# MANUFACTURING INDUSTRY JOB SHOP FLOOR DECISIONS THROUGH HYBRID GENETIC ALGORITHM

Dr. Nageswara Rao.M[1*], K B L N Srinivas[2], Sai Rakesh. N[3], Jagadeesh.V [4]

[1] *Department of Mechanical Engineering, KLEF, Vaddeswaram, Guntur, AP, India*

[2,3,4] *Final Year Students Department of Mechanical Engineering, KLEF, Vaddeswaram, Guntur, AP, India*

**Abstract: This article addresses flexible manufacturing system (FMS) Performance is likely to improve with employment of various resources efficiently. Initially simultaneous scheduling problems are solved by means of priority rules like first come first serve (FCFS), shortest processing time (SPT) and longest processing time (LPT) to find out the operational completion time for 120 problems. Later gene rearrangement genetic algorithm (HGA) is implemented for same set of problems with makespan as objective and the results are compared with the results of priority rules. The results are performed well by using HGA. The same HGA is used to find the finest optimal sequence that minimize the operational completion time.**

**Keywords: FMS, gene rearrangement, makespan, AGVs, Priority rules, Vehicle Scheduling.**

## Introduction

The sequencing and scheduling problem has been solved using priority rules over the last five decades. These priority rules are used to determine the sequence of each job. The sequence of a job is determined as a function of machine parameters. When the priority of each job is determined, jobs are sorted and then the job with the highest priority is selected to be processed first. Several priority rules have been reported by many researchers in this work FCFS, SPT and LPT rules are modified to solve simultaneous scheduling problems Initial Scheduler is required to solve FMS scheduling problems with meta-heuristic techniques such as HGA. These schedulers usually from priority rule algorithms, which have been combined with meta-heuristic algorithms to schedule the machine and AGVs effectively. However, there is no comparison study that investigates and ranks the performance of these priority rule algorithms. We feel that a comparison study would enable users to choose the priority rule algorithm best suited for their meta-heuristic scheduling techniques. Using performance metrics, we compared different algorithms that would assist users to decide which algorithms are suitable for their scheduling problems.

## Literature Survey

Priority sales are used to decide which job will be processed next at work center, where several jobs are waiting to be processed. The jobs waiting for processing are sequenced using one of many priority sequencing rules. It is assumed that the work center can process only one job at a time. A large number of sequencing rules are used in research and in practice to sequence the jobs waiting for processing at a work center [1]. Later Heuristic optimization algorithms (heuristics) seek good feasible solutions to optimization problems in circumstances where the complexity of the problem or the limited time available for its solution does not allow exact solution [2]. Further to increase the chance of getting Global optimal solution with considering population size through meta- heuristic algorithm likes Genetic Algorithm. The work can also be extended by increasing the size of the population through Meta-heuristic Algorithms. Scheduling of an FMS is a complex problem to solve and hence it has created interest among the researchers [3]. Even though FMS scheduling problem are considered earlier, scheduling of material handling system was not considered [4]. Among those who determined on material handling system, only few considered simultaneous scheduling of machines and AGVs [5]. A carefully designed and managed material handling system is important to achieve the required integration of FMS [6]. Hence there is a need for scheduling both the machines and material handling system simultaneously for the successful implementation of an FMS, which makes the scheduling of FMS [7]. There is a limited research in simultaneous scheduling problems. Metaheuristic Algorithms are well received by the research community, because of their capability to tackle more complex problems [8]. In this paper, different Priority Rules such as the First Come First Serve (FCFS), Shortest Processing Time (SPT) and Longest Processing Time (LPT) are used to implement simultaneous scheduling problems [9]. Also gene rearrangement genetic algorithm is also used to implement simultaneous scheduling problems [10]. The suitability of these algorithms for solving the simultaneous scheduling problems in FMS is evaluated by considering 120 bench mark problems [11]. Therefore in this work it is aimed to scheduling both the machines and vehicles in FMS environment simultaneously [12], by simulating three priority rules and one meta-heuristic algorithm.

## 1. Scheduling Problem

Simultaneous scheduling problems in FMS with four layout configurations as shown in Fig.1 and ten job sets are used [13-33]. The AGV travel times and the machine allocation and operation times for the jobs are given in Appendix A

