(Research Article)

Minimization of Makespan in Job Shop Scheduling with Heuristic and Genetic Algorithms

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Abstract

As the performance of manufacturing system is directly related to the optimum utilization of time and resources, optimal scheduling of work activities plays an important role. Job shop scheduling is an optimization problem, in which a set of jobs has to be processed on a set of machines such that some specific objective functions are to be minimized. Here an effort has been made to minimize the makespan and average job flow time of the job shop scheduling problem of following two natures: 5-job 3-machine problem and 10-job 5-machine problem. Data for these problems were collected from a small scale industry. This paper describes the steps in well-known heuristics such as Palmer's, Campbell Dudek and Smith (CDS) & Nawaz Enscore and Ham (NEH) and a simple algorithm for proposed Genetic Algorithm. This paper investigates the present scheduling system followed by the industry and presents the solutions for the problems considered through heuristics and proposed Genetic Algorithm. Then the comparisons were made among the results obtained through proposed genetic algorithm, heuristics and LEKIN scheduling software to suggest an optimal sequence for the problems considered.

Keywords: Job shop scheduling, Makespan, Average job flow time, Heuristic algorithms, Genetic algorithm.

1. Introduction

Planning and scheduling are common to many different engineering domains, these are daily life activities. Whether the project is as large as the Magnificent Metro projects or something as simple as the redesign of the packaging for an industrial tape dispenser, both planning and scheduling play a vital role. Scheduling is an important decision making process that is used on regular basis in various manufacturing and service industries. Scheduling is the process of allocating the shared resources by applying the limiting factors of time and cost for the competing activities to perform a collection of tasks. A schedule is an allocation of operations to time intervals of the machines. All scheduling problems can be broadly categorized as, single-machine scheduling (only one machine) and multi-machine scheduling (more than one machine). Both job shop and flow shop production cope with a scheduling problem to find a feasible sequence of jobs on given machines such that certain objective(s) is to be optimized. These objectives can be minimization of makespan, minimization of average job flow time, minimization of maximum lateness, etc.

Typically, there are m machines and n jobs for scheduling. Jobs have to be processed on these machines with different routes or sequences. There are $n!$ ways (solutions) to sequence jobs on each machine. For some type of scheduling problem, all machines use the similar sequence. So, the numbers of feasible solutions to find the optimal solution are $n!$ solutions. For the job shop scheduling problem, each machine has different sequences; therefore, number of feasible solution increase to $(n!)^m$ solutions.

Scheduling is easy and fast up to n -job and 2-machine scheduling problems, but it becomes NP-hard (nondeterministic polynomial-hard) when the number of machines ≥ 3 ; that means when the size of problem grows up, the time for determining the optimal solutions of the problem increase exponentially. Therefore, the heuristic methods are used to speed up the process of finding the good enough optimal solution, where an exhaustive search is impractical. Heuristic refers to experience-based techniques for solving, learning, and discovery the new approaches to a problem.

The genetic algorithm is a search-based general optimization technique based on the principles of genetics and natural selection. It is an evolutionary algorithm inspired by Darwin's principle of natural selection. The central idea of natural selection is the survival of the fittest one for the next generation. What is the principle of natural selection? i.e. Select the Best, Discard the Rest; so the fittest will survive.

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2. Literature Review

In '50s, Johnson [1] first presented an algorithm for an n-job 2-machine problem that can find the optimal sequence effectively without much calculation. Palmer's algorithm was given by Palmer [2] which used the slope index approach to sequence the jobs in optimal order with the decreasing value of slope index. This algorithm can be applied to n-job m-machine problems. A simple heuristic extension of Johnson's algorithm was proposed by Campbell et al. [3] popularly known as CDS heuristic algorithm. This uses the Johnson's algorithm in number of iteration before reaching the final solution. Nawaz et al. [4] developed a heuristic algorithm, based on the total processing time of the individual jobs. According to this algorithm, to obtain the optimal sequence priority should be given to the jobs having higher total processing time.

Man et al. [5] basically introduces the genetic algorithm (GA) as a complete entity, which can be used as design tool and also explain "why" and "when" GA should be used as an optimization tool. Laha and Mandal [6] have presented a new heuristic genetic algorithm (NGA) that combines the good features of both the genetic algorithms and heuristic search for the scheduling on makespan criterion in the flow shop environment. Li and Chen [7] did the study on characteristics of agile job shop scheduling problem and proposed a new genetic algorithm for solving the same. They improved the local optimal solution by adopting two-row chromosome structure based on working procedure and machine distribution. Verma et al. [8] developed an algorithm for job shop scheduling problem based on genetic algorithm and they proved that even a relatively simple genetic algorithm is capable for job shop scheduling. An overview of genetic algorithms was described for job shop scheduling problem [14]. Yadav and Prajapati [9] did the study of genetic algorithm and given an overview of genetic algorithm and modelling, its working and solution space.

