* 2003) has been incorporated to determine an appropriate mutation ratio that helps in minimizing the CPU time during the execution of the programme as well as it also prevents the solution from being entrapped in the local minima.

3. Lean and agile "Leagile": An overview

The establishment of a new supply chain strategy depends on the consideration of two foremost critical elements, the customer satisfaction and market place understanding. A manufacturing enterprise can endeavour to develop a strategy that will meet the requirements of both the supply chain and end consumer, only when the constraints of the market place are understood. In recent years the attention has been grown towards the implementation of lean and agile concepts. Lean manufacturing concept originated from Toyota Production System (TPS) (Ohno, 1988) aiming the reduction and elimination of the waste. It is motivated by the Japanese strategy of continuous improvement, i.e. Kaizen theory. Lean focuses on doing more with less, i.e. fewer inventories, less space, less money, less time to deliver products and works efficiently, where the demand is stable and predictable as well as the product variety is low. Lean focuses on the elimination of basically seven types of wastes that are overproduction, waiting time, time incurred in transportation, inventory, motion, defective units, and over-processing. Lean concept implementation in an organisation brings about improvements in terms of reduced cost, high inventory turns, reduced lead times, increased flexibility, and defect prevention.

However, the inclination of the market towards the variety of the products with short product development and lead times led many manufacturing industries towards the problems with inventories, overheads, and inefficiencies. This issue encouraged the development of an alternative to the lean production system that can handle the problems more efficiently. Agile production system emerged as an alternative to the lean principles (Richards, 1996). Agile strategy aims in using the market knowledge and virtual cooperation to utilize the advantageous opportunities in a volatile market place. It focuses on the adaptation according to the changes in the market. Successful functioning of agile manufacturing system in an organisation requires enterprise level integration that includes design integration, process planning, and scheduling. Agility can handle the increased product variety and overcome the problems faced in lean strategy, as leanness is the prerequisite for agility. Therefore, the increased range of product variety specialized, and fragmented customers, and markets have imposed the manufacturing industries to adopt the agile strategies.

Both the lean and agile strategies have proven their usefulness in their respective situations, but the present market scenario demands a more robust strategy that can encapsulate the salient features of both. This gave birth to a new strategy termed as "Leagile". The Leagile strategy combines the lean and agile principles through a decoupling point, which separates the production line into two parts at the point of product differentiation (Naylor *et al.*, 1999). The diagrammatical representation of the leagile strategy is shown in Figure 2. From the figure it can be clearly visualized that lean manufacturing is practiced in the upstream of the decoupling point, based on the level planned production whereas; agile manufacturing is employed in the downstream, focussing directly on satisfying customer orders. Lean manufacturing values long term supplier partnerships whereas, agile manufacturing focuses on short term partnerships with suppliers after the point of product differentiation. In leagile strategy the appropriate positioning of the decoupling point affects its performance in satisfying the customer needs efficiently. The aim of the leagile strategy is to place the decoupling point as far as from the supplier end, i.e. near the user end, so that the total lead time required to deliver the products to customers can be minimized. Leagility aims in product generalisation, i.e. product is made generic as far as possible and then assembled to the final form as per the market demand. In real scenario two decoupling points exist, the material decoupling point is the farthest point downstream to which products can be modularized and still remain adaptable to customer specifications whereas, the information decoupling point is the furthest point upstream to which information on real final demand can penetrate the supply chain. In leagile strategy the flow of information is very important in order to comprehend the uncertainties of the demand.

<<Insert Figure 2 here>>

The ability of the leagile strategy to handle the product variations, demand uncertainty, and provide the customers proper satisfaction proves its applicability in present scenario. In the present work an integrated process planning and scheduling model along with the outsourcing has been proposed. The application of the leagile principles in the integrated process planning and scheduling model can enhance its performance. The integrated model already inherits the benefits associated by outsourcing strategy. Hence, the production can be carried out if necessary at the outsourced plant and the product can be later converted to the final form when the demand for the certain type arrives. The production proceeds as per the process planning and scheduling module. If the leagile principles are employed the product generalisation can be aimed and demand uncertainty can be handled efficiently, i.e. the parts are produced in the generic form and it can be assembled to produce the desired product as per the demand in the assembly unit. This will enable the model to reduce the overhead inventories as well as reduce the losses incurred when the demand for certain product changes. The incorporation of the leagile principles will make the manufacturing enterprises more flexible. Hence, the lead time to manufacture a product can be decreased and production can be shifted as per the present market demand. This will avoid the delayed and out dated production and enable enterprises to produce as per the current market demand and provide instant product delivery. In this condition, the leagile strategy can be of great importance in performance enhancement where the integrated model has been implemented as it makes the manufacturing enterprises more flexible and efficient.

4. Problem Environment

The present market inclination has shifted towards the integration of the enterprises, having joint coordination (Bauer *et al.*, (1991), Wortmann (1991)), and focusing on optimum production goal in response to the customer demand. The manufacturing industries consume most of their time in the processing of the parts. In order to overcome these drawbacks, an effective process planning and scheduling model aiming to reduce the makespan and delivery time, needs to be implemented. To overcome the inadequacy of not delivering the product within the due date, outsourcing strategy has been adopted. But its implementation needs to be economically feasible. If outsourcing is economical, the procured goods are straightforwardly transported to subsidiary plant, or else transported to the main manufacturing plant for operation. The diagrammatical representation of a simple manufacturing supply chain involving outsourcing is shown in Figure 3. It consists of five units: (a) Customers, (b) Assembly unit, (c) Processing unit, (d) Sourcing of material, and (e) Outsourcing unit. Normally, the manufacturing industries following this type of the supply chain strategy have multiple customer orders with varying due dates. Each order may have several parts with dissimilar array of operations. Some of these operations may have precedence relationship that must have to be taken into account while deciding the operation sequence.

<<Insert Figure 3 about here>>

The paper also suggests the manufacturing enterprises, the benefits of inheriting the leagile strategy in their integrated production planning and scheduling model. The applicability of the leagile principles in the integrated model has been shown through a diagram presented in Figure 4. In this supply chain organization, the management has been divided in two parts, the first part, i.e. integrated process planning and scheduling management takes care of the scheduling, outsourcing, global material forecasted demand, and safety stock replenishment requirements planning whilst, the second part deals with materials planning and management at local level (McCullen and Towill, 2001). This modern supply chain is aimed towards the pull distribution system and manages the stock at the central warehouse until the last possible moment avoiding the stock imbalance. The customized dispatching of the products from the warehouse to the local and outstation distribution centers increases the efficiency of the manufacturing industries. Direct shipment from the industry, to the port of departure, in order to dispatch the volume products to the global destinations, reduces the lead time to a great extent. Hence, the leagile strategy enables the enterprises to tackle the fluctuating demand of the customers and allows them to meet the customer demand within the specified due date. It brings about the reduction of waste and maximizes the overall profit.