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

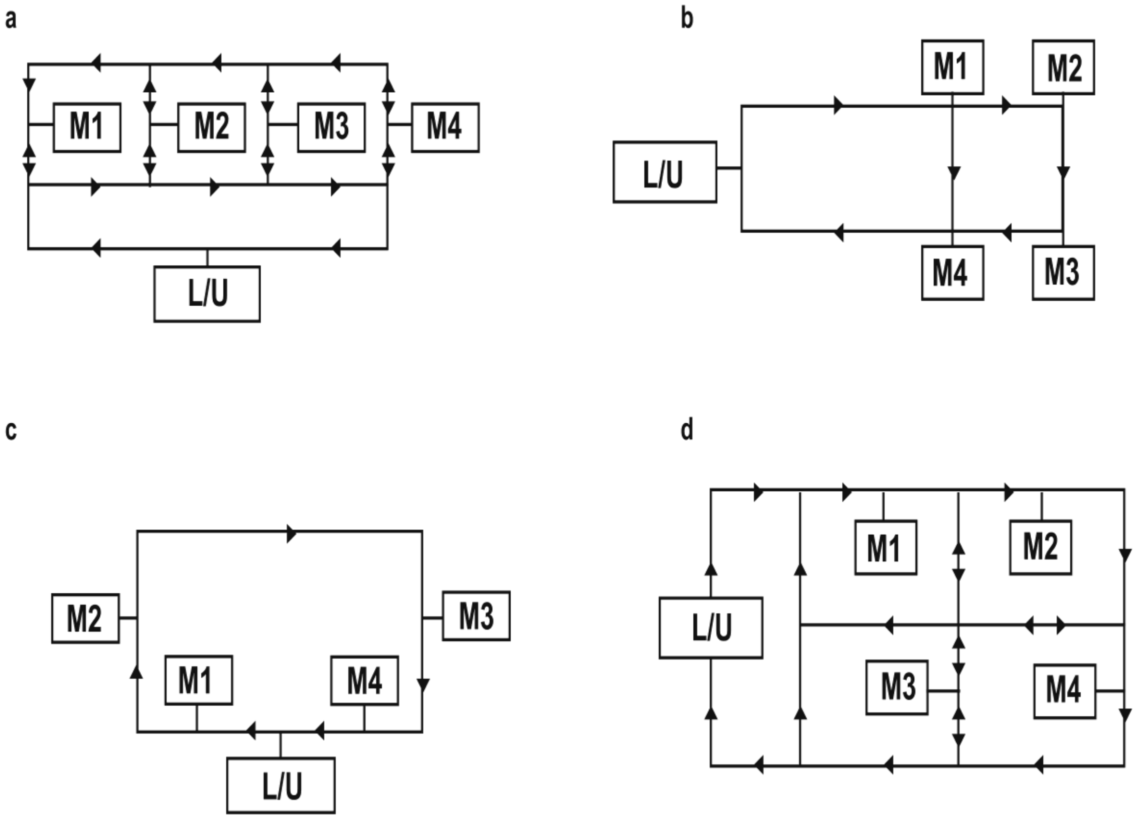

Fig: 1 Layout configurations used for examples

## 2. Simultaneous Scheduling of machines and AGVs in FMS

Jobs are scheduled based on the operation sequence derived by the algorithms. The problem considered needs scheduling of material handling system along with that of machines. In this work FCFS, SPT, LPT and HGA are modified to solve simultaneous scheduling problems which are discussed below

### 4.1. First Come First Serve

The steps involved in FCFS are given below:

Step 1: To consider the job set

Step 2: Adding job$_i$ in the main queue

### 4.2. Shortest Processing Time

The steps involved in SPT are given below:

Step 1: To consider the job set

Step 2: To find out each job total processing times

Step 3: According to processing times to arrange the jobs in ascending order

Step 4: According to job order sequence to perform the operations in the queue.

### 4.3. Longest Processing Time

The steps involved in LPT are given below:

Step 1: To consider the job set

Step 2: To find out each job total processing times

Step 3: According to processing times to arrange the jobs in descending order

Step 4: According to job order sequence to performs the operations in the queue.

### 4.4. Hybrid Genetic Algorithm

The steps involved in HGA are given below:

Step 1: Genetic representation

Step 2: Initial Population

Step 3: Evaluation Function

Step 4: Reproduction selection Scheme

Step 5: Genetic Operators

Step 6: Receptor Editing (Gene Rearrangement) Scheme for creating new generation

Step 7: Termination criterion

Step 8: Genetic Algorithm parametric setting

The implementation of the above rules is explained in the following articles.

## 5. Implementation of Priority rules and HGA

Developed priority rules to solve NP-hard problems arise in the scheduling problems. The proposed priority rules and HGA are implemented to the scheduling problems presented in Appendix- A. the details of which are presented here below.

### 5.1. Simultaneous Scheduling - First Come First Serve

For implementation of FCFS, Job set 1 and Layout 1 are considered as an example with travel time halved and process time triple. FCFS computes the add job ‘i’ initially in the main queue for different jobs and the sequences are obtained based on the main queue.

The FCFS is explained in the following steps for the job set 1:

Step 1: Considering the job set

| Job Set No | Layout | No of Jobs | No of operations | Sequence of Machines |
|---|---|---|---|---|
| 1 | 1 | 5 | 13 | Job 1: M1-M2-M4<br>Job 2: M1-M3-M2<br>Job 3: M3-M4-M1<br>Job 4: M4-M2<br>Job 5: M3-M1 |

Step 2: Adding job 'i' initially in the main queue

1 – 2 - 3 - 4- 5 -6 -7 – 8 – 9 – 10 -11-12 -13

Step 3: Considering the machine number (M.No) of the given sequence for the job as explained in section 3.3.