Singhal et al. [10] proposed an improved algorithm which is obtained by modifying the NEH algorithm. They were shown that this algorithm produces improved quality solutions with algorithmic complexity same as the original algorithm.

Semanco and Modrak [11] proposed a constructive heuristic approach for the solution of the permutation flow-shop problem, known as MOD heuristic. It was shown that the proposed algorithm is a feasible alternative for practical application when solving n-job and m-machine in flow-shop scheduling problems to give relatively good solutions in a short-time interval. A comparison was made among the various heuristics algorithms based on the make span by Modrak et al. [12]. The heuristics used are namely Palmer's, Gupta's algorithm, CDS, NEH and MOD heuristic algorithms. The NEH uses maximum iterations among all other while Palmer uses single iteration to reach the final

result. Though Palmer's algorithm was very fast but it lacked accuracy and the result obtained from Palmer's algorithm don't coincide with the best result among all other heuristic algorithms.

Choudhari and Khanna [13] did the survey on various machine scheduling techniques for flow shop environment. Their objective was the minimization of total production time, while considering setup time, processing time, transporting time, returning time and they used the heuristic approach to arrive at the optimal solution. Silva and Klement [15] solved a multi-periods job shop scheduling problem using a generic and modular decision support tool. They demonstrated that the proposed tool can be easily adapted to several different planning or scheduling problems variants. Liu et al. [16] utilized the statistical measure skewness to construct a new priority rule, which is applied to the NEH heuristic, for solving scheduling problems in permutation flowshops.

3. Methodology

This section describes the various heuristic algorithms and proposed genetic algorithm which are used to arrive at the desired results.

3.1 Palmer's heuristic algorithm: This heuristic is based on the calculation of slope index for each job by assigning some specific weights to each machine. This heuristic comprises the following steps:

1. Consider an n-jobs m-machine problem.
2. Assign the specific weight = $\{m - (2i - 1)\}$ to the i^{th} machine. Where m is total number of machines.
3. Compute the slope S_j for j^{th} job as follows:

$$S_j = - \sum_{i=1}^m \{m - (2 \times i - 1)\} \times p_{ij} \quad (1)$$

Where m=number of machine in problem considered
 p_{ij} = processing time of j^{th} job on i^{th} machine

4. Order the jobs in the sequence based on descending (decreasing) order of S_j values.
5. Calculate the makespan for the sequence obtained.

3.2 Campbell Dudek Smith (CDS) heuristic algorithm: This algorithm converts a given n-job m-machine problem into (m-1) number of 2-machine surrogate problems. Each surrogate problem is solved using Johnson's rule. The value of makespan ($C_{\max}$) for each surrogate problem is found out.

The sequence of surrogate problem having minimum value of $C_{\max}$ after applying Johnson's rule is selected for scheduling jobs on the machines.

For each surrogate problem the processing time of all the jobs on both machines are calculated as follows:

$k = \text{surrogate problem} = 1, 2, 3, \dots, m-1.$
 $j = \text{job} = 1, 2, 3, \dots, n.$

$$M'_1 = \sum_{i=1}^k p_{ij} \quad \text{and} \quad M'_2 = \sum_{i=m-k+1}^m p_{ij} \quad (2)$$

where M'_1 = processing time for the 1st machine,
 M'_2 = processing time for the 2nd machine.

3.3 Nawaz Ensore Ham (NEH) heuristic algorithm: This algorithm constructs jobs sequence in iterative manner. NEH algorithm is described as:

1. Find the total work content (T_j) using the following expression:

$$T_j = \sum_{i=1}^m p_{ij} \quad (3)$$

2. Arrange jobs in a work content list according to decreasing values of T_j .
3. Select first two jobs from the list, and form partial sequences by interchanging the place of the two jobs.
4. Out of the two partial sequences, select the partial sequence with lower value of $C_{\max}$ and called it incumbent sequence.
5. Pick next job from the work content list, and place it all locations in the incumbent sequence. Calculate the value of $C_{\max}$ for all the sequences.
6. Retain the sequence with minimum value of $C_{\max}$ as incumbent sequence and discard all the other sequences.
7. If there is no job left in the work content list to be add to incumbent sequence, stop. Otherwise, go step 5.

