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A Genetic Algorithm Applied Heuristic to Minimize the Makespan in a Flow Shop

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Abstract

In this work the flowshop scheduling situation in modern manufacturing has been analyzed. In a permutation flowshop design the machines arranged in series were the jobs are processed in a same order without eliminating any machine. Thus, it resulted in a need for development of more effective alternate methodology in finding an optimal solution with newer heuristic. A new heuristic (BAT heuristic) was proposed for the flow shop problems to achieve the minimal makespan by reaching the Lower Bound (LB) through a reverse engineering method. With this sequence resulting in optimal makespan reached sooner and with reduced computational time. This heuristic has been applied with Genetic Algorithm (GA) for further minimization of makespan. The GA applied BAT heuristic was evaluated by solving Taillard benchmark problem in MATLAB environment. The results were compared with traditional heuristics like CDS and NEH heuristics and found that the GA applied BAT heuristic yielded results better with 11% & 3% more compared to CDS and NEH heuristics.

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1. Introduction

Generally the scheduling problems are classified as fixed batch size problem (static problem) and stochastic process problems (dynamic problem). In fixed batch size problem, the number of machines may be one or more. In case of one machine it is called as single machine problem. Most of the single machine problems are generally

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considered as situations of critical machine. In rare cases multi machine problems are considered with one or more critical machines, which case the situation will tend to be hybrid natured flowshop.

A Permutation Flow Shop (PFS) is a shop design of machines arranged in series in which the jobs are processed in a same order without eliminating any machine. This has forced researchers to focus their efforts in finding an optimal solution with newer heuristics.

An algorithm was developed, for flowshop scheduling problems with 'N' jobs through 2 machines [1]. The NP-completeness of the flow shop scheduling problems had been discussed in detail [2]. Palmer [3] was the first to propose a heuristic with a slope index procedure, which was an effective and simple methodology in tracing a better makespan.

The significant work in the development of an efficient heuristic was discussed by CDS [4]. Their algorithm consists essentially in splitting the 'M' machine problem into a series of equivalent two-machine flow shop problems and solving it by Johnson's rule. Dannenbring [5] had developed a procedure called 'rapid access', which attempted to combine the advantages of Palmer's slope index and CDS procedures.

Stinson and Simith [6] had proposed a different approach called travelling salesman problem with two steps. The solution was found to be better than Palmer [7] and CDS methods, but with increased computational effort.

Since the problem is known to be NP-hard, the meta-heuristics are required to solve efficiently the industry size problems. Thus, the meta-heuristics with search techniques were developed to reach the near optimal solutions for the PFS problems [8].

For applying a local search technique in a PFS, an initial solution is generated and then it applies a move mechanism to search the neighborhood of the current solution to choose the better one [9]. An application to the PFS problem is proposed in various combinatorial optimization problems [10]. Schuster and Framinan [11] used the neighborhood search technique which was specially designed for flow shop problems. This technique is better compared to other results.

A step of local search starts with the current feasible solution x Є X to which is applied a function m Є M(x) that transforms x into x', a new feasible solution (x' = m(x)). This transformation is called a move and {x': x' = m(x); x, x' Є X; m Є M(x)} is called the neighborhood of x.

In this work an attempt was made to minimize the makespan of a PFS problem through the combined effect of mathematical and computational aspects through BAT heuristics.

Nomenclature

M	Number of machines in the PFS
N	Number of jobs in the PFS
P_{ij}	Processing time of j^{th} job in i^{th} machine
T_i	Summation of processing time of N jobs in i^{th} machine
a_{ij}	Summation of processing time of j^{th} job in 1^{st} to $(k-1)^{th}$ machine
b_{ij}	Summation of processing time of j^{th} job in $(k+1)^{th}$ to M^{th} machine
A_i	Minimum of a_{ij} for i^{th} machine
B_i	Minimum of b_{ij} for i^{th} machine
S_i	Summation of T_i, A_i and B_i for i^{th} machine
LB	Minimum of S_i
Z	Pivoted machine
ZA, ZB	Pivoted jobs
k	Looping variable of pivoting machine
i	Looping variable of machine from 1to M.
j	Looping variable of job from 1 to N.

