

Appropriate Evolutionary Algorithm for Scheduling in FMS

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Abstract— Driven by open global competition, rapidly changing technology, and shorter product life cycles, manufacturing organizations come across significant amount of uncertainty and hence continuous change. Customers' demand for a greater variety, high quality and competitive cost is in increasing trend. Flexible Manufacturing Systems (FMS) have brought in significant advantages and benefits to manufacturing industries. The ability of FMSs to flex and adapt to both internal and external changes gives rise to improvement in throughput, product quality, information flows, reliability, and other strategic advantages. However, appropriate scheduling methodology can better derive these benefits. The powers Evolutionary Algorithms like genetic algorithm (GA) and simulated annealing (SA) can be beneficially utilized for optimization of scheduling FMS. The present work utilizes these powerful approaches and tries to find out their appropriateness for planning & scheduling of FMS producing variety of parts in batch mode.

Keywords- *Flexible Manufacturing System; Scheduling Constraint; Genetic Algorithm; Simulated Annealing;*

I. INTRODUCTION

With the increasing sophistication of production practices there has been a corresponding increase in the importance and profitability of efficient production scheduling. The global nature of the present manufacturing environment has necessitated an improvement in the way companies manufacture their products. This increase in demand has been matched by an increase in theoretical findings. The current state of production scheduling is a mixture of approaches from different areas. The intractability of the problem also lends itself to making the developments widely varied. Since the scheduling problem is not amenable to any particular solution, it is treated as NP-hard problem, and it can be treated as a subset of operational research [1,2,3]. Production scheduling concerns the efficient allocation of resources over time for the manufacture of goods. The objective of the present scheduling problem is to find a way to assign and to sequence the activities of these shared resources such that production constraints are satisfied and production costs are minimized. FMS is designed to combine the high efficiency of a transfer line and the flexibility of a job shop to best suit to the batch production of mid-volume and mid-variety products. It may be realized that for an industry it is possible to reach for high flexibility by making innovative

technological and organizational efforts. There has been a paradigm shift in manufacturing industries over the years which can be attributed to this idea [4, 5]. Given the part types and their volume in each batch FMS Scheduling is concerned with the real time operation of the system and the allocation of tools to the machine and allocation of operations to machines and is concerned with the following:

- Releasing of part types to the system: Only a subset of the part types constitutes a batch. Releasing rule priorities the part type of the batch leading to their ordered entry to the system.
- Assignment of operations of part type to machines: Routing flexibility provides alternate machines for an operation of a part type. Operation assignment rule is used to assign an operation to one amongst the alternate machines available for the purpose.
- Dispatching of part types waiting for processing before a machine: At any given point of time several part types wait in the local buffer for their turn to get service in a machine. Dispatching rules are used to prioritize them.

The present work is envisaged to work out the optimal scheduling process for modular FMS setups. The scheduling deals with optimizing the cost function in terms of machining time. The search space includes a number of feasible combinations and out of these, the best fit solution is derived with help of Genetic Algorithm (GA) and Simulated Annealing (SA). In order to accomplish the objective, the methodology is split into the following:

- Detailing the machining processes involved in the manufacture of the parts
- Application of GA and SA for scheduling
- Optimization of scheduling time with alternate assignments within FMS.
- Comparison of results obtained from the scheduling optimization methods and recommending the appropriate one.

II. MODEL FORMULATION

A. Description of the parts

FMS has the capability to process a large number of part types. However, in the present study, the parts to be processed in the selected setups are so chosen that they are almost similar in their functions with differences in their physical and geometrical properties. The study of the physical properties (design attributes) and manufacturing requirements (manufacturing attributes) of the considered

parts put them under one group from group technology viewpoint. The parts are manufactured in batches and depending on the demand, there can be variation in batch size as well as the product renewal rate. The machining requirements are almost same for all the parts. The parts have been chosen keeping in view that they can be manufactured under the set of facilities under consideration without major changes in the setup requirements. The machining requirements for the parts are: 1) facing, 2) turning, 3) drilling, 4) boring, and 5) thread cutting. The details of machining operations of part-1, part-2 and part-3 (as shown in Figures 1(a) - (c) respectively) are given in Tables 1–3 respectively.