<<Insert figure 4 about here>>

The integrated process planning and scheduling problem measured in this paper has been modeled as a Traveling Salesman Problem (TSP) with precedence relationship, in order to ease its solution strategy. The model considers the travel distance between two machines which corresponds to the transition time between the operations. Based on the operational time, the machine is selected among the alternatives available. Since, each TSP determines the process planning and scheduling for each part type hence, for multiple part types problem, multiple TSP has been considered. Characteristic of these types of system is guided by its lot size (Nasr and Elsayed, 1990). If, transfer batch is equal to the process batch then part is transferred to the subsequent stage after the completion of the batch operation, whereas, if transferred batch is not equal to the process batch then part is immediately moved to the subsequent operation after the completion of current operation.

The present work deals with the generation of a feasible operation sequence merging the features of ESCSA algorithm, directed graph and topological sort (TS) techniques. In a directed graph, vertices represent operations while, edges represent precedence relations between different operations (Horowitz and Shani, 1984). First ESCSA algorithm is executed to assign a fixed priority number corresponding to each vertex of the directed graph; thereafter topological sort technique is applied to generate a unique feasible operation sequence according to the assigned priority number. The present work aims towards the minimization of the makespan while satisfying the due date as a constraint. The problem also assumes the other constraints such as precedence constraint, processing time constraint, machine constraint, and operation constraint. In real scenario there is a substantial chance of machine failure, which can cause delay in processing or can cause cessation of the flow. Hence, in order to reduce the complexity of the problem the machine failure has been not taken into account in the proposed work. Another assumption has also been considered to simplify the complexity is that an operation can be performed on one machine only; the part can't be partly processed on one machine, and rest on the another for the same operation.

Various decision variables have been also considered during solving the problem. The various decision variables, objective functions, and the constraints considered in the present problem will be described in the further subsections.

4.1 Notations

The various parameters used to demonstrate the objective function and the constraints are mentioned below:

d_c	:	Customer demand index, d_c= {1, 2, 3... D}, where, D the last demand index
i	:	Part number, i = 1, ,2, 3, … I , where I is the last part
j	:	Operation number, j = 1, 2, 3 … J, where, J is the last operation
m	:	Machine number, m = 1, 2, 3 … M, where M is the last machine
S_{ijmdc}	:	Starting time of operation j for part i on machine m for customer demand d_c
AT_{dc}	:	Assembly time of the product for customer demand d_c
TO_{d_cij}	:	Transportation time in outsourcing operation j of part i for customer demand d_c
DD_{d_c}	:	Delivery date of customer demand d_c
MS_{d_c}	:	Makespan for customer demand d_c
PT_{d_cijm}	:	Processing time for operation j of part i assigned to machine m for customer demand d_c
MT_{md_c}	:	Working time of machine m for completing customer demand d_c
DT_{d_c}	:	Delivery time of customer demand d_c
T_{PT}	:	Total Processing Time
$\Delta\bar{F}(f;r)$	:	Average fitness value at generation r
$\Delta\bar{F}(f;r-1)$	:	Average fitness value at generation r-1
β	:	Population size

λ	:	Scaling factor
υ	:	Offspring size
Δ m (r)	:	Mutation rate

4.2 Decision variables integrality

The various decision variables considered in the present work can be characterized using the binary (0-1) values are described below:

$$\alpha_{d_c ijm} = \begin{cases} 1, \text{if operation j of part i is assigned to the machine m} \\ \text{for the customer order } d_c \\ 0, \text{otherwise} \end{cases} \quad \ldots (1)$$

$$\gamma_{d_c ijm} = \begin{cases} 1, \text{if predecessor of operation j of part i processed for} \\ \text{customer order } d_c \text{ on the machine m} \\ 0, \text{otherwise} \end{cases} \quad \ldots (2)$$

$$\psi_{jkm} = \begin{cases} 1, \text{if opearation j precedes operation k on the machine m} \\ 0, \text{otherwise} \end{cases} \quad \ldots (3)$$

$$\chi_{d_c ijk} = \begin{cases} 1, \text{if there is a precedence relation between operation j and} \\ \text{k for the part type i of the customer order } d_c \\ 0, \text{otherwise} \end{cases} \quad \ldots (4)$$

4.3 Objective function

The present work emphasizes on the minimization of the overall makespan of the system. Hence, the total processing time (T_{PT}) required for processing all the parts of the customer order can be expressed as:

$$T_{PT} = \sum_{d_c=1}^{D}\sum_{i=1}^{I}\sum_{j=1}^{J} PT_{d_c ijm}\alpha_{d_c ijm} + \sum_{d_c}^{D}\sum_{i=1}^{I}\sum_{j=1}^{J} \gamma_{d_c ijm} TO_{d_c ij} \quad \ldots (5)$$

Keeping in mind the fact that parallel processing of the parts take place the working time for each machine (MT_{md_c}) for completing customer demand d_c can be calculated as:

$$MT_{md_c} = \sum_{i=1}^{I}\sum_{j=1}^{J} PT_{d_c ijm}\alpha_{d_c ijm} + \sum_{i=1}^{I}\sum_{j=1}^{J} \gamma_{d_c ijm} TO_{d_c ij} \qquad \ldots (6)$$

Therefore, the overall objective of the minimization of the makespan time, simultaneously satisfying the due date of the customer order measured in the proposed model can be expressed as:

$$MS_{d_c} = \text{Minimize}(\text{Max}(MT_{md_c})) \qquad \ldots (7)$$

After the makespan corresponding to the operation sequence is decided, the delivery date of the customer order can be calculated according to the following expression:

$$DD_{d_c} = \text{Max}(MS_{d_c} + AT_{d_c} + DT_{d_c}) \qquad \ldots (8)$$

The constraints bound on the objective measured in the proposed model have been described in the next section.