2. Methodology

The newly proposed heuristic (BAT heuristic) is to find an optimal makespan using mathematical logics with local search technique. The methodology of the proposed heuristic is explained as follows with the assumptions.

2.1. Assumptions

- Pre-emption is not allowed. Once an operation is started on the machine it must be completed before another operation can begin on that machine.
- Machines never break down and are available throughout the scheduling period.
- All processing time on the machine are known, deterministic, finite and independent of sequence of the jobs to be processed.
- Each machine is continuously available for assignment, without significant division of the scale into shifts or days and without consideration of temporary unavailability such as breakdown or maintenance.
- Each job is processed through each of the m machines once and only once. Furthermore a job does not become available to the next machine until and unless processing on the current machine is completed i.e. splitting of job or job cancellation is not allowed.
- In-process inventory is allowed. If the next machine in the sequence needed by a job is not available, the job can wait and join the queue of that machine.

2.2. Algorithm

Step 1. Assign the processing time of 'N' jobs in 'M' machines. And frame the PFS problem N x M matrix.
Step 2. Calculate a_{ij} and b_{ij} values using the equations (1) and (2).

$$a_{ij} = \sum_{i=1}^{k-1} P_{ij} \tag{1}$$

$$b_{ij} = \sum_{i=k+1}^{m} P_{ij} \tag{2}$$

Step 3. Calculate Ti, Ai, and Bi values using the equations (3), (4) and (5).

$$T_i = \sum_{j=1}^{n} P_{ij} \tag{3}$$

$$A_i = \min(a_{ij}) \tag{4}$$

$$B_i = \min(b_{ij}) \tag{5}$$

Step 4. Calculate the Si values for 'M' machines using the equation (6).

$$S_i = T_i + A_i + B_i \tag{6}$$

Step 5. Calculate the LB value for the N x M PFS problem using the equation (7).

$$LB = \max(S_i) \tag{7}$$

Step 6. Identify the Z machine by the below stated condition in equation (8).

$$Z = k; \text{if } (LB == T_k + A_k + B_k) \quad (8)$$

Step 7. Identify the pivot jobs ZA and ZB using the condition stated in equation (9) and (10).

$$ZA = j; \text{if } (A_k == a_{kj}) \quad (9)$$

$$ZB = j; \text{if } (A_k == b_{kj}) \quad (10)$$

Step 8. Place the ZA and ZB pivoted jobs in the sequence under the condition, if the pivoted job is ZA, (Z≠1) && (ZA≠1) then place the ZA at beginning of the sequence. If the pivoted job is ZB, (Z≠M) && (ZB≠N) then place the ZB at end of the sequence.
Step 9. After the step 9 is successful, eliminate the ZA and ZB jobs from the N x M PFS problem.
Step 10. Apply local search technique by repeating the step 3 to step 10.
Step 11. Arrange the jobs in a sequence according to the pivoting conditions.

2.3. Genetic algorithm (GA) for flow shop scheduling [12]

GA is an optimization method of searching based on evolutionary process which works with a population of solutions. In the proposed GA, a population of solutions was considered and the fitness of each solution was evaluated by using a problem specific objective function after crossover as well as mutation operations. Then the best solution among all solutions was selected and this ensures that a better solution. The stages of GA are as follows.

- *Chromosome representation*- A solution to the N-job and M-machine problem was represented as a chromosome. A chromosome consists of 'M' parts; each part corresponding to each machine and consisting of 'n' bits that represent the order of jobs on that machine.
- *Fitness function*- It evaluated the performance measures to be optimized. A fitness value was found for each chromosome or schedule which was the weighted sum of makespan
- *Initial population*- The initial solution or population plays a critical role in determining the quality of final solution. The sequence from the heuristic is taken as initial solution.
- *Selection*- The better chromosome is selected by comparing the parent and daughter chromosomes under each stage or spin.
- *Crossover*- The crossover process was used to breed a pair of children chromosomes from a pair of parent chromosomes. The crossover operator randomly chooses a locus and exchanged the sub-sequences before and after that locus between two chromosomes. Thus two new children chromosomes were developed from two parent chromosomes by crossover.
- *Mutation*- If a random number generated was less than the mutation probability then mutation would be carried out. Here, mutation was done by interchanging two bits of a chromosome selected at random.

