The application of LPT, CEGA, and PSO method on flow shop scheduling with parallel machine

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Abstract. The production system in a fabrication company often face some problems, such as the inability to deliver orders to the customer at the due time. This situation could drive the company to bear the cost of penalties. This problem can be overcome if the production schedule arranged properly. One of the indicator optimal scheduling is minimize of makespan. This research investigates a company who dealing with fabrication structure and make to order production system with flow shop production lines and parallel machine arrangements. In order to solve the scheduling problem, several methods are applied consist of the heuristic approach of the Longest Processing Time (LPT) method and the metaheuristic approach using the Cross Entropy method combined with Genetic Algorithm to Cross-Entropy Genetic Algorithm (CEGA) and Particle Swarm Optimization (PSO). The algorithm was run in MATLAB software and the results show that proposed method using the Particle Swarm Optimization (PSO) and Cross Entropy Genetic Algorithm (CEGA) obtained makespan value of 8,394 minutes. The makespan for existing scheduling condition is 9,117 minutes. The proposed methods are shown a better results.

1. Introduction

The production system in a fabrication company often have some problems, one of the problem is when unable to deliver orders to the customer at the due time. This can cause the company to bear the cost of penalties. One alternative solution is improving the production schedule. The importance of production scheduling is to properly manage existing resources in order to create effectiveness and efficiency. One of the indicator optimal scheduling is minimize of makespan. This research investigates a fabrication company which the production system is make to order with flow shop production lines and parallel machine arrangements. One of the late deliveries occurred when making Steel Bridge B-60 which is one of the types of Truss Bridge. The Company has priority rules that Cross Grider (CG), Top Chord (TC), Bottom Chord (BC), Diagonal Chord (DG), and Stringer (ST) part produce at the beginning because it has the biggest dimension. This scheduling research is limited to schedule only five parts that have a permanent sequence of jobs in the company. This research will provide the smallest makespan of scheduling results with Permutation Scheduling. This research has some assumptions that the state of the engine when production is normal, no one is in the process of maintenance or shut down, all raw materials are available at the beginning of production, and transportation time includes set-up time and set-up time will be added with process time into total
time. This research was carried out with the heuristic approach of the LPT (Longest Processing Time) method and the metaheuristic approach using the CEGA (Cross Entropy Genetic Algorithm) and Particle Swarm Optimization (PSO) using help of MATLAB software. The purpose of this research is to propose a better sequence of job in the production process of Steel Bridge B-60, calculate makespan before and after the flow shop scheduling, and calculate the percent efficiency of makespan.

2. Literature review

Production scheduling is defined as the process of allocating resources or existing machines to run a set of tasks within a certain timeframe.[1] Longest Processing Time is one of the method for scheduling parallel machine to minimize makespan and mean flow time. The step is sort jobs from the largest processing time to the smallest ($t_1 \geq t_2 \geq \ldots \geq t_n$) into the list and do scheduling based on such order. CEGA Cross Entropy - Genetic Algorithm Algorithm is the development of an algorithm which combine of Cross Entropy and Genetic Algorithm (CEGA) algorithms. The combination of this algorithm aims to expand the solution search on elite Cross Entropy (CE) samples when in optimal locality by adding a crossing mechanism and mutation in the Genetic Algorithm (GA) which serves to avoid the possibility of finding solutions stuck in the optimal local area, because the GA mechanism can produce new chromosomes that have the nature of maintaining the chromosome nature in the initial population.[2] Cross Entropy (CE) method has advantage to solve combinatorial problem such scheduling problem[3]. As an adaptive importance sampling procedure, this method has a good reputation when applied in wide range complicated problem. The PSO algorithm was introduced by Dr. Eberhart and Dr. Kennedy in 1995, was an optimization algorithm that mimicked the processes that occur in the lives of populations of birds and fish in survival. PSO models search activities for the best solution in a solution space as the flight activity of groups of particles in a solution space.[4] The position of the particles in the solution space is a solution candidate that contains optimization variables. Each of these positions will be associated with a value called objective value or the value of fitness which is calculated based on the objective function of the optimization problem to be resolved [5] The application of PSO in solving scheduling flow shop problem has been applied broadly [6].