4.4 Constraints

a). *Precedence Constraint*: Precedence relationship between operation j and k for the part type i of the customer order d_c is feasible only if;

$$\chi_{d_c ijk}(\alpha_{d_c ijm} S_{d_c ijm} + \alpha_{d_c ijm} PT_{d_c ijm}) \le \alpha_{d_c ijm} S_{d_c ikm} \quad \forall \;\; d_c, i, j, k, m \qquad \ldots (9)$$

b). *Processing Time Constraint*: The completion time should be either positive or zero i.e.

$$PT_{d_c ijm} \ge 0 \qquad \ldots (10)$$

c). *Machine Constraint*: The machine can start a new operation only after the completion of the previous one;

$$\eta(1-\psi_{jkm})+(\alpha_{d_c ijm}S_{d_c ikm}-\alpha_{d_c ijm}S_{d_c ijm})\geq PT_{d_c ijm}\alpha_{d_c ijm} \quad \forall\ d_c,\ i,\ j,\ k,\ m \qquad \dots (11)$$

Where, η is a very large positive number.

d). *Operation Constraint*: This constraint implies that operation can be performed on one machine only;

$$\sum_{m=1}^{M}\alpha_{d_c ijm}=1 \qquad \dots (12)$$

The detailed overview of the background of the proposed ESCSA Algorithm along with the algorithm steps has been discussed in the next section.

5. Background of Enhanced Swift Converging Simulated Annealing Algorithm

The constraints bound by the present market scenario have made the conventional optimization methods inefficient in handling the complexities. Most of the conventional methods are prone to be entrapped in the local minima, as well as they require a large search space and long computational time to converge to the optimal solution thus, resulting in the degraded performance. The conventional methods such as integer linear programming (ILP) (Christopher *et al.*, (1992), Barbara *et al.*, (1996)*)*, branch and bound (Potts and Wassenhove (1985), Desrochers *et al.* (1992)), and other mathematical programming methods are not only time consuming as well as they do not guarantee the optimal solution. To overcome these inabilities of local search heuristics such as Genetic Algorithm (GA), Simulated Annealing (SA), Tabu Search, etc. came into existence. However, these methods are also not found to be more efficient for example SA is found to be superior to GA but the computational expensiveness restricts its application in some cases. Hence, in order to meet the demand of the present market environment, a robust algorithm is required that can be efficient in exploring the search space in less computational time, and can be converged to the optimal or near optimal solution.

The shortcomings of the conventional search methods motivated the authors in the present paper to propose an intelligent and efficient Enhanced Swift Converging Simulated Annealing (ESCSA) Algorithm, which merges the prominent features of Genetic Algorithm (GA), Simulated Annealing (SA), and a Fuzzy Logic Controller (FLC). The proposed algorithm extends the previous approach of Mishra *et al.* (2006). The present algorithm additionally inherits the FLC (Kim *et al.*, 2003) which helps in selection of the appropriate mutation ratio, thus reduces the chances of getting entrapped in the local minima. The FLC also reduced the total computational time involved to solve the problem. Encapsulating these salient features the proposed algorithm is capable of finding the optimal/near optimal solution in less computational time as compared to other local search techniques such as GA, SA, Tabu Search, Hybrid-Tabu etc.

5.1 The ESCSA Algorithm

The proposed ESCSA algorithm merges the salient features of GA, SA, and the FLC. The algorithm starts with a randomly generated set of population and initialization of the temperature. Afterwards, the crossover and mutation are carried out. Here the FLC helps in the standardization of the mutation ratio. Based on the alterations in the fitness value the mutation ratio is then updated. The procedure of standardization of the mutation ratio is described in the Appendix I. After that, the best child (offspring) produced in each family is selected based on some selection criteria for the next generation's population. This selection procedure is motivated by the simulated annealing (SA) approach which utilizes the probability function to accept downhill moves escaping the entrapment in the local minima. Two basic criteria considered are;

i). *Fitness Criterion*: This criterion signifies that the next generation's population is selected based on their fitness value, i.e. if the offspring generated has fitness better than the parent, it will go to the next generation.

ii). *Probabilistic Criterion*: As per this criterion even if the child has fitness value less than that of the parent, it will be given some probability for its acceptance. This also helps the solution to avoid entrapment in the local minima. The Cauchy's distribution function is used to define the probability as stated in equation (13);

$$C(T(r), \Delta Y) = \frac{T(r)}{T^2(r) + (\Delta Y)^2}, \qquad \dots (13)$$

Where T(r) = Temperature during the r^{th} generation, and

Δ Y = Difference of the fitness value,

When C (T(r), Δ Y) > δ, where δ is any random number between interval [0, 1], then the substandard one moves to the next generation.

After selection, the temperature is reduced as per the cooling schedule. Cooling schedule is of prime importance as it determines the value of transition probability function used during the selection criterion. The temperature declines as the search proceeds and at the end it is expected to move away from a worse neighboring solution. Finally the searching procedure is stopped following the stopping criteria. The steps of the proposed algorithm are mentioned below:

Step 1: Assign the values of the population size (P), Initial temperature T (1), and the maximum number of generations.

Step 2: Randomly generate a set of population chromosomes as initial parent population. The proposed work uses the operation oriented encoding scheme. The sample population shown contains operation priorities in first row, whereas the second row represents machines where subsequent operations are to be performed

4	5	2	6	10	7	6	8	5	2
5	3	2	1	2	4	2	4	3	1

Step 3: Evaluate the fitness value (Y1) for each parent.

Step 4: Perform the crossover operation. Single cut point crossover has been used in this algorithm, e.g.

Parent1 2 1 5 4 3 2 5 2 3 1 5 1 4 3 2 5

Parent 2 1 2 1 2 4 3 1 4 3 2 5 1 5 3 4 2

After performing the crossover operation by swapping the right parts of the genes, following the cut point with the other parent, the resulting child or offspring is obtained as

Child 1 2 1 5 4 3 2 5 4 3 2 5 1 5 3 4 2

Child 2 1 2 1 2 4 3 1 2 3 1 5 1 4 3 2 5

Step 5: All the offspring generated is subjected to swap mutation with rate proportional to their fitness value and it is updated using FLC as;

If $\mu \le \Delta\overline{F}(f;r-1) \le \omega$ and $\mu \le \overline{\Delta F}(f;r) \le \omega$

then increase P_m for the next generation

If $-\omega \le \Delta\overline{F}(f;r-1) \le -\mu$ and $-\omega \le \Delta\overline{F}(f;r) \le -\mu$

then decrease P_m for next generation

If $-\mu \le \Delta\overline{F}(f;r-1) \le \mu$ and $-\mu \le \Delta\overline{F}(f;r) \le \mu$

then rapidly increase P_m for next generation

end

end

Where μ is a given real number in proximity of zero, ω is a given maximum value of fuzzy membership function; - ω is a given minimum value of fuzzy membership function and P_m is the mutation rate.

Step 6: Evaluate the fitness of the each child generated and select the best one in every family based on the highest fitness value (Y2).