3. Results and discussion

3.1. Result Analysis of Benchmark Problems

The benchmark problems proposed by Taillard [13] are tested against the newly proposed heuristic (BAT heuristic) for the various sizes of the problems with 20, 50 & 100 jobs through 5, 10 & 20 machines. The results obtained from the MATLAB environment for the CDS heuristic, NEH heuristic, BAT heuristic and GA applied BAT heuristic were compared and tabulated in table 1 to 9.

Table 1. 20 jobs through 5 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
873654221	1232	1409	1286	1336	1278
379008056	1290	1424	1365	1360	1360
1866992158	1073	1255	1159	1185	1081
216771124	1268	1485	1325	1338	1299
495070989	1198	1367	1305	1273	1235
402959317	1180	1387	1228	1280	1195
1369363414	1226	1403	1278	1303	1251
2021925980	1170	1395	1223	1313	1206
573109518	1206	1360	1291	1239	1230
88325120	1082	1196	1151	1170	1108

Table 2. 20 jobs through 10 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
587595453	1448	1829	1680	1752	1583
1401007982	1479	2021	1729	1906	1660
873136276	1407	1773	1557	1884	1508
268827376	1308	1678	1439	1585	1384
1634173168	1325	1781	1502	1597	1430
691823909	1290	1813	1453	1518	1414
73807235	1388	1826	1562	1628	1484
1273398721	1363	2031	1609	1735	1550
2065119309	1472	1831	1647	1831	1609
1672900551	1356	2010	1653	1855	1614

Table 3. 20 jobs through 20 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
479340445	1911	2559	2410	2571	2305
268827376	1711	2285	2150	2236	2105
1958948863	1844	2565	2411	2510	2342
918272953	1810	2434	2262	2438	2233
555010963	1899	2506	2397	2452	2307
2010851491	1875	2422	2349	2370	2235
1519833303	1875	2489	2362	2398	2273
1748670931	1880	2362	2249	2383	2212
1923497586	1840	2414	2320	2392	2255
1829909967	1900	2469	2277	2372	2186

Table 4. 50 jobs through 5 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
1328042058	2712	2816	2733	2735	2724
200382020	2808	3032	2843	2987	2838

496319842	2596	2703	2640	2789	2621
1203030903	2740	2884	2782	2898	2751
1730708564	2837	3038	2868	3013	2864
450926852	2793	3031	2850	2852	2829
1303135678	2689	2969	2758	2878	2725
1273398721	2667	2835	2721	2745	2683
587288402	2527	2784	2576	2634	2554
248421594	2776	2942	2790	2820	2782

Table 5. 50 jobs through 10 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
1958948863	2907	3421	3135	3122	3045
575633267	2821	3246	3032	3256	2927
655816003	2801	3280	2986	3251	2871
1977864101	2968	3393	3198	3220	3078
93805469	2908	3375	3160	3118	3031
1803345551	2941	3400	3178	3356	3020
49612559	3062	3520	3277	3222	3148
1899802599	2959	3387	3123	3102	3063
2013025619	2795	3251	3002	3101	2936
578962478	3046	3429	3257	3440	3131

Table 6. 50 jobs through 20 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
1539989115	3480	4328	4082	4268	3936
691823909	3424	4216	3921	4087	3813
655816003	3351	4189	3927	4160	3733
1315102446	3336	4280	3969	4062	3832
1949668355	3313	4122	3835	4095	3701
1923497586	3460	4267	3914	4013	3787
1805594913	3427	4134	3952	4134	3843
1861070898	3383	4262	3938	4033	3778
715643788	3457	4212	3952	4157	3845
464843328	3438	4270	4079	4115	3857

Table 7. 100 jobs through 5 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
896678084	5437	5592	5519	5495	5493
1179439976	5208	5563	5348	5389	5268
1122278347	5130	5493	5219	5340	5175
416756875	4963	5273	5023	5225	5023
267829958	5195	5461	5266	5311	5255
1835213917	5063	5259	5139	5233	5135
1328833962	5198	5557	5259	5342	5246

1418570761	5038	5387	5120	5303	5094
161033112	5385	5758	5489	5686	5448
304212574	5272	5723	5341	5342	5325

Table 8. 100 jobs through 10 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
1539989115	5759	6209	5846	5937	5800
655816003	5345	5873	5453	5523	5362
960914243	5623	6024	5824	6134	5681
1915696806	5732	6377	5929	6089	5841
2013025619	5431	6018	5679	6019	5503
1168140026	5246	5742	5375	5633	5328
1923497586	5523	6201	5704	5738	5627
167698528	5556	6234	5760	6279	5646
1528387973	5779	6349	6032	6420	5925
993794175	5830	6387	5918	6338	5903

Table 9. 100 jobs through 20 machines.

