*International Conference on Computer Aided Engineering (CAE 2007) Department of Mechanical Engineering, I.I.T. Madras*

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## Abstract

Driven by open global competition, rapidly changing technology, and shorter product life cycles, manufacturing organizations come across continuous change and hence significant amount of uncertainty. Customers' demand for a greater variety, high quality and competitive cost is in increasing trend. Traditional manufacturing approaches face threats to remain competitive. Flexible Manufacturing Systems (FMS) have brought in significant advantages and benefits to manufacturing sector, particularly to small and medium sized ones. 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 power of Genetic Algorithm (GA) can be beneficially utilized for optimization of scheduling FMS. The present work utilizes this approach for planning & scheduling of FMS producing large variety of parts in batch mode.

***Key words**: Flexible Manufacturing System, Scheduling, Constraint, Genetic Algorithm*

## 1. 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 parts. This increase in practical demand has been matched by an increase in theoretical developments. 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, the frontiers of research in this area are vast. So 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. Scheduling problems arise whenever a common set of resources-labor, material and equipment must be used to make a variety of different parts during the same period of time. 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.

## 2. FMS and its scheduling

The utility of an FMS lies in mid -volume and mid-variety part types. 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 parts. Today's manufacturing strategy is to seek benefits from flexibility. This is feasible when a production system is under complete control of FMS technology. Having in mind the process-product matrix, 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, 6].

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. In other words FMS Scheduling is concerned with the following:

a. Releasing of part types to the system: Only a subset of the part types constitutes a batch. Releasing rule prioritizes the part type of the batch leading to their ordered entry to the system.

b. 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.

c. 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.

## 3. Problem statement

The problem can be formulated as follows: n jobs from a job set {1, 2, .... n}, with $n > 1$, have to be processed on m machines {1, 2,…m},with $m>1$, in the order given by the indexing of the machines. Each job consists of m operations and each operation requires a different machine. The processing time of each job i on machine j is fixed and denoted by $t_{ij}$ ($i=1, \dots,n$ ;$j=1,\dots,m$). Preemption is not allowed, thus, the operation of each job on a machine requires an uninterrupted period of time. Each job can be processed on one machine at a time and each machine can process only one job at a time. The objective is to find the optimal schedule (permutation of all jobs), which has the minimum sum of job completion times. Let $C(j_i, k)$ denote the completion time of job $j_i$ on machine k, and let $(j_1, j_2, \dots, j_n)$ denote a permutation of jobs, then the completion time for an n-job m-machine problem is calculated as follows:

$C(j_1; 1)= t_{j_11}$ ,

$C(j_1; k)=C(j_1, k - 1) + t_{j_1k}$ ,$k= 2,\dots, m$,

$C(j_i ; 1)=C(j_{i-1}, 1)+ t_{j_i1}$, $i= 2,\dots n$,

$C(j_i ; k)=\max\{C(j_{i-1}, k),C(j_i, k - 1)\}+ t_{j_ik}$, (1)

$i = 2,\dots, k = 2\dots,m$

The make span is calculated by the relation:

$C_{max} = C(j_n;m)$. (2)

The objective function for the problem corresponds to the minimization of the makespan given in Eq. (2).Consequently the objective of any heuristic is to find a near optimal schedule whose objective cost, i.e. whose makespan is the minimum over the set of all feasible schedules.

## 4. Genetic Algorithm

Genetic Algorithms (GAs) are 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 principle 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 mutation operator allows for global search of the design space and prevents the algorithm from getting trapped in local minima.

## 5. Objectives of the work

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 GA. Precisely, the objectives of the present work are:

- Analysis of parts to be produced in an FMS,
- Detailing the machining processes involved in manufacture of the parts,
- Application of GA for scheduling,
- Optimization of scheduling time with alternate assignments within FMS.