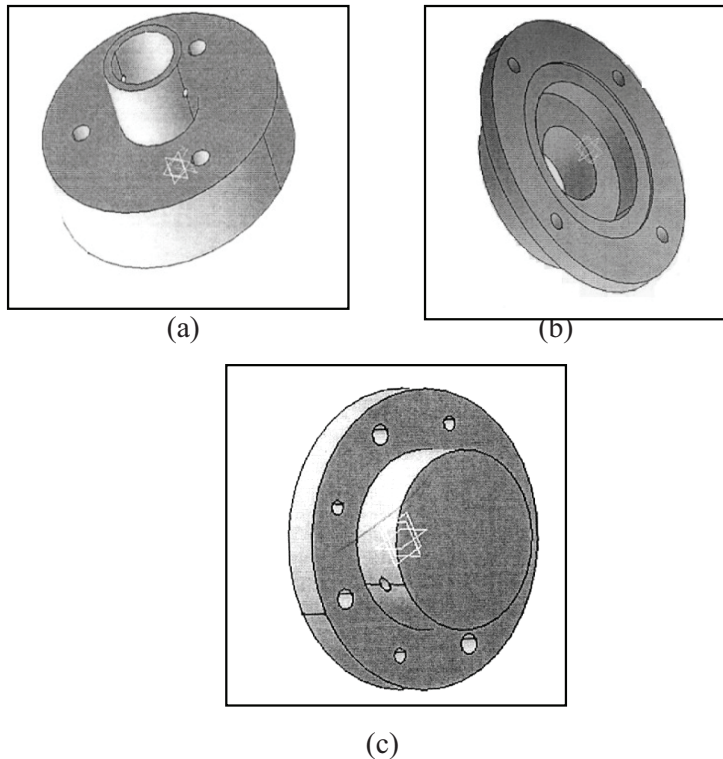


Figure .1 (a) Graphical model of part 1 , (b) Graphical model of part 2 and (c) Graphical model of part 3

TABLE 1 PROCESSING OPERATIONS FOR PART-1

Sl.No.	Operation	Tool used
1	Facing of face 1 (F ₁₁)	Facing tool
2	Turning of ϕ 75 (T ₁₁)	Turning tool
3	Drilling of ϕ 2.5 (D ₁₁)	Drills
4	Step boring of ϕ 60 and ϕ 20 (B ₁₁)	Boring tool
5	Facing of face 2 (F ₁₂)	Facing tool
6	Turning of ϕ 25 (T ₁₂)	Turning tool
7	Thread cutting M30 \times 2.5 (TH ₁₁)	Threading tool
8	Drill ϕ 6, 3 nos. (D ₁₂)	Drills

TABLE 2 PROCESSING OPERATIONS FOR PART-2

Sl.No.	Operation	Tool used
1	Facing of face 1 (F ₂₁)	Facing tool
2	Turning of ϕ 114 (T ₂₁)	Turning tool
3	Drilling of ϕ 7,4 nos. (D ₂₁)	Drills
4	Step boring of ϕ 76, ϕ 60 & ϕ 32 (B ₂₁)	Boring tool
5	Facing of face 2 (F ₂₂)	Facing tool
6	Turning of ϕ 72 (T ₂₂)	Turning tool
7	Drill ϕ 5, 2 nos. (D ₂₂)	Drills
8	Thread cutting M30 \times 5, 2 nos. (TH ₂₁)	Threading tool

TABLE 3 PROCESSING OPERATIONS FOR PART-3

Sl.No.	Operation	Tool used
1	Facing of face 1 (F ₃₁)	Facing tool
2	Turning of ϕ 100 (T ₃₁)	Turning tool
3	Drilling of ϕ 7,4 nos. (D ₃₁)	Drills
4	Drilling of ϕ 5,4 nos. (D ₃₂)	Drills
5	Thread cutting M30 \times 5, 4 nos. (TH ₃₁)	Threading tool
6	Facing of face 2 (F ₃₂)	Facing tool
7	Turning of ϕ 60 (T ₃₂)	Turning tool
8	Drilling of ϕ 2.5, (D ₃₃)	Drills