3. RESULTS AND DISCUSSION

This is the total job time data that obtained by adding the setup and process time of each job on each machine, and multiply it by the number of parts.

| Machine | Cutting (Minutes) | Fit-Up Machine (Minutes) | Wedding LMH (Minutes) | Straightening (Minutes) | Fit-Up Fab (Minutes) | Welding (Minutes) | Finishing (Minutes) |
|---------|------------------|--------------------------|-----------------------|------------------------|---------------------|-----------------|--------------------|
| TB60-CG | 89,06            | 131,84                   | 419,34                | 155,12                 | 284,79              | 288,60          | 76,38              |
| TB60-TC | 150,70           | 220,96                   | 638,86                | 262,28                 | 478,70              | 487,04          | 130,84             |
| TB60-BC | 160,56           | 244,12                   | 707,76                | 279,16                 | 532,80              | 526,60          | 135,08             |
| TB60-DG | 323,40           | 484,12                   | 1545,00               | 562,24                 | 1056,68             | 1058,92         | 274,64             |
| TB60-ST | 565,04           | 751,90                   | 2431,32               | 975,14                 | 1679,08             | 1678,08         | 313,40             |
Table 2. Available machine

| No | Machine Name       | Quantity of Machine |
|----|--------------------|---------------------|
| 1  | Cutting Machine    | 1                   |
| 2  | Fit-Up Machine     | 1                   |
| 3  | Welding LMH        | 2                   |
| 4  | Straightening      | 1                   |
| 5  | Fit-Up Fab         | 2                   |
| 6  | Welding (Manual)   | 3                   |
| 7  | Finishing Station  | 2                   |

3.1 Existing Scheduling

This is the existing scheduling in the company with the sequence of job is 1-2-3-4-5. The Gantt Chart in Figure 1 shows the makespan for existing scheduling is 9117 minutes.

Figure 1. Gantt chart of existing scheduling

3.2 Scheduling with Longest Processing Time (LPT) method

This is the gantt chart of scheduling with LPT method with the sequence of job is 5-4-3-2-1. The makespan based on the gantt chart LPT scheduling above is 8394 minutes.

Figure 2. Gantt chart of LPT method scheduling

3.3 Scheduling Using Cross Entropy-Genetic Algorithm (CEGA) Method

1. Step 1: Select initial parameter
   - Initial Sample (N) = 10, Elite Sample Ratio (ρ) for determining the elite sample = 3%, smoothness index.
   - (α) = 0.5, cross over parameter (Pps) = 1, stopping criteria (β) = 0.0001
2. Step 2: Generate initial random population and calculate makespan as the objective function
   - Generate initial random population with roulette wheel method and random value mechanism.
   - The first step is count the total probability of each permutation (example = 5 job, 5! = 120 permutations with 120 probability) and generate 10 random number for select the population sample.
Table 3. Generate random sample

| No | Random Value | Probability Value | Permutation Value | Makespan (Minutes) |
|----|--------------|-------------------|------------------|-------------------|
| 1  | 0.026        | 0.025             | 12435            | 9120              |
| 2  | 0.178        | 0.179             | 23541            | 8705              |
| 3  | 0.238        | 0.238             | 24351            | 9031              |
| 4  | 0.290        | 0.290             | 31425            | 9117              |
| 5  | 0.313        | 0.313             | 31254            | 8794              |
| 6  | 0.411        | 0.411             | 35142            | 8554              |
| 7  | 0.456        | 0.457             | 42153            | 9429              |
| 8  | 0.531        | 0.533             | 45123            | 8717              |
| 9  | 0.570        | 0.567             | 51432            | 8394              |
| 10 | 0.676        | 0.677             | 54123            | 8394              |

3. Step 3: Select elite sample
   The formula of selecting elite sample is: \( \rho \times N \) (1), Elite sample = 0.03 \times 10 = 0.3 \approx 1. So it will be 1 elite sample that will be still appear until the last step, it never be cross over or mutation. The elite sample is a job with the smallest makespan which is sample 9 with the sequence of job is 5-1-4-3-2.

4. Step 4: Calculate Linier Fitness Rangking (LFR)
   The purpose of calculate LFR is to select parents for crossover process. This is formula for calculate LFR:
   \[
   LFR \left( \frac{(N-i+1)}{N} \right) = \frac{Fmax-(Fmax-Fmin)\times(i-1)}{(N-1)} \tag{2}
   \]
   where \( Fmax = \frac{1}{Z(1)}; Fmin = \frac{1}{Z(N)}; Fmax = \frac{1}{8394} = 0.00119; Fmin = \frac{1}{9429} = 0.00106

5. Step 5: Select Cross Over Parents
   a. Select Parents 1
      Parents 1 in this cross over process is the elite sample which is the job with the smallest makespan. So the parents 1 is Sample 9 with the job sequence is 5-1-4-3-2.
   b. Select Parents 2
      This process using LFR value. If cumulative LFR bigger than random value, then the sample become parents 2.

6. Step 6: Cross Over Update Parameter
   Cross Over Update parameter is used to get the new parameter for stopping criteria evaluation.
   \[
   Pps(i) = (1-\alpha)\times\left(\frac{Z_e}{Z_{best}}\right)+(Pps*\alpha) \tag{3}
   \]
   \[
   Pps(i) = (1-0.5)\times\left(\frac{8394}{8394}\right)+(1*0.5), Pps(i) = 0.75
   \]
   The new parameter update value will be used for a basic to determining whether a chromosome needs to be cross over or not.