Step 7: Evaluate Δ Y = Y2 – Y1

Step 8: Select the parent for the next generation out of each family following the transition rules as below:

If (ΔY>0 or F (T (r), ΔY)>δ)

best child is accepted as parent for new generation

else

the previous one remains as new parent.

Step 9: Reduce the temperature as per the following schedule;

$$T(r) = \frac{3.2 * T(1)}{1 + \log(T^r(1))}, \quad \dots (14)$$

Step 10: perform r = r + 1

Step 11: Select the best child from the final population having the highest fitness value. This gives the optimal or near optimal solution.

Step 12: If r > maximum number of generation. Stop the search procedure.

6. Computational results and discussion

Through the extensive literature review it has been found that the conventional methods such as SA and Tabu search methods converge to the optimal/near optimal solutions after a relatively high number of iterations. Hence, it is inevitable to find an effective metaheuristic that can converge to the optimality in relatively less number of iterations. Enthused by this, in the proposed work an efficient and robust metaheuristic ESCSA algorithm has been developed to overcome the drawbacks inherited in the conventional optimization methods. When applying the ESCSA algorithm on the IPPS problem it has been found that it has faster convergence and requires less computational time as compared to the other conventional methods.

In the present work to reveal the efficacy of the proposed ESCSA algorithm in an IPPS environment a test problem has been considered. The results obtained by applying the proposed algorithm has been compared to the GA, SA, Tabu search, and Hybrid Tabu search algorithms to analyze its robustness and capability in handling such complex problems.

The test problem is applicable for the multiple customer order. In this test problem the manufacturing enterprise consists of five machines (M_1, $M_{2,}$ … M_5), where M_5 is the outsourced machine. There are total 5 products that are to be produced by 20 operations. The total transportation time between the outsourced machine and the manufacturing unit is 10 units. Due dates of customers' orders are $DD_{d1} \leq 45$ and $DD_{d2} \leq 75$. The assembly and delivery time of these operations included in orders are; $AT_{d1} = AT_{d2} = 5$, and $DT_{d1} = DT_{d2} = 5$. Therefore, to produce the customer's order according to their due dates, makespan of the operation sequence corresponding to each order must be $MS_{d1} \leq 35$, and $MS_{d2} \leq 65$. The alternative machines corresponding to the operations are shown in Table 1. The precedence relationship between various operations is shown in Figure (5). In Figure (5) P1, and P5 are the sequential processes where as the P2, P3 and P4 are standard with the parallel sequences.

<<Insert Table 1 about here >>

<<Insert Figure 5 about here>>

The result of the problem measured in this work has been presented in Table 2. The Gantt chart of the optimal schedule obtained has been shown in Figure 6. To show the efficacy of the ESCSA algorithm the results obtained have been compared to those obtained by GA, SA, Tabu, and Tabu-SA algorithms. The comparative analysis shows that the proposed ESCSA algorithm gives the best result as compared to the other methods. The makespan comes out to be 30 (as can be visualized from the Gantt chart for the first order) and 55 for the respective due dates which outperformed comparatively from the other optimization techniques. In terms of the computational time too, the ESCSA surpasses the other methods. The comparative plot in terms of convergence among the various algorithms has been presented in Figure 7. From the Table 2 it can be observed that GA takes less number of iterations as compared to the ESCSA algorithm but it does not gives the minimal makespan i.e. it gets entrapped in the local minima. The comparative plot in terms of makespan has been shown in Figure 8. The percentage improvements in the results as compared to other methods are presented in Table 3. These assessments show significant improvements in the results reflecting the effectiveness of the algorithm in handling such complex integrated process planning and scheduling problems. Therefore, the ESCSA algorithm comes out to be more efficient in terms of the computational time and number of iterations as compared to GA, SA, Tabu, and Tabu-SA algorithms and can be efficiently used to tackle more complex real world problems. The result also clearly depicts the benefits of the outsourcing strategy in reducing the overall makespan time. Hence, outsourcing provides significant advantages to the enterprises in their performance optimization whereas, Leagility too improves the performance of the industries in terms of reduced makespan and enhanced flexibility to adjust as per the fluctuating demand.

<<Insert Table 2 about here>>

<<Insert Table 3 about here>>

<<Insert Figure 6 about here >>

<<Insert Figure 7 about here>>

<<Include Figure 8 about here>>

The proposed ESCSA algorithm has been coded in C++ language and the problem has been tested on Intel Pentium IV, 1.8 GHz processor. In nutshell, the aforesaid computational results not only validate the efficacy and superiority of the proposed algorithm but also provide a new dimension to the solution of complex combinatorial problems in real time.

7. Conclusion

In the present work authors have proposed an integrated process planning and scheduling model inherited with outsourcing and leagile strategies. The work emphasizes on the performance optimization of such problems under the existing complex scenario. Motivated by the drawbacks of the Genetic Algorithm and Simulated Annealing based approaches, the authors have proposed a new Enhanced Swift Converging Simulated Annealing (ESCSA) algorithm, encapsulating the salient features of the Fuzzy Logic Controller (FLC) to solve the complex problem. The integrated process planning and scheduling model inheriting outsourcing and leagile concepts has been formulated aiming the minimization of the makespan, while satisfying the due dates of the customer orders in a manufacturing supply chain. Our formulation and proposed algorithm provides a superior and simple planning tool to strategically select the outsourcing machine and perform the operations on them while considering several technological constraints encountered in the real shop floor situation. Literature review has revealed that it is a computationally complex problem and mathematically intractable to solve. The proposed ESCSA algorithm incorporates the salient features of GA, SA, and FLC and does away with their shortcomings.

The paper also suggests the advantages of incorporating the leagile principles in their production strategy. In recent years leagile principles has attracted the manufacturing industries due to its ability to handle the product variation and demand uncertainty while simultaneously enhancing the profit by reducing the wastes. It also enables the industries to be flexible and be responsive as per the demand variations. The present paper focuses on its significance in the proposed integrated process planning and scheduling model with outsourcing. The result already explains the benefits associated with the incorporation of the outsourcing strategy in terms of reduced makespan.

Though the proposed algorithm is found to be superior to the conventional optimization tools, the future work needs to be carried out in the direction where more complex and larger real time problems can be efficiently solved in least computational time by this algorithm. The future research needs to be focused on solving problems involving multi-objective such as, inventory cost, tardiness of jobs, and mean flow time simultaneously involving number of constraints and decision variables. The proposed algorithm has some promising aspects that deserve further investigations. The proposed way of selecting the mutation rate with the help of FLC needs further exploration to enhance its precision. The leagile principles have shown its potential in enhancing the performance of manufacturing industries. In this connection, leagile concepts need to be implemented and tested in the diverse field of manufacturing environment.