1-2- 4- 1- 3 - 2- 3- 4- 1 - 4 - 2- 3- 1

Step 4: The AGV '1' is selected

Step 5: The vehicle's previous location (VPL) is identified

For example considering first operation VPL=L/U

Step 6: The previous operation machine number (POMN) is identified as

POMN=L/U

Step 7: The vehicle ready time (VRT) is identified as VRT=0

Step 8: The previous operation completion time (POCT) is found to be '0'

Step 9: Vehicle empty trip time (VET) is calculated with

VET = VRT + TRT1=0+0=0

Where TRT1 = VPL to POMN= L/U to L/U= 0

Step 10: The maximum vehicle empty travel time is found from

Max (VET) = Maximum (POCT and VET)= Max(0,0)=0

Step 11: The total travel time of vehicle (TT) is evaluated from

TT=VET+ Time taken from previous machine to latest machine.

= 0 + L/U to M1 (from travel time data for layout '1')

= 0 + 3(half of the travel time) = 3

Step 12: Found machine ready time (MRT) from

MRT = Time until the job is completed on the assigned job operation = 0

Step 13: Identified the maximum of TT and MRT from

Maximum travel time of AGV = Maximum (TT, MRT)

= Max (3, 0) = 3

Step 14: The maximum travel time is added to the process time to get the operational completion time (OCT) or makespan.

OCT = Maximum TT+ Process Time = 3 + 24(Process time Tripled) = 27

Step 15: Repeated the steps from 4 to 14 for all other operations.

Step 16: Identified the maximum operational completion time. It represents the possible completion time (makespan) of given job set.

The calculated values of various parameters for all operations are shown in table 1

Table 1: Completion time through FCFS (for Problem set 1 and layout-1)

| **Operation Number** | **Machine Number** | **Vehicle Number** | **Travel Time** | **Job Ready** | **Job Reach** | **Process Time** | **Make Span** |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 3 | 3 | 24 | 27 |
| 2 | 2 | 2 | 27 | 30 | 30 | 48 | 78 |
| 3 | 4 | 1 | 78 | 82 | 82 | 36 | 118 |
| 4 | 1 | 2 | 35 | 38 | 38 | 60 | 98 |
| 5 | 3 | 2 | 98 | 102 | 102 | 30 | 132 |
| 6 | 2 | 1 | 132 | 135 | 135 | 54 | 189 |
| 7 | 3 | 2 | 106 | 111 | 132 | 36 | 168 |

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | 4 | 2 | 168 | 171 | 171 | 24 | 195 |
| 9 | 1 | 1 | 195 | 200 | 200 | 45 | 245 |
| 10 | 4 | 2 | 174 | 180 | 195 | 42 | 237 |
| 11 | 2 | 2 | 237 | 241 | 241 | 54 | 295 |
| 12 | 3 | 1 | 206 | 211 | 211 | 30 | 241 |
| 13 | 1 | 1 | 241 | 245 | 245 | 45 | 290 |

Table 1 shows operation scheduling of through FCFS rule for job set 1 layout 1 is shown. From the vehicle heuristic algorithm for first two operations AGVs are selected sequentially in case of third operation AGV '1' is selected basing on the availability of AGV with minimum travel time this constraint will be taking care in the algorithm. For job set 1 and layout 1 the operational completion time (makespan) is 290

### 5.2. Simultaneous Scheduling - Shortest Processing Time

For implementation of SPT rule, Job set 1 and Layout 1 are considered as an example. SPT rule computes the process times for different jobs and the sequences are obtained based on the process time arranged in the ascending order.

The SPT is explained in the following steps for the job set 1:

Step 1: Considering the job set same as section 5.1

Step 2: Each job total processing times are found

| Machine Number | Job 1 | Job 2 | Job 3 | Job 4 | Job 5 |
|---|---|---|---|---|---|
| M1 | 8 | 20 | 15 | 0 | 15 |
| M2 | 16 | 18 | 0 | 18 | 0 |
| M3 | 0 | 10 | 12 | 0 | 10 |
| M4 | 12 | 0 | 8 | 14 | 0 |
| Total Process Time | 36 | 38 | 35 | 32 | 25 |

Step 3: According to total processing times the jobs are arranged in ascending order

J5- J4- J1- J1- J2

Step 4: As per the job order sequence operations in the queue are performed

12- 13 - 10 - 11 –7 - 8 -9- 1- 2 – 3 – 4 – 5 – 6

Step 5: For identifying the maximum operational completion time of the above sequence, the steps discussed in 5.1 are executed. It represents the possible completion time of given job set

12- 13 - 10 - 11 –7 - 8 -9- 1- 2 – 3 – 4 – 5 – 6---Makespan-349

### 5.3. Simultaneous Scheduling - Longest Processing Time

For implementation of LPT rule, Job set 1 and Layout 1 are considered as an example. LPT rule computes the process times for different jobs and the sequences are obtained based on the process time arranged in the descending order.

The LPT is explained in the following steps for the job set 1:

Step 1: Considering the job set same as section 5.1

Step 2: Each job total processing times are found

| Machine Number | Job 1 | Job 2 | Job 3 | Job 4 | Job 5 |
|---|---|---|---|---|---|
| M1 | 8 | 20 | 15 | 0 | 15 |
| M2 | 16 | 18 | 0 | 18 | 0 |
| M3 | 0 | 10 | 12 | 0 | 10 |
| M4 | 12 | 0 | 8 | 14 | 0 |
| Total Process Time | 36 | 38 | 35 | 32 | 25 |

Step 3: According to total processing times the jobs are arranged in descending order

J2- J1- J4- J3- J5

Step 4: As per the job order sequence operations in the queue are performed

4 – 5 - 6 – 1- 2 – 3 - 7 – 8 – 9- 10- 11-12 - 13

Step 5: For identifying the maximum operational completion time of the above sequence, the steps discussed in 5.1 are executed. It represents the possible completion time of given job set.