B. Description of the setups

The three setups under consideration consist of four machines (M) to accomplish the desired machining operations viz. facing, turning, drilling, boring and thread cutting as described before, on all the three parts. Setup consists of two numbers of lathes, namely lathe-1 (M1) and lathe-2 (M3) and two numbers of machining centre, machining centre-1 (M2) and machining centre-2 (M4). In setup-2, a CNC drilling machine replaces the machining centre-2 of setup-1 as machine M4. Rest of the machines in the setup remains unaltered. In setup-3, another CNC drilling machine replaces the machining centre-1 of setup-1 as machine M2. Rest of the machines in the setup remain the same as in setup-2. Alternate routes have been considered in the setups for all the three parts with machining breakdown and availability fully captured.

The three different alternate routes via which the parts are manufactured in setup-1 are: R1 = M1 \rightarrow M2 \rightarrow M3 \rightarrow M4, R2 = M3 \rightarrow M4 \rightarrow M2 \rightarrow M1, and R3 = M1 \rightarrow M4 \rightarrow M3 \rightarrow M2. The operations performed, at all the machines via different routes, for each part in setup-1 are given in Table 4 for part-1, part-2 and part-3 correspondingly. The alternate routes for setup-2 are: R1= M1 \rightarrow M2 \rightarrow M3 \rightarrow M4, R2= M3 \rightarrow M4 \rightarrow M2 \rightarrow M1, and R3= M1 \rightarrow M4 \rightarrow M3 \rightarrow M2. The operations performed, at all the machines via different routes, for each part in setup-2 are given in Table 4 for part-1, part-2 and part-3 correspondingly. The routes for setup-3 are: R1= M1 \rightarrow M2 \rightarrow M3 \rightarrow M4, R2= M3 \rightarrow M4 \rightarrow M2 \rightarrow M1, and R3= M1 \rightarrow M4 \rightarrow M3 \rightarrow M2.

TABLE 4 MACHINES ON ROUTES OF SETUP-1

Route1: $M_1(F_{11}, T_{11}) \rightarrow M_2(D_{11}, B_{11}) \rightarrow M_3(F_{12}, T_{12}) \rightarrow M_4(D_{12}, TH_{11})$
Route2: $M_3(F_{11}, T_{11}) \rightarrow M_4(D_{11}, B_{11}) \rightarrow M_2(F_{12}, T_{12}, D_{12}) \rightarrow M_3(TH_{11})$
Route3: $M_1(F_{11}, T_{11}) \rightarrow M_4(D_{11}, B_{11}) \rightarrow M_3(F_{12}, T_{12}) \rightarrow M_4(D_{12}, TH_{11})$
Route1: $M_1(F_{21}, T_{21}) \rightarrow M_2(D_{21}, B_{21}) \rightarrow M_3(F_{22}, T_{22}) \rightarrow M_4(D_{22}, TH_{21})$
Route2: $M_3(F_{21}, T_{21}) \rightarrow M_4(D_{21}, B_{21}) \rightarrow M_2(F_{22}, T_{22}, D_{22}) \rightarrow M_3(TH_{21})$
Route3: $M_1(F_{21}, T_{21}) \rightarrow M_4(D_{21}, B_{21}) \rightarrow M_3(F_{22}, T_{22}) \rightarrow M_4(D_{22}, TH_{21})$
Route1: $M_1(F_{31}, T_{31}) \rightarrow M_2(D_{31}, D_{32}, TH_{31}) \rightarrow M_3(F_{32}, T_{32}) \rightarrow M_4(D_{33}, TH_{32})$
Route2: $M_3(F_{31}, T_{31}) \rightarrow M_4(D_{31}, D_{32}, TH_{31}) \rightarrow M_2(F_{32}, T_{32}, D_{33}) \rightarrow M_3(TH_{32})$
Route3: $M_1(F_{31}, T_{31}) \rightarrow M_4(D_{31}, D_{32}, TH_{31}) \rightarrow M_3(F_{32}, T_{32}) \rightarrow M_4(D_{33}, TH_{32})$