Appendix I

In the proposed work to reduce the chances of entrapment in the local minima and also to reduce the computational time, a Fuzzy Logic Controller (FLC) based on some rules has been created. The FLC helps in the standardization of the mutation ratio. Based on the alterations in the average fitness the mutation ratio is updated. The average fitness alterations at generation r and r-1 are represented as follows:

$$\Delta \overline{F}\ (f, r) = \left(\frac{\sum_{n=1}^{\beta} F(f_n; r)}{\beta} - \frac{\sum_{n=\beta+1}^{\beta+\vartheta} F(f_n; r)}{\upsilon} \right) \lambda \qquad \dots (15)$$

$$\Delta \overline{F}\ (f, r\text{-}1) = \left(\frac{\sum_{n=1}^{\beta} F(f_n; r-1)}{\beta} - \frac{\sum_{n=\beta+1}^{\beta+\vartheta} F(f_n; r-1)}{\upsilon} \right) \lambda \qquad \dots (16)$$

Where $f = \{f_1, f_2 \dots f_n\}$, β is the population size, υ is the offspring size satisfying the constraint and λ is the scaling factor regulating the average fitness value. The implementation approaches for the mutation FLC is given as follows:

- Input and output of mutation FLC

  Input: Δ $\overline{F}$ (f, r), and Δ $\overline{F}$ (f, r-1);

  Output: the change in mutation rate Δ m (r).

- Membership functions of Δ $\overline{F}$ (f, r-1), Δ $\overline{F}$ (f, r), and Δ m (r)

  The membership functions are shown in Figure 9, and Figure 10, where NLR: negative larger; NL; negative large; NM: negative medium; NS: negative small; ZE: zero; PS: positive small; PM: positive medium; PL: positive large; PLR: positive larger. Δ $\overline{F}$ (f, r-1), and Δ $\overline{F}$ (f, r) are normalized in the range [-0.1, 1.0], and Δ m (r) in the range [-0.1 to 0.1] as per their corresponding maximum values.

- Fuzzy decision table

  The fuzzy decision table is drawn based on the number of experiments and expert opinion as shown in Table 4.

- Defuzzification for control actions

  Finally the defuzzification is performed to convert the linguistic variables into integer form. The Defuzzification table for control action of mutation is shown in Table 5.

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Table 1: Alternative Machines Corresponding to the Operations

Part No	Operations No	Processing/ Outsourcing unit	*Unit processing time*
P1	O_{11}	M1	5
		M2	3
	O_{12}	M2	7
	O_{13}	M3	6
	O_{14}	M2	3
		M4	3
		M5	4
P2	O_{21}	M1	7
	O_{22}	M2	4
		M3	6
	O_{23}	M3	7
		M4	7
	O_{24}	M2	4
		M5	10
P3	O_{31}	M1	4
		M2	5
		M3	8
	O_{32}	M4	5
	O_{33}	M4	6
		M5	5
	O_{34}	M1	4
		M5	4
P4	O_{41}	M2	2
		M3	6
	O_{42}	M3	8
	O_{43}	M3	3
		M4	8
	O_{44}	M2	6
		M4	7
		M5	4
P5	O_{51}	M1	3
		M3	5
	O_{52}	M3	7
	O_{53}	M4	9
		M5	6
	O_{54}	M1	6
		M5	3

M5 = Outsourcing Machine
O_{xy} = Operation number y for part number x.

Table 2: Computational result for the undertaken problem

Solution methodology	CPU Time in sec	Number of iterations/ generations	Makespan
GA	18	726	64

SA	22	1010	62
TABU	19	734	62
Hybrid Tabu-SA	8	840	57
ESCSA	7	810	55

Table 3: Percentage comparative improvement with other methods

Solution Methodology	% Improvements
GA	14.06 %
SA	11.29 %
Tabu	11.29 %
Hybrid Tabu-SA	3.5 %

Table 4: : Fuzzy Decision Table For Mutation

Δ $\overline{F}$ (*f*, *r*)	**Δ $\overline{F}$ (*f*, *r*-1)**								
	NLR	NL	NM	NS	ZE	PS	PM	PL	PLR
NLR	NLR	NL	NL	NM	NM	NS	NS	ZE	ZE
NL	NL	NL	NM	NM	NS	NS	ZE	ZE	PS
NM	NL	NM	NM	NS	NS	ZE	ZE	PS	PS
NS	NM	NM	NS	NS	ZE	ZE	PS	PS	PM
ZE	NM	NS	NS	ZE	PM	PS	PS	PM	PM
PS	NS	NS	ZE	ZE	PS	PS	PM	PM	PL
PM	NS	ZE	ZE	PS	PS	PM	PM	PL	PL
PL	ZE	ZE	PS	PS	PM	PM	PL	PL	PLR
PLR	ZE	PS	PS	PM	PM	PL	PL	PLR	PLR

Table 5: : Defuzzification Table For Control of Mutation

$\Delta\overline{F}$ **(*f*, *r*)**	$\Delta\overline{F}$ **(*f*, *r*-1)**								
	-4	-3	-2	-1	0	1	2	3	4
-4	-4	-3	-3	-2	-2	-1	-1	0	0
-3	-3	-3	-2	-2	-1	-1	0	0	1
-2	-3	-2	-2	-1	-1	0	0	1	1
-1	-2	-2	-1	-1	0	0	1	1	2
0	-2	-1	-1	0	2	1	1	2	2
1	-1	-1	0	0	1	1	2	2	3
2	-1	0	0	1	1	2	2	3	3
3	0	0	1	1	2	2	3	3	4
4	0	1	1	2	2	3	3	4	4