## 6. Methodology

A systematic approach is adopted to achieve the objectives of the present work through defining and understanding the manufacturing scenario in FMS. This forms a base to use a mathematical model for optimization of the scheduling time for the system under consideration. The study of previous literatures reveal that the flexibility measurement provides a better understanding of the ability of a production system. The different approaches made by researchers are mostly theoretical and specific problems are not dealt with. Further, it is observed that attempts have been made for relative and logical assessment of manufacturing flexibility of a system. The present study is aimed at quantification of manufacturing flexibility of production systems. Manufacturing flexibility 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 of measurement of flexibility with three numbers of setups, each producing same three numbers of parts through three alternate routes.

### *6.1 Description of the parts*

FMS has the capability to process 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 differentiations 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 Fig.1,Fig.2 and Fig.3 respectively)are shown in Table1, Table 2 and Table 3 respectively.

### *6.2 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-1 consists of two numbers of lathes, namely lathe-1($M_1$) and lathe-2 ($M_3$) and two numbers of machining centers, machining center-1 ($M_2$) and machining center-2 ($M_4$). In setup-2, a CNC drilling machine replaces the machining center-2 of setup-1 as machine $M_{4.}$ Rest of the machines in the setup is unaltered. In setup-3, another CNC drilling machine replaces the machining center-1 of setup-2 as machine $M_2$. Rest of the machines in the setup remain same as in setup-2.

Alternate routes have been considered in the setups for all the three parts with machine breakdown and availability fully captured. The three different alternate routes via which the parts are manufactured in setup-1 are:

$R_1 = M_1 \rightarrow M_2 \rightarrow M_3 \rightarrow M_4$,
$R_2 = M_3 \rightarrow M_4 \rightarrow M_{2,}$ and
$R_3 = M_1 \rightarrow M_4 \rightarrow M_3 \rightarrow M_4$.

Table 1 Processing Operations for Part - 1

| Sl. No. | Operation | Tool used |
|---|---|---|
| 1 | Facing of face 1 ($F_{11}$) | Facing tool |
| 2 | Turning of $\varphi$ 75 ($T_{11}$) | Turning tool |
| 3 | Drilling of $\varphi$ 2.5 ($D_{11}$) | Drills |
| 4 | Step boring of $\varphi$ 60 and $\varphi$ 20 ($B_{11}$) | Boring tool |
| 5 | Facing of face 2 ($F_{12}$) | Facing tool |
| 6 | Turning of $\varphi$ 25 ($T_{12}$) | Turning tool |
| 7 | Thread cutting M30×2.5 ($TH_{11}$) | Threading tool |
| 8 | Drill $\varphi$ 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 $\varphi$ 114 ($T_{21}$) | Turning tool |
| 3 | Drilling of $\varphi$ 7, 4 nos. ($D_{21}$) | Drills |
| 4 | Step boring of $\varphi$ 76, $\varphi$ 60 & $\varphi$ 32 ($B_{21}$) | Boring tool |
| 5 | Facing of face 2 ($F_{22}$) | Facing tool |
| 6 | Turning of $\varphi$ 72 ($T_{22}$) | Turning tool |
| 7 | Drill $\varphi$ 5, 2 nos. ($D_{22}$) | Drills |
| 8 | Thread cutting M30×5, 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 $\varphi$ 100 ($T_{31}$) | Turning tool |
| 3 | Drilling of $\varphi$ 7, 4 nos. ($D_{31}$) | Drills |
| 4 | Drilling of $\varphi$ 5, 4 nos. ($D_{32}$) | Drills |
| 5 | Thread cutting M30×5, 4 nos. ($TH_{31}$) | Threading tool |
| 6 | Facing of face 2 ($F_{32}$) | Facing tool |
| 7 | Turning of $\varphi$ 60 ($T_{32}$) | Turning tool |
| 8 | Drilling of $\varphi$ 2.5, ($D_{33}$) | Drills |
| 9 | Thread cutting M30×2.5 ($TH_{32}$) | Threading tool |

Fig. 1 Graphical model of part 1

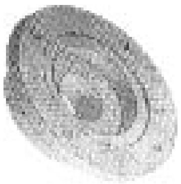

Fig. 2 Graphical model of part 2

Fig. 3 Graphical model of part 3

The operations performed at all the machines via different routes, for each part in setup-1 are given in Table 4.