TABLE 5 MACHINES ON ROUTES OF SETUP-2

Route1: $M_1(F_{11}, T_{11}) \rightarrow M_2(D_{11}, B_{11}) \rightarrow M_3(F_{12}, T_{12}, TH_{11}) \rightarrow M_4(D_{12})$
Route2: $M_3(F_{11}, T_{11}) \rightarrow M_4(D_{11}, B_{11}) \rightarrow M_2(D_{12}) \rightarrow M_3(F_{12}, T_{12}, TH_{11})$
Route3: $M_1(F_{11}, T_{11}) \rightarrow M_2(D_{11}, B_{11}) \rightarrow M_3(F_{12}, T_{12}, TH_{11}) \rightarrow M_2(D_{12})$
Route1: $M_1(F_{21}, T_{21}) \rightarrow M_2(D_{22}, B_{21}) \rightarrow M_3(F_{22}, T_{22}, TH_{21}) \rightarrow M_4(D_{21})$
Route2: $M_3(F_{21}, T_{21}) \rightarrow M_4(D_{21}, B_{21}) \rightarrow M_2(B_{21}) \rightarrow M_3(F_{22}, T_{22}, TH_{21})$
Route3: $M_1(F_{21}, T_{21}) \rightarrow M_2(D_{22}, B_{21}) \rightarrow M_3(F_{22}, T_{22}, TH_{21}) \rightarrow M_2(D_{21})$
Route1: $M_1(F_{31}, T_{31}) \rightarrow M_2(D_{32}, D_{33}) \rightarrow M_3(F_{32}, T_{32}, TH_{31}, TH_{32}) \rightarrow M_4(D_{31})$
Route2: $M_3(F_{31}, T_{31}, F_{32}, T_{32}) \rightarrow M_4(D_{31}, D_{32}) \rightarrow M_2(D_{33}) \rightarrow M_3(TH_{31}, TH_{32})$
Route3: $M_1(F_{31}, T_{31}) \rightarrow M_2(D_{32}, D_{33}) \rightarrow M_3(F_{32}, T_{32}, TH_{31}, TH_{32}) \rightarrow M_2(D_{31})$

TABLE 6 MACHINES ON ROUTES OF SETUP-3

Route 1: $M_1(F_{11}, T_{11}) \rightarrow M_2(D_{11}, B_{11}) \rightarrow M_3(F_{12}, T_{12}, TH_{11}) \rightarrow M_4(D_{12})$
Route 2: $M_3(F_{11}, T_{11}) \rightarrow M_4(D_{11}, B_{11}) \rightarrow M_2(F_{12}, T_{12}, D_{12}) \rightarrow M_3(TH_{11})$
Route 3: $M_1(F_{11}, T_{11}) \rightarrow M_2(D_{11}, B_{11}) \rightarrow M_3(F_{12}, T_{12}) \rightarrow M_2(D_{12}, TH_{11})$
Route 1: $M_1(F_{21}, T_{21}) \rightarrow M_2(D_{22}, B_{21}) \rightarrow M_3(F_{22}, T_{22}, TH_{21}) \rightarrow M_4(D_{21})$
Route 2: $M_3(F_{21}, T_{21}) \rightarrow M_4(D_{21}, B_{21}) \rightarrow M_2(F_{22}, T_{22}, D_{22}) \rightarrow M_3(TH_{21})$
Route 3: $M_1(F_{21}, T_{21}) \rightarrow M_2(D_{21}, B_{21}) \rightarrow M_3(F_{22}, T_{22}) \rightarrow M_2(D_{22}, TH_{21})$
Route1: $M_1(F_{31}, T_{31}) \rightarrow M_2(D_{32}, D_{33}, TH_{31}, TH_{32}) \rightarrow M_3(F_{32}, T_{32}) \rightarrow M_4(D_{31})$
Route2: $M_3(F_{31}, T_{31}) \rightarrow M_4(D_{31}, D_{32}, D_{33}) \rightarrow M_2(F_{32}, T_{32}) \rightarrow M_3(TH_{31}, TH_{32})$
Route3: $M_1(F_{31}, T_{31}) \rightarrow M_2(D_{31}, D_{32}, TH_{31}) \rightarrow M_3(F_{32}, T_{32}) \rightarrow M_2(D_{33}, TH_{32})$

The operations performed, at all the machines via different routes, for each part in setup-3 are given in Table 6 for part-1, part-2 and part-3 correspondingly.