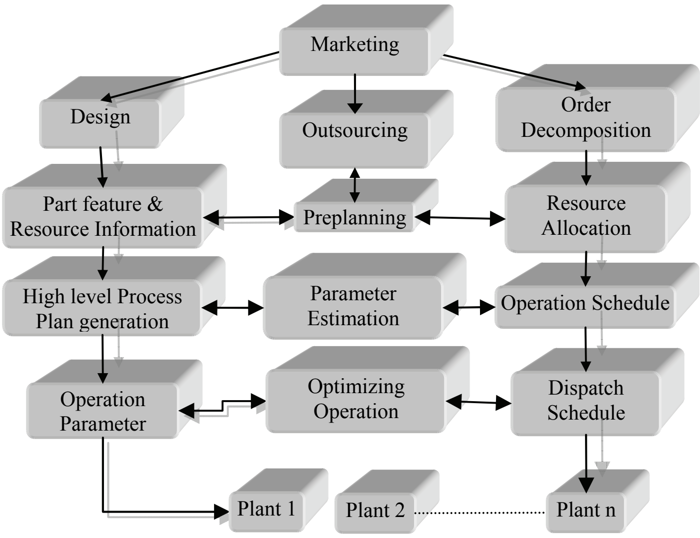

Figure 1: Process planning and scheduling model with outsourcing

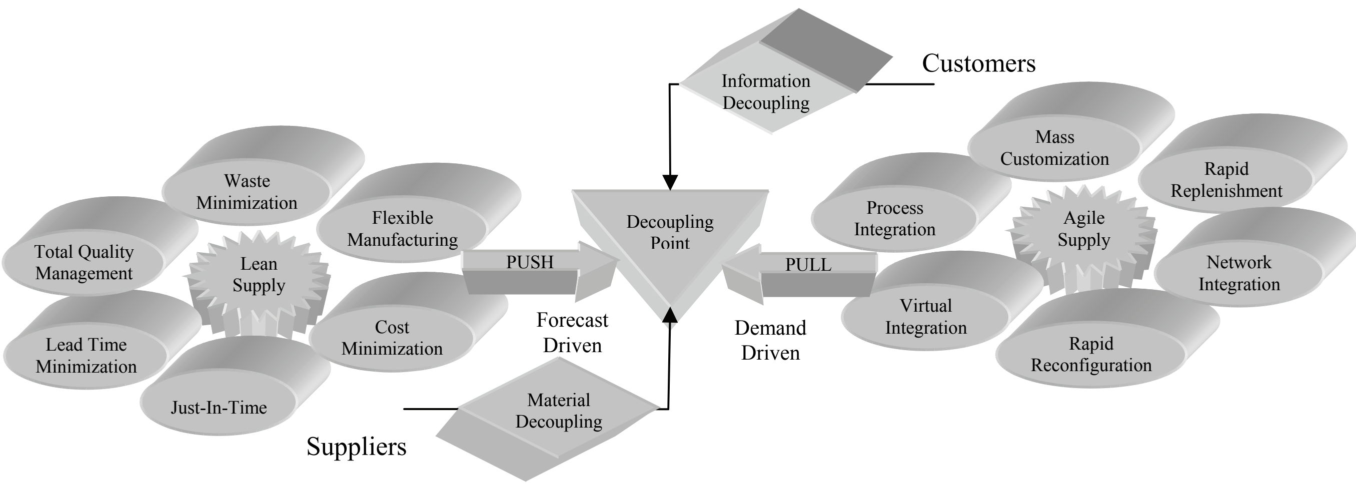

Figure 2: Leagile Supply Chain

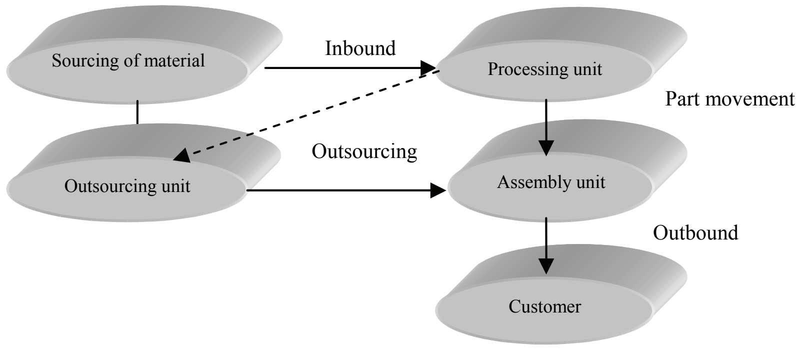

Figure3: Structure of supply chain involving processing units and outsourcing unit