3.4 Proposed Genetic Algorithm:

Table 1. Basic Terminologies in Genetic Algorithm

Natural Evolution		Genetic Algorithm
1	Population	Solution (Set of Chromosomes)
2	Chromosome	String (A Solution)
3	Gene	Elemental Position in String
4	Allele	Value at a certain Position
5	Genotype	Coded String
6	Phenotype	Uncoded String
7	Fitness Function	Objective Function

Since the Genetic Algorithm is a general algorithm which applied to variety of problems and one can formulate it according to their problem and the complexity of the problem.

For the scheduling problems, 5-job 3-machine problem and 10-job 5-machine problem, following are the steps in the Proposed Genetic Algorithm based on the concepts of original one:

Step 1: Population Initialization: First step is to obtain the initial population, the set of solutions to proceed further. For scheduling problem, this is the job priority sequence with makespan and average job flow time. Set of 5 solutions is obtained through the combination of both solutions from the three heuristic algorithms and two solutions are randomly selected.

Step 2: Evaluation of Fitness: Fitness for each solution is determined using the fitness function. Multi-criteria approach has been used for fitness. Since our objective is to minimize the makespan and average job flow time, so the fitness function is: makespan and average job flow time. If first one is fail, next one will be used for fitness evaluation.

Step 3: Selection for Reproduction: This is the most important step to reach the optimal solution. For our scheduling problem fittest solution is selected on the basis of Rank Order Selection criteria. In this criterion, the solution having the least value for the fitness function is to be given the first rank and so on. The first ranked solution will be selected for reproduction.

Step 4: Genetic Operator: After the selection of solution, genetic operators are applied for the reproduction. There are two kinds of genetic operators: Crossover and Mutation. For the crossover two solutions are required and for mutation only one. Since there are scheduling problems for which mutation operator works better because solution is a sequence in which repetitions of job are not allowed. So shift mutation is used for reproduction. In the shift mutation genes (here jobs) are altered in positions through shifting from one position to another to obtain optimal sequence.

Step 5: New Population: New set of 5 solutions are obtained through mutation. Fitness is evaluated for each solution.

Step 6: Termination Criteria: If fitness value obtained in new population is better than fitness value of the initial population, then terminate the process; otherwise replace the least-fit value in previous set of solution by the fittest one from new population and repeat the procedure until termination condition is met. Perform at least three iterations, to obtain the good results.

Figure 1. Flowchart of the Proposed Genetic Algorithm

3.5 Pseudo code for the Proposed Genetic Algorithm:

```

{
  initialize population; (population initialization based on
  heuristics and randomly chosen)
  find the fitness of population; (fitness function is
  makespan)
  while termination criteria not satisfied do (minimum
  makespan and average job flow time)
  {
    select fittest individual for mutation; (on the basis of
    rank order selection)
    mutation to generate new population; (shift mutation)
    calculation of fitness of each individual;
    replace least fit individual in initial population with
    the fittest one of new population;
  }
}

```

4. Problem Description & Solution

The data collected for the scheduling problem are processing time, for the jobs on the machines in time unit of “minutes”.

All the jobs are denoted J_j , where $j = 1, 2, 3, \dots, n$.

All the machines are denoted by M_i , where $i = 1, 2, 3, \dots, m$.

Table 2. 5-job 3-machine problem

Job	M1	M2	M3
J1	10	10	12
J2	12	8	20
J3	16	6	14
J4	12	4	20
J5	20	8	8

Table 3. 10-job 5-machine problem

Job	M1	M2	M3	M4	M5
J1	32	8	8	28	24
J2	28	6	8	28	20
J3	36	10	10	30	26
J4	8	4	4	24	6
J5	8	4	4	24	4
J6	6	2	4	24	2
J7	4	4	4	22	4
J8	10	6	8	24	8
J9	12	8	6	24	6
J10	14	4	8	28	10

Solution:

4.1 Through the scheduling technique followed by industry, i.e. First Come First Serve (FCFS) rule:

Table 4. Makespan calculation for J1,J2,J3,J4,J5

Job	M1		M2		M3	
	In	Out	In	Out	In	Out
J1	0	10	10	20	20	32
J2	10	22	22	30	32	52
J3	22	38	38	44	52	66
J4	38	50	50	54	66	86
J5	50	70	70	78	86	94

$C_{\max} = 94$ minutes.