Table 4 Machines on Routes of Setup-1

| | |
|---|---|
| Part 1 | Route 1: $M_1 (F_{11},T_{11}) \rightarrow M_2 (D_{11},B_{11}) \rightarrow M_3 (F_{12},T_{12}) \rightarrow M_4 (D_{12},TH_{11})$<br>Route 2:$M_3 (F_{11},T_{11}) \rightarrow M_4 (D_{11},B_{11}) \rightarrow M_2 (F_{12},T_{12},D_{12}) \rightarrow M_3 (TH_{11})$<br>Route 3: $M_1 (F_{11},T_{11}) \rightarrow M_4 (D_{11},B_{11}) \rightarrow M_3 (F_{12},T_{12}) \rightarrow M_4 (D_{12},TH_{11})$ |
| Part 2 | Route 1: $M_1 (F_{21},T_{21}) \rightarrow M_2 (D_{21},B_{21}) \rightarrow M_3 (F_{22},T_{22}) \rightarrow M_4 (D_{22},TH_{21})$<br>Route 2:$M_3 (F_{21},T_{21}) \rightarrow M_4 (D_{21},B_{21}) \rightarrow M_2 (F_{22},T_{22},D_{22}) \rightarrow M_3 (TH_{21})$<br>Route 3: $M_1 (F_{21},T_{21}) \rightarrow M_4 (D_{21},B_{21}) \rightarrow M_3 (F_{22},T_{22}) \rightarrow M_4 (D_{22},TH_{21})$ |
| Part 3 | Route 1:$M_1 (F_{31},T_{31}) \rightarrow M_2 (D_{31},D_{32},TH_{31}) \rightarrow M_3 (F_{32},T_{32}) \rightarrow M_4 (D_{33}, TH_{32})$<br>Route 2: $M_3 (F_{31},T_{31}) \rightarrow M_4 (D_{31},D_{32},TH_{31}) \rightarrow M_2 (F_{32},T_{32},D_{33}) \rightarrow M_3 (TH_{32})$<br>Route 3: $M_1 (F_{31},T_{31}) \rightarrow M_4 (D_{31},D_{32},TH_{31}) \rightarrow M_3 (F_{32},T_{32}) \rightarrow M_4 (D_{33}, TH_{32})$ |

The routes for setup-2 are: $R_1= M_1 \rightarrow M_2 \rightarrow M_3 \rightarrow M_4$, $R_2= M_3 \rightarrow M_4 \rightarrow M_2 \rightarrow M_3$ and $R_3= M_1 \rightarrow M_4 \rightarrow M_3 \rightarrow M_4$. The operations performed, at all the machines via different routes, for each part in setup-2 are given in Table 5.