4 – 5 - 6 – 1- 2 – 3 - 7 – 8 – 9- 10- 11- 12 - 13- makespan - 361

### 5.4. Simultaneous Scheduling – Hybrid Genetic Algorithm

For implementation of HGA, Job set 1 and Layout 1 are considered as an example. HGA computes the process times for different jobs and the sequences are obtained based on the random manner.

The HGA is explained in the following steps for the job set 1:

**Genetic Representation**

Permutation representation is used in this paper, i.e. a list of jobs is itself taken as a chromosome. For example, if in a flow shop scenario there are 5 jobs {1-2-3-4-5}, one chromosome according to permutation representation can be {1-2-3-4-5}, while another could be {4-5-3-1-2}. Genetic representation must be as per precedence rule (i.e., operation 2 of job 1 cannot be done unless operation 1 has finished and so on) could be given below.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-1 | 1-2 | 1-3 | 2-1 | 2-2 | 2-3 | 3-1 | 3-2 | 3-3 | 4-1 | 4-2 | 5-1 | 5-2 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

Or

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-1 | 3-1 | 2-1 | 5-1 | 4-1 | 3-2 | 4-2 | 5-2 | 2-2 | 1-2 | 2-3 | 3-3 | 1-3 |
| 1 | 7 | 4 | 12 | 10 | 8 | 11 | 13 | 5 | 2 | 6 | 9 | 3 |

**Initial Population**

Double the number of operations is used in this paper, i.e. a list of jobs is itself taken as a operations. For example, if in a flow shop scenario there are 5 jobs with 13 operations it means 26 chromosomes as initial population (double the number of operations)

**Evaluation Function**

For implementation of REGA Algorithm, job set 1 and layout 1 are considered as an example. For the above job order operation sequence is

1-7-4-12-10-8-11-13-5-2-6-9-3

For identifying the maximum operational completion time of the above sequence, the steps discussed in 5.1 are executed. It represents the possible completion time of given job set.

1-7-4-12-10-8-11-13-5-2-6-9-3 – makespan -226

In similar way make span for all 26 sequences are calculate and identify the best sequences based on evaluation function for the reproduction selection scheme

**Reproduction Selection Scheme**

Receptor Editing Genetic Algorithm uses tournament selection procedure is used in this work, which picks randomly "Chromosomes and the winner (based on their fitness) among them is selected for next operation.

**Genetic Operators**

In order to alter the genetic alignment and to reproduce new chromosomes in every generation genetic operation like crossover and mutation are performed.

**Crossover operators**

The crossover operator is an important component of GA. The crossover operation generates offspring from randomly selected pairs of individuals within the mating pool, by exchanging segments of the chromosome strings from the parents. Different types of crossover operators are available in the literature and here in this work, single point crossover and two-point crossover are considered.

***i) Single point crossover:***

In single point crossover randomly a cut point is selected and one side of the genes of the cut point in the first parent is exchanged with the genes of second parent on the same side.

Chromosomes before single point crossover:

**7 1 4 12 10 8 11 13 5 2 6 9 3**

4 1 5 6 7 2 3 10 11 12 13 8 9

Chromosomes after single point crossover:

**7 1 4 12 10 8 11** 10 11 12 13 8 9

4 1 5 6 7 2 3 **13 5 2 6 9 3**

As it can be seen the off springs produced after crossover may violate the precedence constraints and also some genes may be missing whereas others are duplicated. In the present case operations 8, 10, 11 and 12 are duplicated whereas operations 2,3,5 and 6 are missing in offspring 1. The reverse is true in offspring 2 i.e., 2, 3, 5 and 6 are duplicated and 8, 10,11 and 12 are missing. To take care of these problems repair and replace functions are used. Repair function exchanges the genes to yield valid off-springs whereas replace function removes the duplicate genes and replaces them with missing genes.

Chromosomes after single point crossover replace and repair:

**7** 1 4 12 10 8 11 2 5 6 13 3 9

4 1 5 12 7 2 3 13 8 10 6 9 11

***ii) Two-point crossover:***

As the name indicates, in this case two cut points are selected randomly and the genes in between these cut points are exchanged.

Chromosomes before two-point crossover:

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

7 1 4 12 10 | 8 11 2 5 6 | 13 3 9

4 1 5 12 7 | 2 3 13 8 10 | 6 9 11

Similar to single point crossover here also the problems like violation of precedence constraints, duplication and missing of genes may a rise which needs repair and replace.

Chromosomes after two-point crossover, replace and repair

7 1 4 12 8 2 10 13 5 6 11 3 9

4 1 5 12 7 13 10 2 8 11 6 9 3

**Mutation operators**

For exploring the search space effectively, now mutation operation is performed on the selected chromosomes. Different mutation operators are available in the literature and among them random mutation, inverse mutation, adjacent mutation and shift mutation are used in this work and the performance of the GA for different mutations in combination with the above two crossover operators is studied.