$T_{\text{avg}} = (32+52+66+66+94)/5 = 66$ minutes.

Table 5. Makespan calculation for J1,J2,J3,J4,J5,J6,J7,J8,J9,J10

Job	M1		M2		M3		M4		M5	
	In	Out	In	Out	In	Out	In	Out	In	Out
J1	0	32	32	40	40	48	48	76	76	100
J2	32	60	60	66	66	74	76	104	104	124
J3	60	96	96	106	106	116	116	146	146	172
J4	96	104	106	110	116	120	146	170	172	178
J5	104	112	112	116	120	124	170	194	194	198
J6	112	118	118	120	124	128	194	218	218	220
J7	118	122	122	126	128	132	218	240	240	244
J8	122	132	132	138	138	146	240	264	264	272
J9	132	144	144	152	152	158	264	288	288	294
J10	144	158	158	162	162	170	288	316	316	326

$C_{\max} = 326$ minutes & $T_{\text{avg}} = (100+124+172+178+198+220+244+272+294+326)/10 = 212.8$ minutes.

4.2 Through Palmer's Heuristic Algorithm: According to this algorithm slope index for each job is calculated using (1).

Table 6. Slope index calculation in 5-job 3-machine problem

Weight	2	0	-2	
Job	M1	M2	M3	S_j
J1	10	10	12	4
J2	12	8	20	16
J3	16	6	14	-4
J4	12	4	20	16
J5	20	8	8	-24

Two sequences are possible: J2,J4,J1,J3,J5 and J4,J2,J1,J3,J5 out of which latter one gives best result.

Table 7. Makespan calculation for J4,J2,J1,J3,J5

Job	M1		M2		M3	
	In	Out	In	Out	In	Out
J4	0	12	12	16	12	36
J2	12	24	24	32	36	56
J1	24	34	34	44	56	68
J3	34	50	50	56	68	82
J5	50	70	70	78	82	90

$C_{\max} = 90$ minutes & $T_{\text{avg}} = (36+56+68+82+90)/5 = 66.4$ minutes.

For the 10-job 5-machine problem, after arranging jobs in order with decreasing value of S_j value gives optimal sequence as J7,J4,J10,J6,J8,J5,J2,J9,J1,J3.

Table 8. Makespan calculation for J7,J4,J10,J6,J8,J5,J2,J9,J1,J3

Job	M1		M2		M3		M4		M5	
	In	Out	In	Out	In	Out	In	Out	In	Out
J7	0	4	4	8	8	12	12	34	34	38
J4	4	12	12	16	16	20	34	58	58	64
J10	12	26	26	30	30	38	58	86	86	96
J6	26	32	32	34	38	42	86	110	110	112
J8	32	42	42	48	48	56	110	134	134	142
J5	42	50	50	54	56	60	134	158	158	162
J2	50	78	78	84	84	92	158	186	186	206
J9	78	90	90	98	98	104	186	210	210	216
J1	90	122	122	130	130	138	210	238	238	262
J3	122	158	158	168	168	178	238	268	268	294

$C_{\max} = 294$ minutes & $T_{\text{avg}} = (38+64+96+112+142+162+206+216+262+294)/10 = 159.2$ minutes.

4.3 Through CDS Heuristic Algorithm: Makespan calculations for the optimal sequences obtained through CDS algorithm are:

Table 9. Makespan calculation for J4,J1,J2,J3,J5

Job	M1		M2		M3	
	In	Out	In	Out	In	Out
J4	0	12	12	16	16	36
J1	12	22	22	32	36	48
J2	22	34	34	42	48	68
J3	34	50	50	56	68	82
J5	50	70	70	78	82	90

$C_{\max} = 90$ minutes & $T_{\text{max}} = (36+48+68+82+90)/5 = 64.8$ minutes.

Table 10. Makespan calculation for J7,J4,J5,J9,J3,J1,J2,J10,J8,J6

Job	M1		M2		M3		M4		M5	
	In	Out	In	Out	In	Out	In	Out	In	Out
J7	1	4	4	8	8	12	12	34	34	38
J4	4	12	12	16	16	20	34	58	58	64
J5	12	20	20	24	24	28	58	82	82	86
J9	20	32	32	40	40	46	82	106	106	112
J3	32	68	68	78	78	88	106	136	136	162
J1	68	100	100	108	108	116	136	164	164	188
J2	100	128	128	134	134	142	164	192	192	212
J10	128	142	142	146	146	154	192	220	220	230
J8	142	152	152	158	158	164	220	244	244	252
J6	152	158	158	160	164	168	244	268	268	270

$C_{\max} = 270$ minutes & $T_{\text{max}} = (38+64+86+112+162+188+212+230+252+270)/10 = 161.4$ minutes.