III. METHODOLOGY

The different approaches made by researchers are mostly theoretical and specific problems are not dealt with. It is also observed that a good number of authors have attempted to relative and logical assessing of manufacturing a system. The present study is aimed at quantification of manufacturing systems. Scheduling of FMS as a whole is a complex concept influenced by a large number of components with the machines, the flow pattern of the inventories, the processing operations, the parts and the material handling systems being the major ones. The effects of change in these components can be studied accurately by considering an actual production system. However, in the present study, virtual production environments analogous to actual manufacturing facilities in shop floor have been considered which facilitate better manipulation for the purpose of flexibility study in

changed situations. The results of design of experiments give rise to concentrating the study on three numbers of setups, each producing same three numbers of parts through three alternate routes. Selection of setups was carried out in virtual environment using VNC in which three alternate setups were finally selected on the basis of convenience, utility, and operational requirement for producing the three parts. The GA interface interacts with the modules of design process modelling and configuration and prepares the data necessary for the GA-engine. Using the data gathered, the GA-engine searches the near optimal solution among candidates in the population pool. The schedule displayer transforms each candidate solution into a feasible schedule by considering the resource constraints imposed, while the iterative design analyzer is invoked to assess the time span for the schedule. The objective function determines the quality of a schedule. In the first sections, the operators of GA used in this work, namely chromosome encoding, crossover and mutation operators as well as the fitness scaling and selection are addressed in detail. It is important to note that this work focuses on non-interrupted scheduling, where interruption is not allowed when a task is underway. In the second sections, the SA approach for finding out the optimal schedule of operations assignment to machines is carried out. SA is motivated by an analogy to annealing in solids. The algorithm simulates the cooling processes by gradually lowering the temperature of the system until it converges to a steady frozen state. In the present work an attempt has been made to optimize the scheduling of FMS setups using GA and SA.

A. Simulation of the setups

The setups have been modelled in QUEST ver. 4.0 a 3D graphics-based Queuing Event Simulation Tool for analysing the manufacturing process visually and obtaining useful data for further analysis. The production scenarios, product mixes and failure responses for machine and labour utilisation, throughput bottlenecks and inventory evaluation are efficiently explored in this software. The information and statistics generated by the simulation gives useful inputs for studying the behaviour of a manufacturing process and comparing the same with one another. The setups under are modelled using QUEST to study the operation of the entire process, regulating the flow of inventory, determination of material handling time, determination of cycle time and getting a complete picture of scheduling and for plotting of the process charts.

The individual machining times are obtained from modeling the machines and performing virtual operations in VNC ver. 5.0, interactive 3D graphics-based real time simulation software. This enables to improve the quality of CNC part programs, eliminate catastrophic program errors and optimize machining process. The fast and real time simulation eliminates the uncertainty about NC programs. It automatically detects collisions and near misses between tool and fixtures, spindle and workpiece and virtually any part in the work cell. The CNC lathe, CNC machining centre and CNC drilling machine have been retrieved from

the library of VNC and have been modified according to the need of the setups for performing the machining simulation. Virtual NC helps to reduce cycle times by more than 40% and avoid CNC machine downtime for dry runs. The outputs of simulation in VNC have been used as inputs to the models in QUEST. The timings (in seconds) for each individual operation (such as F11, T11, F22, T22, D11, D12, etc.) were recorded for different machines on which the operations were actually carried out, from simulation and are presented in Table 7.

In the setups, robots carry out the loading/unloading operations in various machines for different parts and, the modeling and simulation of these operations are done using another simulation tool IGRIP ver. 5.0, is an interactive 3D graphics simulation tool for designing, evaluation and offline programming of robotic work cells.