Taillard Seeds	Lower Bound	CDS	NEH	BAT	GA applied BAT
450926852	5851	6920	6541	6769	6420
1462772409	6099	6977	6523	6922	6386
1021685265	6099	7229	6639	7030	6445
83696007	6072	7062	6557	6907	6410
508154254	6009	7113	6695	6730	6465
1861070898	6144	7283	6664	7159	6548
26482542	5991	7147	6632	7075	6405
444956424	6084	7235	6739	7225	6605
2115448041	5979	7196	6677	7095	6439
118254244	6298	7164	6677	6893	6602

From the table 1 to 9, it can be seen that by finding the cumulative % of success of GA applied BAT in reaching the LB was better compared to others and it is shown in table 10 and fig. 1.

Table 10. Comparison of heuristics based on the % nearer to LB

M x N	CDS	NEH	BAT	GA applied BAT
5 X 100	85.25%	94.21%	92.61%	97.38%
5 X 50	65.46%	85.60%	75.11%	89.89%
5 X 20	67.83%	74.95%	69.90%	78.88%
10 X 100	93.03%	98.46%	95.55%	99.17%
10 X 50	84.59%	92.67%	89.74%	96.42%
10 X 20	75.88%	83.85%	79.27%	88.09%
20 X 100	93.87%	98.40%	96.55%	98.89%
20 X 50	89.98%	96.96%	92.33%	98.59%
20 X 20	82.33%	90.54%	84.83%	93.22%

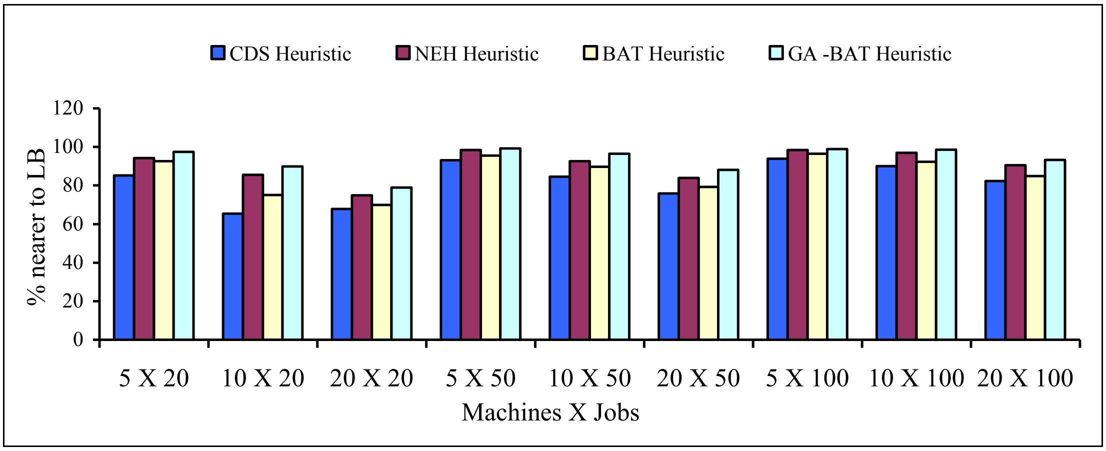

Fig. 1. Comparison of heuristics based on the % nearer to LB.

From the table 10, the overall % nearer to LB was calculated and it is shown in table 11 and fig. 2. It is observed that the BAT heuristic improved by about 7% with application GA and it is better by about 11% and 3% when compared to CDS and NEH heuristics.