**Random Mutation**

In this mutation two genes are randomly selected and their positions are exchanged. If necessary, chromosome is repaired.

Chromosome before random mutation:

7 1 4 12 8 2 10 13 5 6 11 3 9

Chromosome after random mutation:

7 1 4 12 8 5 10 13 2 6 11 3 9

**Adjacent Mutation**

In this case two genes which are adjacent to each other are exchanged.

Chromosome before adjacent mutation:

7 1 4 12 8 2 10 13 5 6 11 3 9

Chromosome after adjacent mutation:

7 1 4 12 8 10 2 13 5 6 11 3 9

**Inverse Mutation:**

Here a set of successive genes are selected and the entire set is reversed and if this leads to infeasible chromosome then it is repaired.

Chromosome before inverse mutation:

7 1 4 12 8 **2 10 13 5 6** 11 3 9

Chromosome after inverse mutation and before repair:

7 1 4 12 8 **6 5 13 10 2** 11 3 9

Chromosome after inverse mutation and after repair:

7 1 4 12 8 10 5 13 6 2 11 3 9

**Shift Mutation**

In this mutation a gene is selected randomly, and it is shifted to another randomly selected position and again if necessary, it is repaired.

Chromosome before shift mutation:

7 1 4 12 8 2 10 13 5 6 11 3 9

Chromosome after shift mutation:

7 1 4 12 8 2 3 10 13 5 6 11 9

Similar to crossover, here also there is a possibility of violation of precedence constraints after mutation operation which is taken care of again by the repair function.

**Receptor Editing Scheme for creating new generation:**

The editing of the chromosomes in the population after the cross over operation is known as receptor editing. In this process a number of worst makespan value chromosomes are eliminated (20 to 90%) from the population and randomly generated chromosomes are added in those places (20 to 90%). After editing the chromosomes in the population, the new population has gone to next iteration until termination criterion is reached. This concept is adopted from

**Termination**

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

The process of selection, crossover and mutation are repeated till the termination criterion is satisfied. A number of termination criteria are available in the literature like, repeating the procedure for number of generations, running the GA for a fixed duration of time, stopping the simulation when there is no improvement in fitness for the last "g" generations. In this work the number of generations is taken as the termination criterion, which is varied from 100 to 1000 generations and its effect on the performance of the algorithm is noted down.

**Genetic Algorithm parametric setting**

Genetic algorithm's evolutionary procedure has been implemented in JAVA language and simulated for various problem sets. Population size is taken as twice the chromosome length (total number of operations in the job set). The results are obtained after repeating the evolutionary procedure for 20 runs and the number of generations is varied from 100 to 1000.

Step 5: For identifying the maximum operational completion time of the above sequence, the steps discussed in 5.1 are executed. It represents the possible completion time of given job set.

7- 1- 12- 10- 4- 2- 11- 13- 8- 5- 9- 3- 6-makespan - 186

## 3. Computational Analysis

The FMS job shop scenario presented here has been taken from BILGE and ULUSOY [12]. The 120 test problems described are attempted here with the HGA. The results have been compared with priority rules. The digits that follow 10.1 indicate the job set and the layout and the layout another digit is appended to the code. Here, having a 0 or 1 as the last digit implies that the process times are doubled or tripled, respectively, where in both cases travel times are halved. For each of the run, the following parameters have been used: population size of double the number of operations, single point crossover at 40%, two point cross over at 20% and 60% Receptor Editing is 15% and stopping criteria of 1000 iterations. Table 2 consists of results for the four approaches mentioned above i.e. FCFS, SPT, LPT, and HGA for problems whose $t_{ij}/p_i$ ratios are higher than 0.25 (total of 40 problems). Table 3 and Table 4 shows results for the four approaches mentioned above i.e. FCFS, SPT, LPT, and HGA for problems whose $t_{ij}/p_i$ ratios are lower than 0.25 (total of 80 problems).

Table 2: Performance analysis (t/p>0.25)

| Job. No | t/p | FCFS | SPT | LPT | HGA |
|---|---|---|---|---|---|
| 1.1 | 0.59 | 173 | 193 | 177 | 96 |
| 2.1 | 0.61 | 158 | 158 | 177 | 113 |
| 3.1 | 0.59 | 202 | 224 | 198 | 120 |
| 4.1 | 0.91 | 263 | 267 | 264 | 116 |
| 5.1 | 0.85 | 148 | 164 | 148 | 89 |
| 6.1 | 0.78 | 231 | 240 | 227 | 140 |
| 7.1 | 0.78 | 195 | 210 | 201 | 133 |
| 8.1 | 0.58 | 261 | 261 | 266 | 185 |
| 9.1 | 0.61 | 270 | 277 | 268 | 116 |
| 10.1 | 0.55 | 308 | 308 | 310 | 167 |
| 1.2 | 0.47 | 143 | 173 | 165 | 82 |
| 2.2 | 0.49 | 124 | 124 | 130 | 86 |
| 3.2 | 0.47 | 162 | 188 | 160 | 98 |
| 4.2 | 0.73 | 217 | 223 | 224 | 90 |
| 5.2 | 0.68 | 118 | 144 | 131 | 73 |
| 6.2 | 0.54 | 180 | 169 | 165 | 110 |