4.4 Through NEH Heuristic Algorithm: According to this algorithm total work content for each job is calculated using (3) and then jobs are sequenced in order with decreasing value of total work content to obtain partial sequence. After performing all iterations, the makespan calculation for optimal sequences through this algorithm are:

Table 11. Makespan calculation for J4,J1,J3,J2,J5

Job	M1		M2		M3	
	In	Out	In	Out	In	Out
J4	0	12	12	16	16	36
J1	12	22	22	32	36	48
J3	22	38	38	44	48	62
J2	38	50	50	58	62	82
J5	50	70	70	78	82	90

$C_{\max} = 90$ minutes & $T_{\text{avg}} = (36+48+62+82+90)/5 = 63.6$ minutes.

Table 12. Makespan calculation for J7,J4,J5,J9,J8,J10,J3,J1,J2,J6

Job	M1		M2		M3		M4		M5	
	In	Out	In	Out	In	Out	In	Out	In	Out
J7	0	4	4	8	8	12	12	34	34	38
J4	4	12	12	16	16	20	34	58	58	64
J5	12	20	20	24	24	28	58	82	82	86
J9	20	32	32	40	40	46	82	106	106	112
J8	32	42	42	48	48	56	106	130	130	138
J10	42	56	56	60	60	68	130	158	158	168
J3	56	92	92	102	102	112	158	188	188	214
J1	92	124	124	132	132	140	188	216	216	240
J2	124	152	152	158	158	166	216	244	244	264
J6	152	158	158	160	166	170	244	268	268	270

$C_{\max} = 270$ minutes & $T_{\text{avg}} = (38+64+86+112+138+168+214+240+264+270)/10 = 159.4$ minutes.

4.5 Through Proposed Genetic Algorithm:

4.5.1. For 5-job 3-machine problem:

Table 13. Initial population with their fitness value

Member	From	Sequence	$C_{\max}$	T_{avg}
1	Palmer's heuristic	J4,J2,J1,J3,J5	90	66.4
2	CDS heuristic	J4,J1,J2,J3,J5	90	64.8
3	NEH heuristic	J4,J1,J3,J2,J5	90	63.6
4	Randomly chosen	J1,J4,J2,J5,J3	94	66
5	Randomly chosen	J2,J5,J3,J4,J1	100	68.8

After performing all three iterations of the proposed genetic algorithm optimal sequence was obtained as J4,J3,J1,J2,J5.

Table 14. Makespan calculation for J4,J3,J1,J2,J5

Job	M1		M2		M3	
	In	Out	In	Out	In	Out
J4	0	12	12	16	16	36
J3	12	28	28	34	36	50
J1	28	38	38	48	50	62
J2	38	50	50	58	62	82
J5	50	70	70	78	82	90

$C_{\max} = 90$ minutes & $T_{\text{avg}} = (36+50+62+82+90)/5 = 64$ minutes.

4.5.2. For 10-job 5-machine problem:

Table 15. Initial population with their fitness value

Member	From	Sequence	$C_{\max}$	T_{avg}
1	Palmer's heuristic	J7,J4,J10,J6,J8,J5,J2,J9,J1,J3	294	159.2
2	CDS heuristic	J7,J4,J5,J9,J3,J1,J2,J10,J8,J6	270	161.4
3	NEH heuristic	J7,J4,J5,J9,J8,J10,J3,J1,J2,J6	270	159.4
4	Randomly chosen	J6,J7,J5,J4,J8,J9,J10,J2,J1,J3	294	157.4
5	Randomly chosen	J6,J7,J4,J5,J8,J10,J9,J2,J1,J3	288	156.8

After performing all three iterations of the proposed genetic algorithm optimal sequence was obtained as J7,J4,J5,J9,J8,J2,J1,J3,J10,J6.