Table 11. Overall comparison of heuristics

CDS	NEH	BAT	GA applied BAT
82.02%	90.63%	86.21%	93.39%

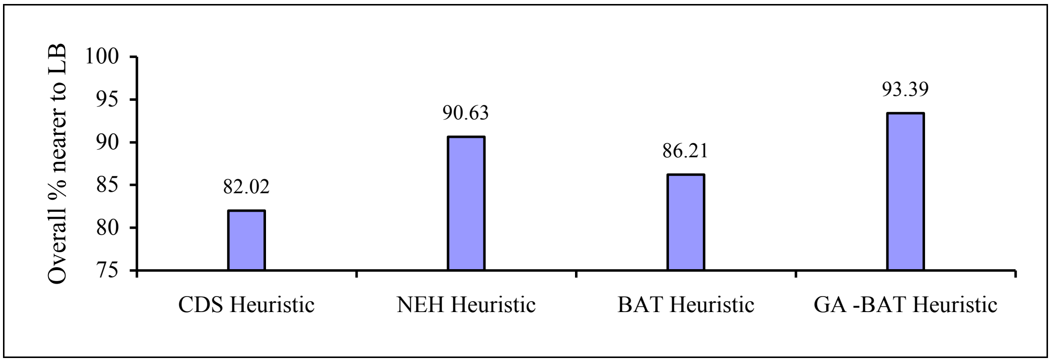

Fig. 2. Comparison of heuristics based on the overall % nearer to LB.

3.2. Analysis of variance (ANOVA)

One way ANOVA was carried out in MINITAB16 environment, considering the makespan reaching the Lower Bound of the CDS, NEH, BAT and GA applied BAT heuristics. This analysis is made to determine the optimal noise level by "smaller as best" concept and the best significant level has been identified from the table 12 and has been shown that the p-value is 0.625 which is greater than f-value of 0.59, at 95% confidence level.

Table 12. ANOVA analyze

Source	DF	SS	MS	F	P
Factor	3	5968534	1989511	0.59	0.625
Error	356	1209810755	3398345		
Total	359	1215779290			

The results of heuristics by benchmark problem are evaluated based on mean value under Pooled Standard Deviation with constrain of “smaller the best” and it is shown in table 13. It can be seen from the table that the GA applied BAT heuristic is better in finding minimum makespan compared to others.

Table 13. CIs for mean based on pooled standard deviation

Level	N	Mean	Standard Deviation
CDS	90	3884	1903
NEH	90	3630	1804
BAT	90	3772	1883
GA Applied BAT	90	3550	1780

*Smaller the best

The Hsu's MCB (Multiple Comparisons with the Best) based on “smaller the best” shown in table 14. It is seen from that the proposed BAT heuristic is minimum at all levels with the confidence level of 95%. It is also represented in fig. 3.

Table 14. Hsu’s MCB for mean based on pooled standard deviation

Level	Lower	Centre	Upper
CDS	-232	335	901
NEH	-487	80	647
BAT	-345	222	789
GA Applied BAT	-647	-80	487

The residual plots of CDS, NEH, BAT and GA applied BAT heuristics was shown in fig. 4. From fig. 3 & 4, it can be seen that the proposed heuristic BAT with GA to performing well by providing minimal makespan at lower, middle and upper limits.