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

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|---|---|---|---|---|---|
| 7.2 | 0.62 | 149 | 160 | 149 | 93 |
| 8.2 | 0.46 | 181 | 181 | 198 | 159 |
| 9.2 | 0.49 | 250 | 249 | 244 | 104 |
| 10.2 | 0.44 | 290 | 288 | 287 | 146 |
| 1.3 | 0.52 | 145 | 175 | 167 | 88 |
| 2.3 | 0.54 | 130 | 130 | 136 | 100 |
| 3.3 | 0.51 | 160 | 190 | 162 | 102 |
| 4.3 | 0.8 | 233 | 237 | 230 | 96 |
| 5.3 | 0.74 | 120 | 146 | 133 | 76 |
| 6.3 | 0.54 | 182 | 171 | 167 | 125 |
| 7.3 | 0.68 | 155 | 166 | 151 | 104 |
| 8.3 | 0.5 | 183 | 183 | 200 | 169 |
| 9.3 | 0.53 | 252 | 251 | 246 | 108 |
| 10.3 | 0.49 | 293 | 294 | 293 | 158 |
| 1.4 | 0.74 | 189 | 207 | 189 | 106 |
| 2.4 | 0.77 | 174 | 174 | 174 | 125 |
| 3.4 | 0.74 | 220 | 250 | 212 | 130 |
| 4.4 | 1.14 | 301 | 301 | 298 | 128 |
| 5.4 | 1.06 | 171 | 189 | 171 | 97 |
| 6.4 | 0.78 | 249 | 252 | 237 | 143 |
| 7.4 | 0.97 | 217 | 242 | 151 | 154 |
| 8.4 | 0.72 | 285 | 285 | 200 | 195 |
| 9.4 | 0.76 | 292 | 311 | 290 | 126 |
| 10.4 | 0.69 | 350 | 350 | 345 | 179 |

In the optimal sequence of machines and AGVs are determined by using FCFS, SPT, LPT and HGA for T/P>0.25 and shown in table no 2. From table 2, out of 40 problems 40 problems gives improved results using HGA in comparison with FCFS, SPT and LPT

Table 3: Performance analysis (t/p<0.25)

| Job.No | t/p | FCFS | SPT | LPT | HGA |
|---|---|---|---|---|---|
| 1.10 | 0.15 | 207 | 248 | 252 | 126 |

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

| | | | | | |
|---|---|---|---|---|---|
| 2.10 | 0.15 | 217 | 217 | 225 | 148 |
| 3.10 | 0.15 | 257 | 327 | 282 | 169 |
| 4.10 | 0.15 | 303 | 328 | 317 | 123 |
| 5.10 | 0.21 | 152 | 190 | 187 | 102 |
| 6.10 | 0.16 | 304 | 281 | 297 | 210 |
| 7.10 | 0.19 | 231 | 240 | 264 | 144 |
| 8.10 | 0.14 | 338 | 338 | 347 | 292 |
| 9.10 | 0.15 | 390 | 367 | 359 | 182 |
| 10.10 | 0.14 | 452 | 429 | 444 | 262 |
| 1.20 | 0.12 | 194 | 238 | 246 | 123 |
| 2.20 | 0.12 | 194 | 194 | 206 | 145 |
| 3.20 | 0.12 | 241 | 311 | 270 | 159 |
| 4.20 | 0.12 | 285 | 312 | 298 | 116 |
| 5.20 | 0.17 | 142 | 180 | 184 | 100 |
| 6.20 | 0.12 | 292 | 260 | 284 | 201 |
| 7.20 | 0.15 | 212 | 218 | 249 | 136 |
| 8.20 | 0.11 | 306 | 319 | 334 | 287 |
| 9.20 | 0.12 | 380 | 355 | 347 | 179 |
| 10.20 | 0.11 | 445 | 423 | 439 | 259 |
| 1.30 | 0.13 | 195 | 239 | 247 | 122 |
| 2.30 | 0.13 | 197 | 197 | 209 | 146 |
| 3.30 | 0.13 | 240 | 312 | 271 | 167 |
| 4.30 | 0.13 | 292 | 317 | 301 | 117 |
| 5.30 | 0.18 | 141 | 181 | 183 | 99 |
| 6.30 | 0.24 | 296 | 261 | 285 | 207 |
| 7.30 | 0.17 | 215 | 221 | 250 | 137 |
| 8.30 | 0.13 | 307 | 320 | 335 | 288 |
| 9.30 | 0.13 | 381 | 356 | 348 | 180 |
| 10.30 | 0.12 | 448 | 426 | 442 | 263 |

| | | | | | |
|---|---|---|---|---|---|
| 1.40 | 0.18 | 213 | 255 | 254 | 124 |
| 2.40 | 0.13 | 221 | 221 | 228 | 149 |
| 3.40 | 0.18 | 261 | 330 | 282 | 162 |
| 4.40 | 0.19 | 315 | 336 | 323 | 131 |
| 5.40 | 0.18 | 155 | 197 | 186 | 100 |
| 6.40 | 0.19 | 310 | 288 | 299 | 201 |
| 7.40 | 0.24 | 239 | 251 | 270 | 143 |
| 8.40 | 0.18 | 343 | 343 | 349 | 294 |
| 9.40 | 0.19 | 396 | 379 | 370 | 185 |
| 10.40 | 0.17 | 466 | 445 | 455 | 271 |