Table 5 Machines on Routes of Setup-2

| | |
|---|---|
| Part 1 | Route 1: $M_1$ ($F_{11}$,$T_{11}$) → $M_2$ ($D_{11}$,$B_{11}$) → $M_3$ ($F_{12}$,$T_{12}$, $TH_{11}$) → $M_4$ ($D_{12}$)<br>Route 2: $M_3$ ($F_{11}$,$T_{11}$) → $M_4$ ($D_{11}$,$B_{11}$) → $M_2$ ($F_{12}$,$T_{12}$,$D_{12}$) → $M_3$ ($TH_{11}$)<br>Route 3: $M_1$ ($F_{11}$,$T_{11}$) → $M_2$ ($D_{11}$,$B_{11}$) → $M_3$ ($F_{12}$,$T_{12}$) → $M_2$ ($D_{12}$,$TH_{11}$) |
| Part 2 | Route 1: $M_1$ ($F_{21}$,$T_{21}$) → $M_2$ ($D_{22}$,$B_{21}$) → $M_3$ ($F_{22}$,$T_{22}$, $TH_{21}$) → $M_4$ ($D_{21}$)<br>Route 2:$M_3$ ($F_{21}$,$T_{21}$) → $M_4$ ($D_{21}$,$B_{21}$) → $M_2$ ($F_{22}$,$T_{22}$,$D_{22}$) → $M_3$ ($TH_{21}$)<br>Route 3: $M_1$ ($F_{21}$,$T_{21}$) → $M_2$ ($D_{21}$,$B_{21}$) → $M_3$ ($F_{22}$,$T_{22}$) → $M_2$ ($D_{22}$,$TH_{21}$) |
| Part 3 | Route 1: $M_1$ ($F_{31}$,$T_{31}$) → $M_2$ ($D_{32}$,$D_{33}$, $TH_{31}$, $TH_{32}$) → $M_3$ ($F_{32}$,$T_{32}$) → $M_4$ ($D_{31}$)<br>Route 2: $M_3$ ($F_{31}$,$T_{31}$) → $M_4$ ($D_{31}$,$D_{32}$, $D_{33}$) → $M_2$ ($F_{32}$,$T_{32}$) → $M_3$ ($TH_{31}$,$TH_{32}$)<br>Route 3: $M_1$ ($F_{31}$,$T_{31}$) → $M_2$ ($D_{31}$,$D_{32}$,$TH_{31}$) → $M_3$ ($F_{32}$,$T_{32}$) → $M_2$ ($D_{33}$, $TH_{32}$) |

The routes for setup-3 are: $R_1= M_1 \rightarrow M_2 \rightarrow M_3 \rightarrow M_4$, $R_2= M_3 \rightarrow M_4 \rightarrow M_2 \rightarrow M_3$ and $R_3= M_1 \rightarrow M_2 \rightarrow M_3 \rightarrow M_2$. The operations performed, at all the machines via different routes, for each part in setup-3 are given in Table 6.

Table 6 Machines on Routes of Setup-3

| | |
|---|---|
| Part 1 | Route 1: $M_1$ ($F_{11}$,$T_{11}$) → $M_2$ ($D_{11}$,$B_{11}$) → $M_3$ ($F_{12}$,$T_{12}$, $TH_{11}$) → $M_4$ ($D_{12}$)<br>Route 2: $M_3$ ($F_{11}$,$T_{11}$) → $M_4$ ($D_{11}$,$B_{11}$) → $M_2$ ($D_{12}$) → $M_3$ ($F_{12}$,$T_{12}$,$TH_{11}$)<br>Route 3: $M_1$ ($F_{11}$,$T_{11}$) → $M_2$ ($D_{11}$,$B_{11}$) → $M_3$ ($F_{12}$,$T_{12}$,$TH_{11}$) → $M_2$ ($D_{12}$) |
| Part 2 | Route 1: $M_1$ ($F_{21}$,$T_{21}$) → $M_2$ ($D_{22}$,$B_{21}$) → $M_3$ ($F_{22}$,$T_{22}$, $TH_{21}$) → $M_4$ ($D_{21}$)<br>Route 2: $M_3$ ($F_{21}$,$T_{21}$) → $M_4$ ($D_{21}$, $D_{22}$) → $M_2$ ($B_{21}$)→ $M_3$ ($F_{22}$,$T_{22}$, $TH_{21}$)<br>Route 3: $M_1$ ($F_{21}$,$T_{21}$) → $M_2$ ($D_{22}$,$B_{21}$) →$M_3$ ($F_{22}$,$T_{22}$,$TH_{21}$) → $M_2$ ($D_{21}$) |
| Part 3 | Route 1: $M_1$ ($F_{31}$,$T_{31}$) → $M_2$ ($D_{32}$,$D_{33}$) →$M_3$ ($F_{32}$,$T_{32}$,$TH_{31}$, $TH_{32}$) → $M_4$ ($D_{31}$)<br>Route 2: $M_3$ ($F_{31}$,$T_{31}$,$F_{32}$,$T_{32}$) → $M_4$ ($D_{31}$,$D_{32}$) → $M_2$ ($D_{33}$) → $M_3$ ($TH_{31}$,$TH_{32}$)<br>Route 3: $M_1$ ($F_{31}$,$T_{31}$) → $M_2$ ($D_{32}$,$D_{33}$) → $M_3$ ($F_{32}$,$T_{32}$,$TH_{31}$,$TH_{32}$) → $M_2$ ($D_{31}$) |