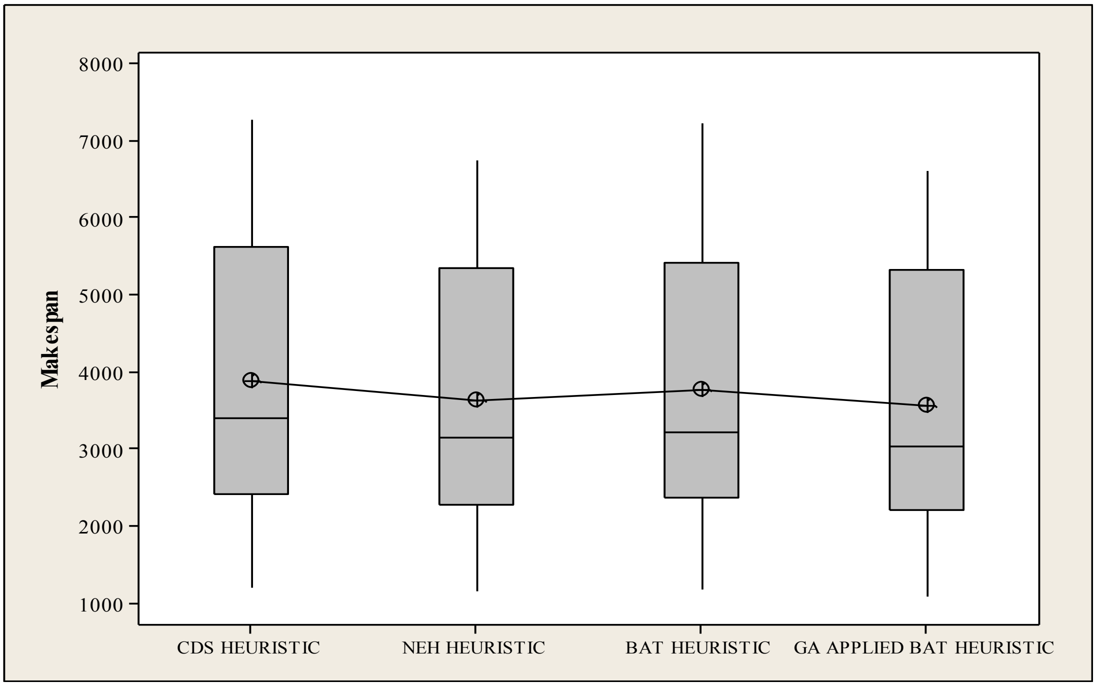

Fig. 3. Boxplot of CDS heuristic, NEH heuristic, BAT heuristic, GA applied BAT heuristic

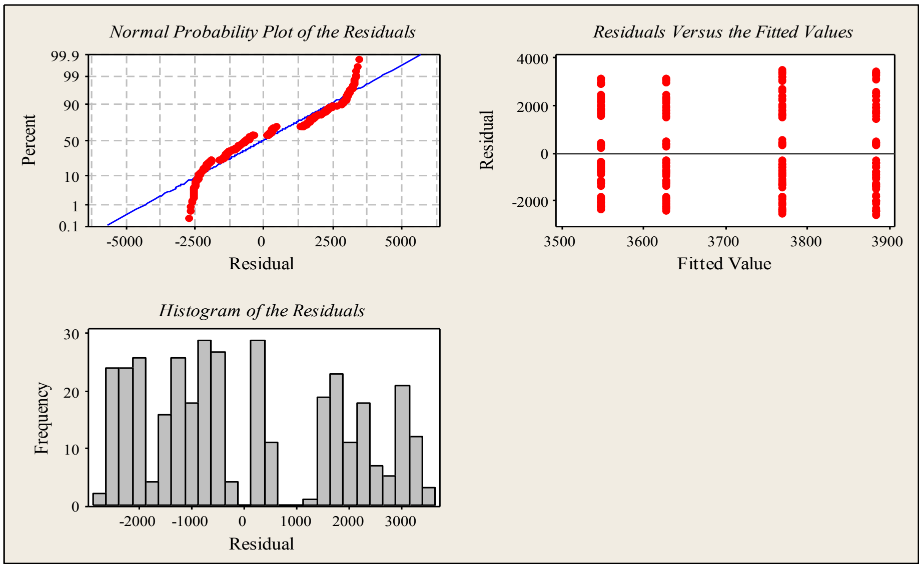

Fig. 4. Residual plots of CDS, NEH, BAT and GA applied BAT heuristics

4. Conclusion

The attempt has been very successful made to find a best neighbor in a sequence to minimize the makespan in a flowshop. The newly proposed BAT heuristic performed well in achieving the above objective and with the application of GA, an improvement of about 7% was observed in minimizing makespan. This work was evaluated through a set of benchmark problems in MATLAB environment. The results were analyzed in MINITAB platform through a statistical analysis tool called ANOVA (One- way). The success percentage achieved in nearing lower bound of the heuristics was examined and it was found that the GA applied BAT heuristic showed a raise of about 11% and 3% in minimizing the makespan compared to CDS and NEH heuristics. The ANOVA-one way stacked was used to evaluate the GA applied BAT heuristic with others and it was observed that the BAT heuristic gained a p-value of 0.625 which was greater than f-value. Thus it is seen that the newly proposed BAT heuristic performs better compared to other heuristics.

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