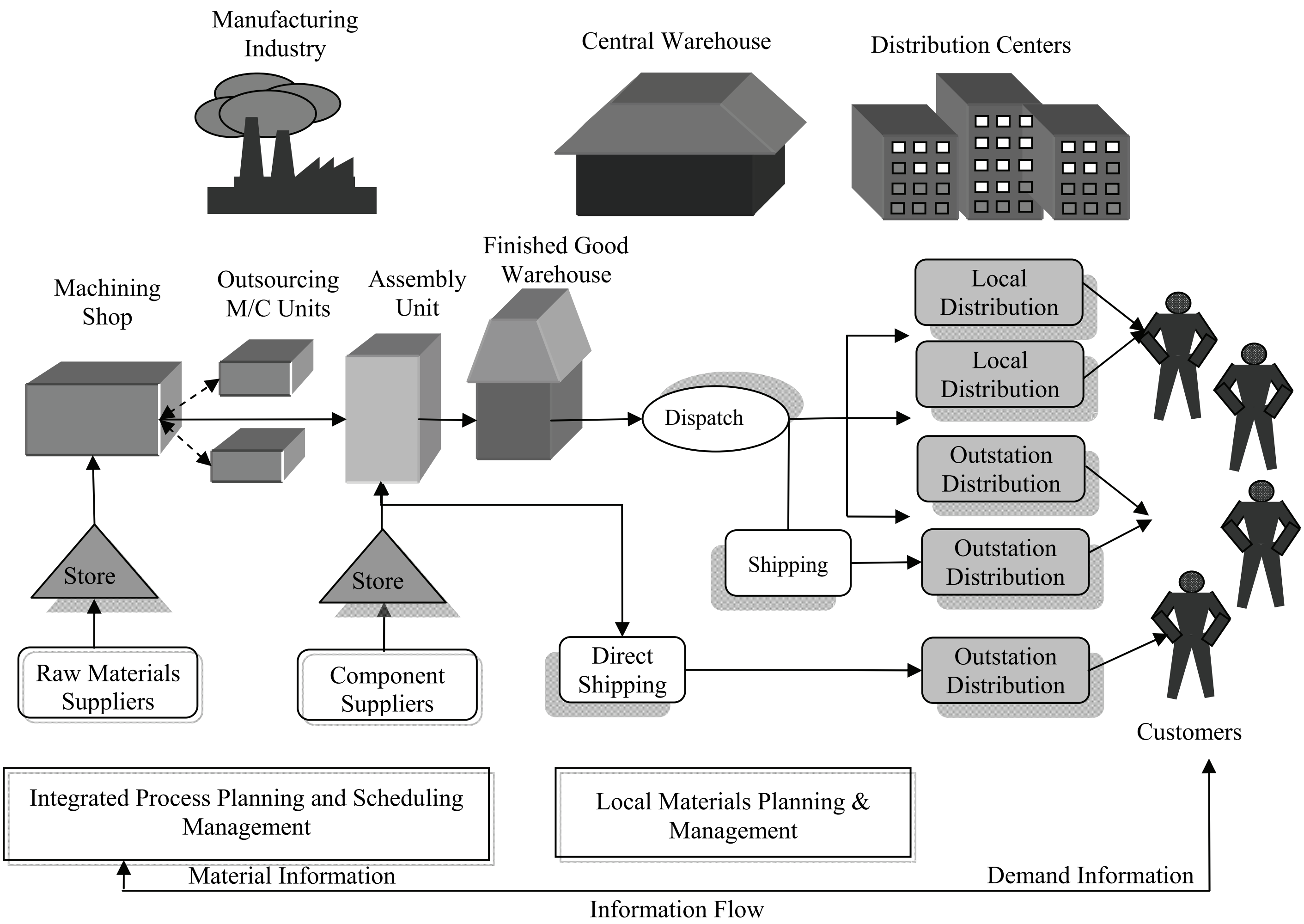

Figure 4: Modern Organization model of a Manufacturing Industry inheriting leagility