7. Step 7: Cross Over. Cross Over methods that used in this research is 2-point order Cross Over
Table 4. Comparison of LFR and random value

| Sample | LFR   | Cumulative LFR | Notation | Random Value |
|--------|-------|---------------|----------|--------------|
| S9     | 0.000119 | 0.10581       | <        | 0.82211      |
| S10    | 0.000118 | 0.21033       | <        | 0.82211      |

Table 5. Generate random value for select cross over

| Sample | Random  | Pps | Conclusion      |
|--------|---------|-----|-----------------|
| S9     | 0.95321 | 0.75| No Cross Over   |
| S10    | 0.50262 | 0.75| Cross Over      |

To determine the part on parents to be crossing, two random numbers are generated for the crossing process in ceil or the parent gene. The random value is then converted to a round value, and it used as a delimiter of the sample portion that will be moved between parents.

Table 6. Cross over process

| Cross Over Parents | Job Sequence | Random Value | Ceil (random *n) | Ceil Cross Over | Cross Over Result | Result   |
|--------------------|--------------|--------------|------------------|-----------------|-------------------|----------|
| S9 VS S1           | 51432        | R1= 0,22243  | 1,11215 = 2      | 51|4|32             | 51432     | For sample S10 |
|                    | 12435        | R2= 0,58040  | 2,90200 = 3      | 12|4|35             | 12435     | For sample S6   |
| S9 VS S1           | 51432        | R1= 0,50240  | 2,51200 = 3      | 51|4|32             | 14352     | For sample S2   |
|                    | 42153        | R2= 0,62441  | 3,12205 = 4      | 421|5|3             | 42135     | For sample S8   |

8. Step 8: Mutation

Mutations are intended to bring new individuals who are different from existing individuals. The mutation process will be chosen randomly and the genes on the site will be changed in value. If the random number (R) is smaller than the parameter mutation (Pm), the digit of the gene will be replaced, and vice versa.(2) The mutation parameter values are determined by the following formula:

\[ Pm = \frac{P_ps}{2} \] (4)

After the value of the mutation (Pm) and N parameters set at is 10 samples, according to (2) the number of chromosome samples that will experience mutations can be calculated by the formula.

\[ Na = Pm \times N \] (5)

Then it can be seen that there are 4 chromosome samples that will undergo a mutation process. To determine the type of mutation on a chromosome, can be calculate as follows:

\[ K = \text{ceil} (Rand \times 3) \] (6)

From these results, there are provisions as follows:

k=1: flip mutation, k =2: swap mutation, k =3 slide mutation
Table 7. Mutation process result

| Sample | Cross Over Result | Mutation Random | Mutation Probability (Pm) | Result | Random (ri,rj) | LJ Value with n = 5 | Random K | K Value with k=3 | Mutation process | Final Result |
|--------|------------------|-----------------|---------------------------|--------|----------------|-------------------|---------|-----------------|-----------------|-------------|
| S9     | 51432            | 0,0316          | 0,375                     | Still S9 |                |                   |         |                 |                 |             |
| S10    | 51432            | 0,00694         | 0,375                     | Mutation | 0,14509        | 0,72545 = 1       | 0,03049 | 0,09147 = 1     | Flip Mutation  | 54132       |
| S6     | 12435            | 0,3455          | 0,375                     | Mutation | 0,11152        | 0,55760 = 1       | 0,59564 | 1,786692 = 2    | Swap Mutation  | 13425       |
| S2     | 14352            | 0,94869         | 0,375                     | No Mutation |              |                   |         |                 |                 |             |
| S8     | 42135            | 0,55741         | 0,375                     | No Mutation |              |                   |         |                 |                 |             |
| S5     | 31254            | 0,79088         | 0,375                     | No Mutation |              |                   |         |                 |                 |             |
| S3     | 24351            | 0,1264          | 0,375                     | Mutation | 0,12966        | 0,64830 = 1       | 0,13956 | 0,41868 = 1     | Flip Mutation  | 25341       |
| S4     | 31425            | 0,91209         | 0,375                     | No Mutation |              |                   |         |                 |                 |             |
| S1     | 12435            | 0,67069         | 0,375                     | No Mutation |              |                   |         |                 |                 |             |
| S7     | 42153            | 0,56825         | 0,375                     | No Mutation |              |                   |         |                 |                 |             |

Table 8. Makespan From New Population

| Sample | New Job Sequence | Makespan (Minutes) |
|--------|------------------|--------------------|
| S9     | 51432            | 8394               |
| S10    | 54132            | 8394               |
| S3     | 25341            | 8544               |
| S5     | 31254            | 8794               |
| S6     | 13425            | 9117               |
| S4     | 31425            | 9117               |
| S1     | 12435            | 9120               |
| S2     | 14352            | 9329               |
| S7     | 42153            | 9429               |
| S8     | 42135            | 9680               |

9. Step 9: Calculate new objective function (makespan) from the new population

This is the result of calculating the value of new objective function (makespan) of the new sample.