### 6.3 Simulation of the setups

The setups have been modeled in QUEST ver. 4.0 for analyzing the manufacturing process visually and obtain useful data for further analysis. QUEST is a 3D graphics based Queuing Event Simulation Tool, for performing graphical simulation of the complete setup. The production scenarios, product mixes and failure responses for machine and labour utilization, 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 behavior of a manufacturing process and comparing the same with one another. QUEST facilitates the modeling of individual processing elements. The three setups under study are modeled using QUEST to study the operation of the entire setup, 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 photographic view of the QUEST model is presented in Fig. 4.

However, the individual machining times are obtained from modeling the machines and performing virtual operations in VNC ver. 5.0. VNC is an 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 center 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 down time 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 operations (such as $F_{11}$, $T_{11}$, $F_{22}$, $T_{22}$, $D_{11}$, $D_{12}$…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. Since the detailed simulation of these operations cannot be performed in QUEST, the modeling and simulation of these operations are done using another simulation tool IGRIP ver. 5.0. IGRIP is an interactive 3D graphics simulation tool for designing, evaluation and off-line programming of robotic work cells. In IGRIP, robotic mechanism can be constructed and analyzed for cycle time, motion planning, collisions, near miss detection, I/O communication and motion constraints. This saves invaluable operator time and boosts productivity by eliminating unnecessary data manipulation. The loading/unloading and part orienting times so determined for different parts on different machines are used in the simulation of the setup in QUEST. However, the material transporting time through conveying elements are directly obtained in QUEST.

Table 7 Machining Time for different Operation

| Machines → |  | 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 |
|  | $TH_{11}$ | × | 080 | 055 | 060 | × | × |
| Part 2 | $F_{21}$ | 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 |
|  | $D_{22}$ | × | × | 075 | 080 | 070 | 090 |
|  | $TH_{21}$ | × | 150 | 110 | 120 | × | × |
| Part 3 | $F_{31}$ | 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 | × | × |

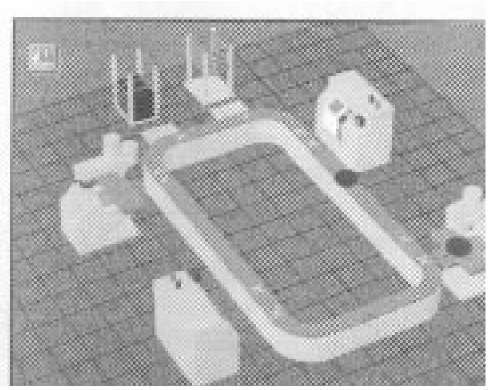

Fig. 4 Photograph of QUEST model for setup-1 (route-1)

$L_1$: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.

*6.4 GA formulation*

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 cost function of the genetic optimization process. The constraints between the machines in the setups and also the constraints lying within individual machine for the processing operations as presented in Table 8 are considered for the processing of the parts. These are termed as inter-machine restrictions and intra-machine restrictions.[7,8,9] 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 inter-machine restriction and the later is an example of intra-machine restriction. The inter-machine 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 inter-machine restrictions and intra-machine restrictions for setup-1, setup-2 and setup-3 are prepared respectively. 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 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 assumed to be same for all the machines.

## 7. Results of the GA model

The proposed approach was coded in MATLAB. The algorithm ran with control parameters obtained from the graphical simulation in QUEST. The proper values of these parameters were determined in a pre-processing phase. The performance of the algorithm was tested over the FMS scheduling benchmarks generated by Taillard [10]. Due to the stochastic behavior of the algorithm, and the fact that it dos not have a natural termination point, it was decided to run the algorithms for a 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 as obtained from the GA runoff programs for setup-1, setup-2, setup-3 respectively and results to be presented in the Table 9, Table 10 and Table 11. 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 due to the fact that the rule base takes care of the operation sequence. The GA optimization technique depends on the size operational requirement and complexity of the part.