Table 16. Makespan calculation for J7,J4,J5,J9,J8,J2,J1,J3,J10,J6

Job	M1		M2		M3		M4		M5	
	In	Out	In	Out	In	Out	In	Out	In	Out
J7	0	4	4	8	8	12	12	34	34	38
J4	4	12	12	16	16	20	34	58	58	64
J5	12	20	20	24	24	28	58	82	82	86
J9	20	32	32	40	40	46	82	106	106	112
J8	32	42	42	48	48	56	106	130	130	138
J2	42	70	70	76	76	84	130	158	158	178
J1	70	102	102	110	110	118	158	186	186	210
J3	102	138	138	148	148	158	186	216	216	242
J10	138	152	152	156	158	166	216	244	244	254
J6	152	158	158	160	166	170	244	268	268	270

$C_{\max} = 270$ minutes & $T_{\text{avg}} = (38+64+86+112+138+178+210+242+254+270)/10 = 159.2$ minutes.

4.6 Through LEKIN Scheduling Software:

4.6.1. For 5-job 3-machine problem:

Figure 2. Makespan calculation through LEKIN software

$C_{\max} = 90$ minutes & $T_{\text{avg}} = 318/5 = 63.6$ minutes.

4.6.2. For 10-job 5-machine problem:

Figure 3. Makespan calculation through LEKIN software

$C_{\max} = 270$ minutes & $T_{\text{avg}} = 1596/10 = 159.6$ minutes.

5. Results Analysis

Table 17. Results for 5-job 3-machine problem

Algorithm	Sequence	C _{max}	T _{avg}
FCFS Rule	J1,J2,J3,J4,J5	94	66
Palmer	J4,J2,J1,J3,J5	90	66.4
CDS	J4,J1,J2,J3,J5	90	64.8
NEH	J4,J1,J3,J2,J5	90	63.6
Proposed GA	J4,J3,J1,J2,J5	90	64
LEKIN Software	J4,J1,J2,J5,J3	90	63.6

Table 18. Results for 10-job 5-machine problem

Algorithm	Sequence	C _{max}	T _{avg}
FCFS Rule	J1,J2,J3,J4,J5,J6,J7,J8,J9,J10	326	212.8
Palmer	J7,J4,J10,J6,J8,J5,J2,J9,J1,J3	294	159.2
CDS	J7,J4,J5,J9,J3,J1,J2,J10,J8,J6	270	161.4
NEH	J7,J4,J5,J9,J8,J10,J3,J1,J2,J6	270	159.4
Proposed GA	J7,J4,J5,J9,J8,J2,J1,J3,J10,J6	270	159.2
LEKIN Software	J7,J4,J5,J9,J2,J8,J10,J3,J1,J6	270	159.6

6. Conclusions

The investigations of the results obtained, allows to be made some important conclusions as follows:

- The scheduling sequences of jobs through the industry's scheduling system are far away from the optimal one.
- For 5-job 3-machine problem NEH heuristic gives the best results among the heuristic algorithms, this is also the optimal solution for this problem. Results from the LEKIN software are also same but with different sequence. The results for this problem through the Proposed Genetic Algorithm are very close to the optimal solution.
- Optimal sequence for this problem is J4,J1,J3,J2,J5 with makespan of 90 minutes and average job flow time of 63.6 minutes.
- For 10-job 5-machine problem NEH heuristic gives the best results among the heuristic algorithms, whereas optimal solutions were obtained through the Proposed Genetic Algorithm. The results of the LEKIN software are agreed with results of the Proposed Genetic Algorithm with same makespan and very small difference in average job flow time, although there is different sequence obtained from both.
- Optimal sequence for this problem is J7,J4,J5,J9,J8,J2,J1,J3,J10,J6 with makespan of 270 minutes and average job flow time of 159.2 minutes.
- For 5-job 3-machine problem the Proposed GA gives the different job priority sequence with same makespan, as per the optimal sequence obtained from the NEH heuristic algorithm. For 10-job 5-machine problem the Proposed GA gives the optimal job priority sequence with least average job flow time of 159.2 minutes for minimum makespan of 270 minutes. When compared with the solutions of other heuristic algorithms, the results obtained through the Proposed GA are optimal with respect to minimum makespan and minimum average job flow time.

Since the Proposed Genetic Algorithm is formulated especially for the problems considered according to the

complexity and circumstances of the problems with some assumptions, so it cannot be generalized for all kind of scheduling problem. Proposed Genetic Algorithm is very simple in nature and easy to implement.

Proposed Genetic Algorithm can execute the optimal solution in short time compared with heuristic algorithms. Proposed GA can give optimal solution compared with heuristic algorithms. But nature of job shop problems are not similar, so tailor made GA algorithm is to be prepared to solve different types of job shop problem.

Nomenclature

$C_{\max}$ = Makespan, total processing time for the job sequence

T_{avg} = Average job flow time, it is the total flow time of all jobs divided by the number of jobs.

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