TABLE 7 MACHINING TIME FOR DIFFERENT OPERATIONS

		L-1	L-2	C-1	C-2	D-1	D-2
Part 1	F ₁₁	020	030	×	×	×	×
	F ₁₂	×	020	020	×	×	×
	T ₁₁	060	070	×	×	×	×
	T ₁₂	×	040	035	×	×	×
	D ₁₁	×	×	100	120	090	100
	D ₁₂	×	×	070	080	070	090
	B ₁₁	×	×	100	120	090	100
Part 2	TH ₁₁	×	080	055	060	×	×
	F ₂₁	030	040	×	×	×	×
	F ₂₂	×	60	050	×	×	×
	T ₂₁	050	060	×	×	×	×
	T ₂₂	×	080	070	×	×	×
	B ₂₁	×	×	120	140	100	110
	D ₂₁	×	×	080	100	070	090
Part 3	D ₂₂	×	×	075	080	070	090
	TH ₂₁	×	150	110	120	×	×
	F ₃₁	100	110	×	×	×	×
	F ₃₂	×	050	040	×	×	×
	T ₃₁	080	100	×	×	×	×
	T ₃₂	×	180	160	×	×	×
	D ₃₁	×	×	120	140	100	120
	D ₃₂	×	×	120	140	100	120
	D ₃₃	×	×	020	020	020	25
	TH ₃₁	×	200	180	200	×	×
	TH ₃₂	×	040	025	030	×	×

L-1: Lathe-1; L-2: Lathe-2; C-1: Machining Center-1; C-2: Machining Center-2; D-1 : Drilling Machine-1; D-2: Drilling Machine-2.

B. Genetic Algorithm

GA is an adaptive search techniques based on specific mechanisms found in natural evolution. GA begins its search from a randomly generated population of designs that evolve over successive generations (iterations). GA employs three operators to propagate its population from one generation to another to perform its optimization process. The first operator is the “Selection” operator that mimics the principal of “Survival of the Fittest”. The second operator is the “Crossover” operator, which mimics mating in biological populations. The crossover operator

propagates features of good surviving designs from the current population into the future population, which will have better fitness value on average. The last operator is “Mutation”, which promotes diversity in population characteristics. The appropriate values of the GA parameters are arrived at, based on the satisfactory performance of trials conducted for this application with different ranges of values. The crossover probability was varied from 0.4 to 0.9 and it was found that the solution was improving faster for a crossover probability of 0.60. Similarly, in the range from 0.001 to 0.010 the mutation probability of 0.005 was found to retain much better solutions than worse solutions.

Population size (n) = 20 samples

Crossover probability (p_c) = 0.600

Mutation probability (p_m) = 0.005.

C. Simulated Annealing

The SA [6] approach for finding out the optimal schedule of operations assignment to machines is carried out, first by giving the machining time of individual operations at different machines as input.