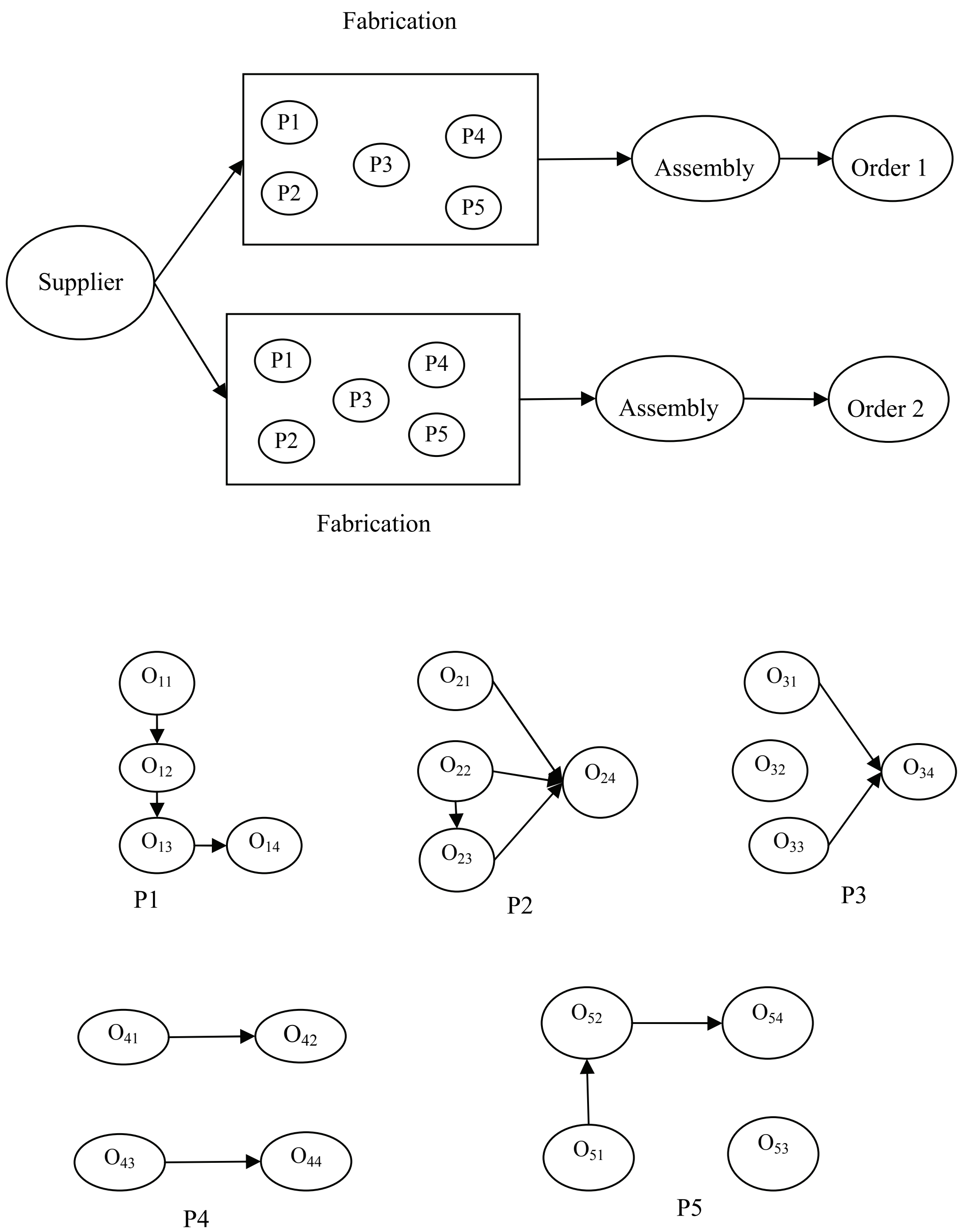

Figure 5: Directed graph of a manufacturing process with precedence relationship

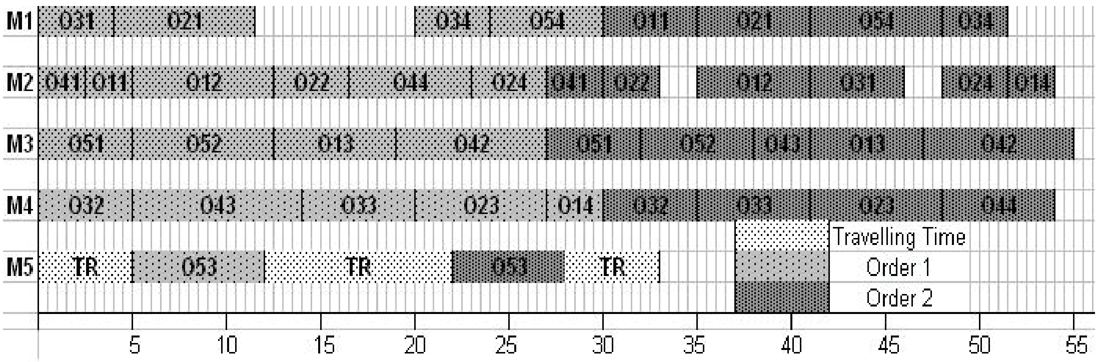

Figure 6: Gantt chart of the schedule

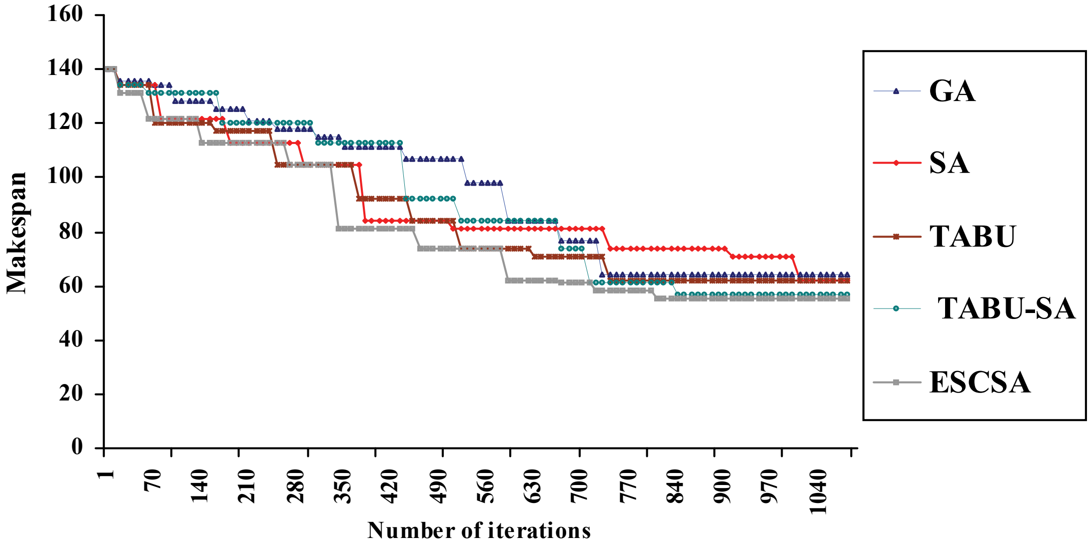

Figure 7: Comparative Convergence with other algorithms

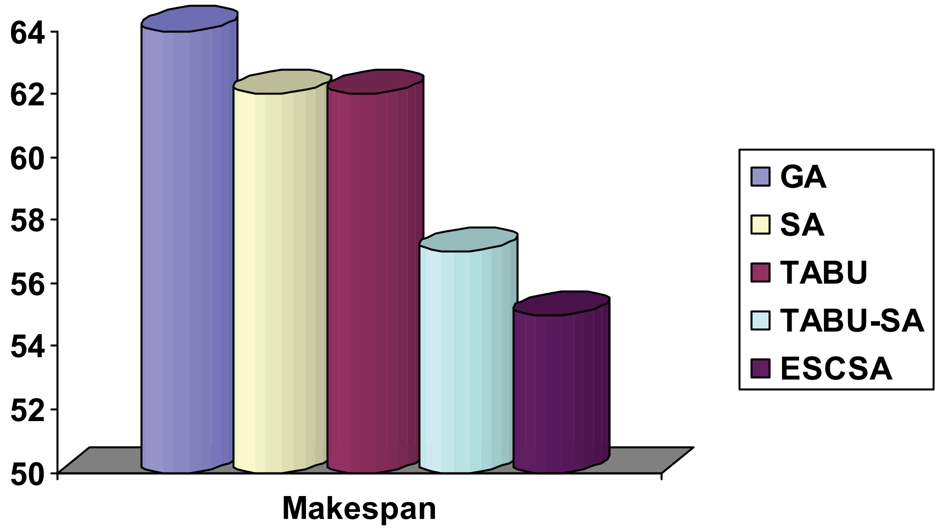

Figure 8: Comparative plot showing the makespan

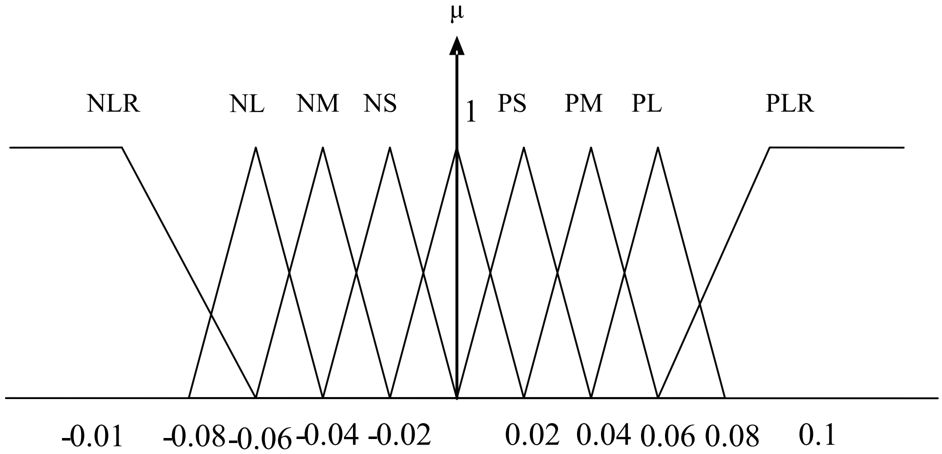

Figure 9: Membership function of Δ m (r)

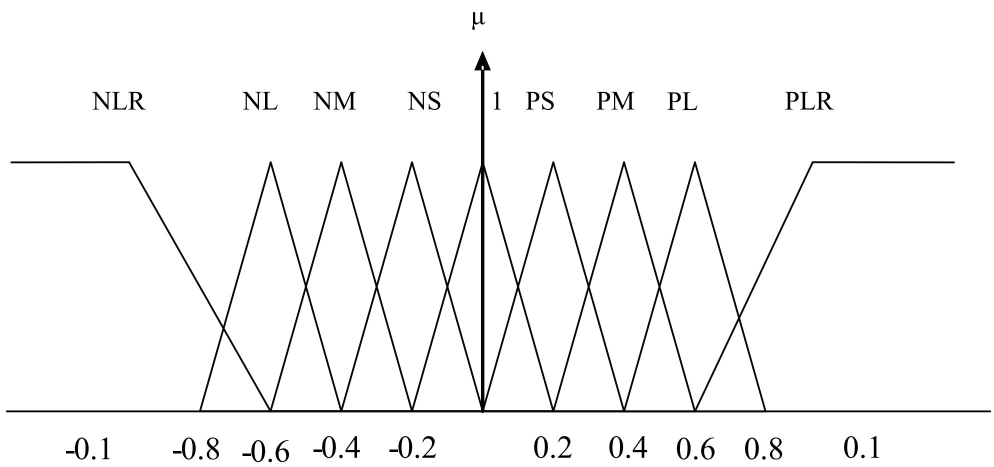

Figure 10: Membership function of Δ $\overline{F}$ (*f*, *r*-1), Δ $\overline{F}$ (*f*, *r*)