In the optimal sequence of machines and AGVs are determined by using FCFS, SPT, LPT and HGA for T/P<0.25 and shown in table no 3. From table 3, out of 40 problems 40 problems gives improved results using HGA in comparison with FCFS, SPT and LPT

Table 3: Performance analysis (t/p<0.25)

| Job.No | t/p | FCFS | SPT | LPT | HGA |
|---|---|---|---|---|---|
| 1.11 | 0.15 | 290 | 349 | 361 | 186 |
| 2.11 | 0.15 | 299 | 299 | 316 | 218 |
| 3.11 | 0.15 | 366 | 473 | 411 | 239 |
| 4.11 | 0.15 | 426 | 467 | 448 | 175 |
| 5.11 | 0.21 | 215 | 262 | 271 | 150 |
| 6.11 | 0.16 | 443 | 398 | 433 | 301 |
| 7.11 | 0.19 | 325 | 334 | 379 | 208 |
| 8.11 | 0.14 | 488 | 488 | 508 | 433 |
| 9.11 | 0.15 | 560 | 521 | 509 | 269 |
| 10.11 | 0.14 | 652 | 617 | 641 | 389 |
| 1.21 | 0.12 | 280 | 339 | 358 | 183 |
| 2.21 | 0.12 | 276 | 276 | 297 | 213 |
| 3.21 | 0.12 | 350 | 457 | 399 | 236 |
| 4.21 | 0.12 | 407 | 450 | 429 | 172 |
| 5.21 | 0.17 | 205 | 252 | 268 | 147 |
| 6.21 | 0.12 | 432 | 377 | 420 | 292 |

| | | | | | |
|---|---|---|---|---|---|
| 7.21 | 0.15 | 299 | 315 | 364 | 202 |
| 8.21 | 0.11 | 469 | 469 | 495 | 428 |
| 9.21 | 0.12 | 550 | 509 | 497 | 266 |
| 10.21 | 0.11 | 645 | 612 | 638 | 389 |
| 1.31 | 0.13 | 279 | 340 | 357 | 182 |
| 2.31 | 0.13 | 279 | 279 | 300 | 216 |
| 3.31 | 0.13 | 349 | 458 | 400 | 237 |
| 4.31 | 0.13 | 412 | 453 | 430 | 173 |
| 5.31 | 0.18 | 204 | 253 | 267 | 146 |
| 6.31 | 0.24 | 433 | 378 | 421 | 285 |
| 7.31 | 0.17 | 302 | 318 | 365 | 203 |
| 8.31 | 0.13 | 470 | 470 | 496 | 429 |
| 9.31 | 0.13 | 551 | 510 | 498 | 267 |
| 10.31 | 0.12 | 648 | 615 | 641 | 387 |
| 1.41 | 0.18 | 296 | 356 | 363 | 184 |
| 2.41 | 0.13 | 307 | 307 | 319 | 217 |
| 3.41 | 0.18 | 370 | 476 | 411 | 239 |
| 4.41 | 0.19 | 434 | 471 | 451 | 177 |
| 5.41 | 0.18 | 218 | 269 | 270 | 148 |
| 6.41 | 0.19 | 445 | 405 | 433 | 304 |
| 7.41 | 0.24 | 329 | 344 | 385 | 203 |
| 8.41 | 0.18 | 493 | 493 | 508 | 434 |
| 9.41 | 0.19 | 560 | 533 | 520 | 269 |
| 10.41 | 0.17 | 666 | 633 | 652 | 391 |

In the optimal sequence of machines and AGVs are determined by using FCFS, SPT, LPT and HGA for T/P<0.25 and shown in table no 4. From table 4, out of 40 problems 40 problems gives improved results using HGA in comparison with FCFS, SPT and LPT.

## 4. Conclusions

The application of a simple REGA to scheduling job shop FMS is demonstrated, where the objective is to minimize makespan. The experiments performed have been reproduced from work reported elsewhere. The results show that the solutions obtained for the proposed approach are comparable to the previous reported studies. The time computation for the proposed REGA is also very efficient. The key advantage of REGA portrayed here is that it provides a general purpose solution to the scheduling problem which is not problem specific, with the peculiarities of any particular scenario being accounted for in fitness function without disturbing the logic of the standard optimization routine. The REGA can be combined with a rule set to eliminate undesirable schedules by capturing the

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

expertise of the human scheduler

**Acknowledgments**

Financial support from DST-SERB, Govt.of India (Sanction No: SB/EMEQ-501/2014)