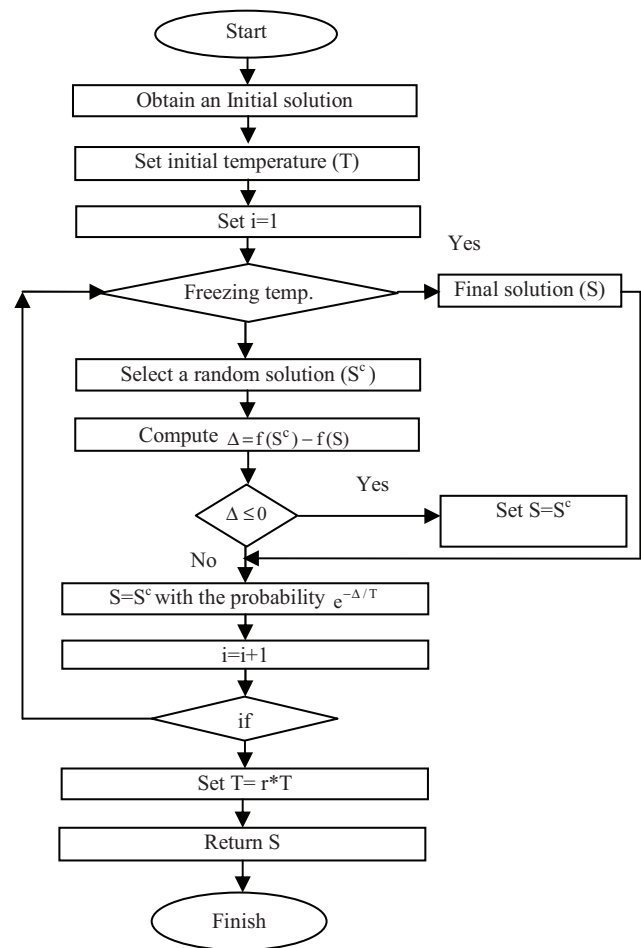


Figure 2. The simulated annealing process

The initial solution is derived by using the shortest processing time (SPT) rule. The other solutions or moves are derived from the neighborhood. The neighborhood search is conducted by interchanging the elements with its neighborhood. The stopping criterion of the algorithm in this work is the maximum number of iterations. The cooling parameter is taken to be 0.9 and the maximum number of iterations is taken to be 50. The parameters were so chosen for fast convergence to the optimal value. Further, sufficient care is taken care of machine overloading. The SA procedure depicted in Figure .2. The SA programs for various jobs are run several times by varying the temperature decrement and the cooling range to obtain the optimal scheduling of the FMSs by minimizing the cost function i.e by minimizing the total machining time for realization of the part. However, the machine setup times are not taken into consideration for minimization of the cost function. Only the machining times are considered for optimal scheduling.

IV. PROBLEM STATEMENT

The processing times for various operations are obtained from the graphical simulations of the processes at different machines. The processing times are used to describe the combined objective function of the genetic optimization process. These are termed as intermachine restrictions and intramachine restrictions [7]. For example in setup-1, if the operation F11 is carried out in M1, the same operation is not performed by M2, M3 and M4. Further in, the same machine (M1), the other operations like F12, T12 and TH11 cannot be done. The former condition is an example of intermachine restriction and the latter is an example of intramachine restriction. The intermachine restrictions take care of the ease in operation for a machine taking into consideration the part orientation. All possible restrictions for all the three setups are found out and put as the rule base in the GA program. The intermachine restrictions and intramachine restrictions for setup-1, setup-2 and setup-3 are prepared. The GA programs for various setups are run several times by varying the population size and the number of generations to obtain the optimal scheduling of the FMS by minimizing the Combined Objective Function (COF), that is, by minimizing the total machining time for realization of the part. However, for computational convenience, the machine setup times are assumed to be same for all the machines. After every generation of the GA cycle, every individual in the population (i.e. feasible schedule) is evaluated using the COF for minimizing the total penalty cost and maximizing machine utilization. Therefore the objective becomes,

Minimize $COF = (W_1) \times (X_p/MPP) + (W_2) \times (X_q / TE)$,
where, W_1 = weight factor for customer satisfaction and W_2 = weight factor for machine utilization.

X_p =total penalty cost incurred, and

$$X_p = \sum_i (CT_i - DD_i) \times UPC_i \times BS_i$$

where, i = job number, CT_i = completion time of job i , DD_i = due date for job i , UPC_i = unit penalty cost for job i , BS_i = batch size of job i .

MPP = maximum permissible penalty

X_q = total machine down time, and

$$X_q = \sum_j MD_j$$

TE= total elapsed time,

PT_{ji} = processing time of i^{th} job with j^{th} machine, where j = machine number, and

$$MD_j = TE - \sum_i PT_{ji}$$

In the computation the weight factors W_1 and W_2 are assumed to be equal and hence, $W_1 = 0.5$ and $W_2 = 0.5$. However, different ratios can be applied to them according to the demand of business situation.

V. RESULTS AND CONCLUSIONS

The proposed approach was coded in MATLAB. The algorithm was run with control parameters obtained from the graphical simulation in QUEST. The proper values of these parameters were determined in a pre-processing phase. Due to the stochastic behavior of the algorithm, and the fact that it does not have a natural termination point, it was decided to run the algorithms for fixed time duration and report the best solution obtained after this time has elapsed. The generated solutions were quantified by the solution quality given in percentage offset from the best known solutions. The optimal schedules and optimized machining times as obtained from the GA and SA runoff programs for setup-1, setup-2, setup-3 respectively and results are presented in the Table 8, Table 9 and Table 10. It is observed from the tables that the total machining time is the lowest in setup-2.