Table 8 Machining Constraints for various Machines in Setup-1

| Machine | Operations | Intra-machine | Inter-machine |
|---|---|---|---|
| $M_1$ | F11,T11,<br>F12,T12,<br>TH11 | M1(1)=1,M1(3),M1(4)=0,M1(5)=0<br>M1(2)=1,M1(3)=0,M1(4)=0,M1(5)=0<br>M1(3)=1,M1(1)=0,M1(2)=0<br>M1(4)=1,M(1)=0,M1(2)=0<br>M1(5)=1,M1(1)=0,M1(2)=0 | M1(1)=1,M2(1)=0,M3(1)=0,M4(0)=0,<br>M1(2)=1,M2(2)=0,M3(2)=0,M4(2)=0,<br>M1(3)=1,M2(3)=0,M3(3)=0,M4(3)=0<br>M1(4)=1,M2(4)=0,M3(4)=0,M4(4)=0<br>M1 (5)=1,M2(8)=0,M3(5) =0,M4(8)=0 |
| $M_2$ | F11,T11,<br>F12,T12,<br>D11,B11,<br>D12,TH11 | M2(1)=1,M2(3)=0,M2(4)=1,M2(5)=0,M2(8)=0<br>M2(2)=1,M2(3)=0,M2(4)=1,M2(5)=0, M2(8)=0<br>M2(3)=1,M2(1)=0,M2(2)=1,M2(6)=0,M2(7)=0<br>M2(4)=1,M2(1)=0,M2(2)=1,M2(6)=0,M2(7)=0<br>M2(5)=1,M2(1)=0,M2(2)=1,M2(6)=0,M2(7)=0<br>M2(6)=1,M2(3)=0,M2(4)=1,M2(5)=0,M2(8)=0<br>M2(7)=1,M2(3)=0,M2(4)=1,M2(5)=0,M2(8)=0 | M2(1)=1,M1(1)=0,M3(1)=1,M4(1)=0<br>M2(2)=1,M1(2)=0,M3(2)=1,M4(2)=0<br>M2(3)=1,M1(3)=0,M3(3)=1,M4(3)=0<br>M3(4)=1,M4(4)=0,M2(5)=1,M4(5)=0<br>M2(6)=1,M4(6)=0,M2(7)=1,M4(7)=0<br>M2(8)=1,M1(5)=0,M3(5)=1,M4(8)=0 |
| $M_3$ | F11,T11,<br>F12,T12,<br>TH11 | M3(1)=0,M3(3)=0,M3(4)=0,M3(5) =0<br>M3(2)=1,M3(3)=0,M3(4)=0,M3(5)=0<br>M3(3)=1,M3(1)=0,M3(2)=0<br>M3(4)=1,M3(1)=0,M3(2)=0<br>M3(5)=1,M3(1)=0,M3(2)=0 | M3(1)=1,M1(1)=0,M2(1)=0, M4(1)=0<br>M3(2)=1,M1(2)=0,M2(2)=0,M4(2)=0<br>M3(3)=1,M1(3)=0,M2(3)=0,M4(3)=0<br>M3(4)=1,M1 (4)=0,M2(4)=0,M4(4)=0<br>M3(5)=1,M1(5)=0,M2(8)=0, M4(8)=0 |
| $M_4$ | F11,T11,<br>F12,T12,<br>D11,B11,<br>D12,TH11 | M4(1)=1,M4(3)=0,M4(4)=1,M4(5)=0,M2(8)=0<br>M4(2)=1,M4(3)=0,M4(4)=1,M4(5)=0,M4(8)=0<br>M4(3)=1,M4(1)=0,M4(2)=1,M4(6)=0,M4(7)=0<br>M4(4)=1,M4(1)=0,M4(2)=1,M4(6)=0,M4(7)=0<br>M4(5)=1,M4(1)=0,M4(2)=1,M4(6)=0,M4(7)=0<br>M4(6)=1,M4(3)=0,M4(4)=1,M4(5)=0, M4(8)=0<br>M4(7)=1,M4(3)=0,M4(4)=1,M4(5)=0,M4(8)=0<br>M4(8)=1,M4(1)=0,M4(2)=1,M4(6)=0,M4(7)=0 | M4(1)=1,M1(1)=0,M2(4)=1,M3(5)=0,M4(8)=0<br>M4(2)=1,M1(2)=0,M2(4)=1,M3(5)=0,M4(8)=0<br>M4(3)=1,M1(3)=0 M2(2)=1,M3(6)=0,M4(7)=0<br>M4(4)=1,M1(4)=0 M2(2)=1,M3(6)=0, M4(7)=0<br>M4(5)=1,M2(5)=0<br>M4(6)=1,M2(6)=0<br>M4(7)=1,M2(7)=0<br>M4(8)=1,M1(5)=0 ,M2(8)=0, M3(5)=0 |