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## APPENDIX A

Travel time matrix for this particular problem

| Layout-1 | | | | | |
|---|---|---|---|---|---|
| From/To | L/U | M1 | M2 | M3 | M4 |
| L/U | 0 | 6 | 8 | 10 | 12 |
| M1 | 12 | 0 | 6 | 8 | 10 |
| M2 | 10 | 6 | 0 | 6 | 8 |
| M3 | 8 | 8 | 6 | 0 | 6 |
| M4 | 6 | 10 | 8 | 6 | 0 |

| Layout-2 | | | | | |
|---|---|---|---|---|---|
| From/To | L/U | M1 | M2 | M3 | M4 |
| L/U | 0 | 4 | 6 | 8 | 6 |
| M1 | 6 | 0 | 2 | 4 | 2 |
| M2 | 8 | 12 | 0 | 2 | 4 |
| M3 | 6 | 10 | 12 | 0 | 2 |
| M4 | 4 | 8 | 10 | 12 | 0 |

| Layout-3 | | | | | |
|---|---|---|---|---|---|
| From/To | L/U | M1 | M2 | M3 | M4 |
| L/U | 0 | 2 | 4 | 10 | 12 |
| M1 | 12 | 0 | 2 | 8 | 10 |
| M2 | 10 | 12 | 0 | 6 | 8 |
| M3 | 4 | 6 | 8 | 0 | 2 |
| M4 | 2 | 4 | 6 | 12 | 0 |

| Layout-4 | | | | | |
|---|---|---|---|---|---|
| From/To | L/U | M1 | M2 | M3 | M4 |
| L/U | 0 | 4 | 8 | 10 | 14 |
| M1 | 18 | 0 | 4 | 6 | 10 |
| M2 | 20 | 14 | 0 | 8 | 6 |
| M3 | 12 | 8 | 6 | 0 | 6 |
| M4 | 14 | 14 | 12 | 6 | 0 |

Data for the Job Sets Used in Example Problems

| | |
|---|---|
| JobSet-1<br>Job 1: Ml(8); M2(16); M4(12)<br>Job 2: Ml(20); M3(10); M2(18)<br>Job 3: M3(12); M4(8); Ml(15)<br>Job 4: M4(14); M2(18)<br>Job 5: M3(10); Ml(15) | JobSet-2<br>Job 1: Ml(10); M4(18)<br>Job 2: M2(10); M4(18)<br>Job 3: Ml(10); M3(20);<br>Job 4: M2(10); M3(15); M4(12)<br>Job 5: Ml(10); M2(15); M4(12)<br>Job 6: M1(10); M2(15); M3(12) |
| JobSet-3<br>Job 1:Ml(16); M3(15)<br>Job 2:M2(18); M4(15)<br>Job 3:Ml(20); M2(10)<br>Job 4:M3(15); M4(10)<br>Job 5:Ml(8);M2(10);M3(15);M4(17)<br>Job 6: M2(10);M3(15);M4(8);Ml(15 | JobSet-4<br>Job1: M4(11); Ml(10); M2(7)<br>Job2: M3(12); M2(10); M4(8)<br>Job3: M2(7); M3(10); Ml(9); M3(8)<br>Job4: M2(7); M4(8); Ml(12);M2(6)<br>Job5:Ml(9);M2(7);M4(8);M2(10);M3(8) |
| JobSet-5<br>Job 1: Ml(6);M2(12);M4(9)<br>Job 2: Ml(18);M3(6); M2(15)<br>Job 3: M3(9);M4(3);Ml(12)<br>Job 4: M4(6);M2(15)<br>Job 5: M3(3);Ml(9) | JobSet-6<br>Job 1: Ml(9); M2(11); M4(7)<br>Job 2: Ml(19); M2(20); M4(13)<br>Job 3: M2(14); M3(20); M4(9)<br>Job 4: M2(14); M3(20); M4(9)<br>Job 5: Ml(11); M3(16); M4(8)<br>Job 6: Ml(10); M3(12); M4(10) |

ISSN (Print): 2204-0595
ISSN (Online): 2203-1731

| | |
|---|---|
| JobSet-7<br>Job 1: Ml(6); M4(6)<br>Job 2: M2(11); M4(9)<br>Job 3: M2(9); M4(7)<br>Job 4: M3(16); M4(7)<br>Job 5: Ml(9); M3(18)<br>Job 6: M2(13); M3(19); M4(6)<br>Job 7: Ml(10); M2(9); M3(13)<br>Job 8: Ml(l1); M2(9); M4(8) | JobSet-8<br>Job 1: M2(12); M3(21);M4(11)<br>Job 2: M2(12); M3(21);M4(11)<br>Job 3: M2(12); M3(21);M4(11)<br>Job 4: M2(12); M3(21);M4(11)<br>Job 5: Ml(10); M2(14);M3(18);M4(9)<br>Job 6: Ml(10);M2(14); M3(18);M4(9) |
| JobSet-9<br>Job 1: M3(9);Ml(12);M2(9);M4(6)<br>Job 2: M3(16);M2(11); M4(9)<br>Job 3: Ml(21); M2(18); M4(7)<br>Job 4: M2(20); M3(22); M4(11)<br>Job 5:M3(14);Ml(16);M2(13); M4(9) | JobSet-10<br>Job1:Ml(11);M3(19);M2(16);M4(13)<br>Job2: M2(21);M3(16); M4(14)<br>Job3:M3(8); M2(10); Ml(14); M4(9)<br>Job4: M2(13); M3(20); M4(10)<br>Job5: Ml(9); M3(16); M4(18) ;<br>Job6:M2(19);Ml(21); M3(11);M4(15) |