This is due to the fact that the operations such as F11, T11, D11, B11, D12, TH11 are more effectively carried out in the machines they are assigned to in setup-2. The optimization technique adopted in the present work will always produce the optimal value of the cost function as it is based on the principle of survival of fittest. Any type of layout can be implemented as the rule base takes care of the operation sequence. The GA optimization technique depends on the size of operational requirement and the complexity of the part. However, the approaches differ widely from each other with respect to coding, parameters used, the constraints handled and the goals pursued. Despite of these differences, all approaches have in common that the domain knowledge is required in order to produce competitive results.

TABLE 8 OPERATION ASSIGNMENT AND PROCESSING TIME AT MACHINES IN SETUP-1

Machines	M_1		M_2		M_3		M_4	
	GA	SA	GA	SA	GA	SA	GA	SA
Operation assigned	F_{11}, T_{11}	F_{31}, F_{32}, T_{31}	F_{12}, D_{11}, TH_{11}	$D_{31}, D_{32}, D_{33}, TH_{32}$	T_{12}	TH_{31}	B_{11}, D_{12}	T_{32}
Machining time	80	240	175	268	45	180	157	160
% of Machine Utilization	17.5	28.3	38.3	31.6	9.8	21.1	34.4	19
Total Machining Time:457 (GA), Total Machining Time:848 (SA)								

TABLE 9 OPERATION ASSIGNMENT AND PROCESSING TIME AT MACHINES IN SETUP-2

Machines	M_1		M_2		M_3		M_4	
	GA	SA	GA	SA	GA	SA	GA	SA
Operation assigned	F_{12}, T_{12}	F_{11}, T_{11}, D_{11}	B_{11}, D_{12}, T_{12}	F_{12}, T_{12}	F_{11}, T_{11}	D_{12}, B_{11}	D_{11}, TH_{11}	TH_{11}
Machining time	42	170	170	53	95	170	180	60
% of Machine Utilization	8.6	37.5	34.9	11.7	19.5	37.6	37	13.2
Total Machining Time:487 (GA), Total Machining Time:453 (SA)								

TABLE 10 OPERATION ASSIGNMENT AND PROCESSING TIME AT MACHINES IN SETUP-3

Machines	M_1		M_2		M_3		M_4	
	GA	SA	GA	SA	GA	SA	GA	SA
Operation assigned	F_{11}, T_{11}	F_{21}, D_{21}	D_{11}, TH_{11}	B_{21}	F_{12}, T_{12}	F_{22}, TH_{21}	B_{11}, D_{12}	T_{21}, T_{22}, D_{22}
Machining time	80	110	155	120	53	160	157	203
% of Machine Utilization	18	18.5	34.8	20.2	12	27	35.2	34.3
Total Machining Time:445 (GA), Total Machining Time:593 (SA)								

The present work used two different approaches viz. GA and SA on the same set of problems to determine the optimized schedule in an FMS. The choice of the methods has been made on the basis that most of the previous work reported the use of these two methods in optimizing similar problems and the methods are used independently. The present work uses both these methods to find out the appropriate one for the purpose. The coding of the methods is designed in a manner that yields global optima for the solution. The results show that GA scores over SA in dealing with the FMS scheduling under constraint condition and such behavior of GA against that of SA may be attributed to the fact that, the intricacies of the problem are well taken care of by the coding methods of GA. A

comparison of the total machining time obtained from the GA and that obtained from SA is presented in Figure 3. GA achieves a good efficiency with respect to the total machining time.

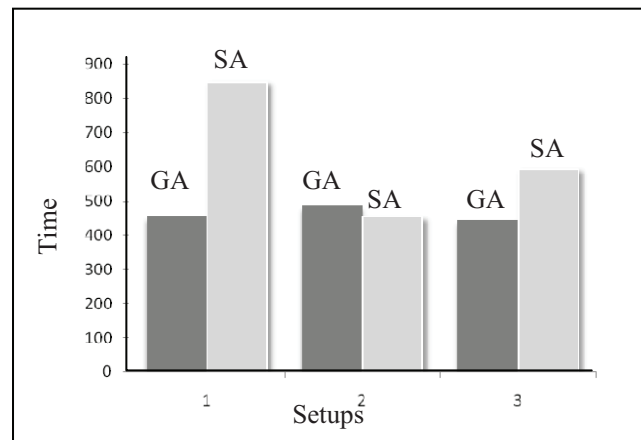


Figure 3. Comparison of machining time of GA and SA

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