## 8. Conclusion

Throughout the previous works Numerous GA approaches to production scheduling are reported by large no. of authors. The approaches differ strongly from each other with respect to the coding, encoding, operations used, the constraints handled and the goals pursued. Despite these differences all approaches have in common that the domain knowledge is required in order to produce competitive schedules. The present approach is aimed towards finding out the global optima in the search space with some restrictions. The results obtained here can be claimed to be the optimal one. The potential of GA for minimizing the makespan in an FMS was explored in this paper. In conclusion, the GA with features from both global and local search techniques, results to a robust optimization tool capable of producing high quality solutions for the FMS scheduling. Future work will examine the performance of the hybrid Simulated Annealing Algorithm on other harder scheduling problems such as the job shop and the open shop scheduling problems. This is a relatively unexplored area of research based on a simple principle: the systematic change of neighborhood within the search.

Table 9. Operation Assignment and processing time at machines in setup-1

| **Machines** | **M1** | **M2** | **M3** | **M4** |
|---|---|---|---|---|
| Operation assigned | F12, T12 | B11, D12 | F11, T11 | D11, TH11 |
| Machining time(Secs) | 42 | 170 | 95 | 180 |
| % of Machine Utilization | 8.6% | 34.9% | 19.5% | 37% |
| Total Machining Time:487 Seconds | | | | |

Table 10. Operation Assignment and processing time at machines in setup-2

| **Machines** | **M1** | **M2** | **M3** | **M4** |
|---|---|---|---|---|
| Operation assigned | F11, T11 | D11, TH11 | F12, T12 | B11, D12 |
| Machining time(Secs) | 80 | 155 | 53 | 157 |
| % of Machine Utilization | 18% | 34.8% | 12% | 35.2% |
| Total Machining Time:445 Seconds | | | | |

Table 11. Operation Assignment and processing time at machines in setup-3

| **Machines** | **M1** | **M2** | **M3** | **M4** |
|---|---|---|---|---|
| Operation assigned | F11, T11 | F12,D11, TH11 | T12 | B11, D12 |
| Machining time(Secs) | 80 | 175 | 45 | 157 |
| % of Machine Utilization | 17.5% | 38.3% | 9.8% | 34.4% |
| Total Machining Time:457 Seconds | | | | |

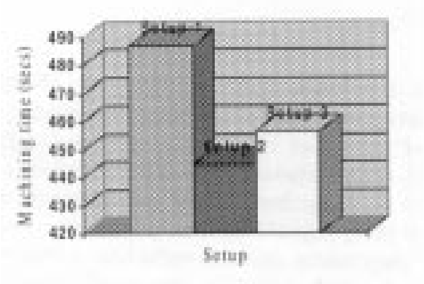

Fig. 5 Optimal machining time for various setups

Moreover, the case of multi-objective optimization will be investigated. Particularly, the research will be focused on scheduling optimization with the aim of simultaneously minimizing objectives like makespan, total flow time, total tardiness, machine utilization, idle time, sum of set-up times, etc. The appropriate combination of these criteria into a single objective function is a difficult task and will constitute a significant subject of future research.

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