Based on Table 9, it is known that the makespan value with the CEGA method shows that the minimum value is 8394 minutes with a job sequence of 5-1-4-3-2 and 5-4-1-3-2.

In scheduling the CEGA method using MATLAB software, the iterations are carried out 3 times by changing the parameters of the smooth coefficient value of low (0.1), medium (0.5) and high (0.9). The Gantt chart is built according to result from MATLAB. The Gantt chart of scheduling with the smallest makespan that is until S9 with a job sequence of 5-1-4-3-2 and sample S10 with a sequence of 5-4-1-3-2.
4. Scheduling Using Particle Swarm Optimization (PSO) Method

The result in this method obtained by running process in the MATLAB software, here are the stages of the PSO method based on the results of running iteration 1:

4.1. Determination of Initial Parameters

In this research the determination of the initial parameters used are: Iteration = 10, Particle Number (N) = 5, Maximum Velocity (vmax) = 0.8, Minimum Velocity (vmin) = 0.2, Inertia Weight (w) = 0.8, Cognitive Learning Factor (c1) = 2, Social Learning Factor (c2) = 2.

4.2. Initialization

The initial position of the particle is taken from the existing condition or the existing job sequence of 1-2-3-4-5 then multiplied by 0.1 so that the position value for each particle are 0.1; 0.2; 0.3; 0.4; 0.5.

4.3. Fitness Value and Personal Best Determination

The fitness value in iteration 1 is obtained from the makespan value of the existing condition which is equal to 9.118 minutes. Personal best is a vector that describes the best position for a particle based on the best fitness value. Personal best value in this research is adjusted to the initial particles so that the personal best value for iteration 1 is the same as the initial particle sequence of 1-2-3-4-5 job sequences.

4.4. Global Best Determination

In the previous stage, it was explained that for the iteration 1 the best personal best is obtained from the initial sequence of particles so that the global best value is the same as the personal best value.

4.5. Velocity Update

Here is the velocity update in iteration 1: for particle 1 is 0.3914, for particle 2 is 0.2702, for particle 3 is 0.7200, for particle 4 is 0.2954, and for particle 5 is 0.0890. As according to the example calculation as follows:

\[ v_{11} = w_{11} + c_{1} r_{1} (p_{best11} - x_{1}) + c_{2} r_{2} (g_{best11} - x_{1}) \]

\[ v_{11} = 0.8 (-0.908) + 2 \times 0.201 (1 - 0.1) + 2 \times 0.420 (1 - 0.1) \]

\[ v_{11} = 0.3914 \]

4.6. Position Update

Here is the update position in iteration 1 for particle 1 is 0.4914, for particle 2 is 0.4702, for particle 3 is 1.0200, for particle 4 is 0.6954, and for particle 5 is 0.5890. As according to the example calculation as follows:

Example Calculation (for particle 1 in iteration 1):

At this stage there is a graph that shows the results of the PSO algorithm, and for more details can be seen in the picture below:

Figure 3. Gantt chart of the best CEGA scheduling, (a) sample 9th (b) sample 10th
Figure 4. Makespan reduced during iteration by applying PSO Method

Based on the picture above, the best makespan value obtained from the fitness value in each iteration (10 iterations) is indicated by a blue line where it starts from the iteration 1 graph decreases to iteration 2 and then starts from iteration 2 to iteration 5 graph constant, then graph decrease at iteration 6 and constant until iteration 10, it indicates that from iteration 1 to iteration 6 still changes but after iteration 6 to iteration 10 the makespan value remains constant or unchanged. From the picture above it can also be seen that the determination of the criteria when to stop to get the best makespan value is at the iteration 6 with the makespan value of 8,394 minutes with the sequence ob 5-2-1-4-3. The results of the gantt chart obtained for the best iteration are 6 iterations this PSO method that have a sequence of job 5-2-1-4-3 is shown in Figure

Based on the gantt chart above, it can be seen that makespan scheduling using the PSO (Particle Swarm Optimization) method is 8,394 minutes.

Figure 5. Gantt chart scheduling of PSO method (Particle Swarm Optimization) as the best iteration (iteration 6)

4.8. Comparison Between Existing Scheduling with LPT, CEGA and PSO method

This is the table for Comparison Between Existing Scheduling with LPT, CEGA and PSO method.

Table 9. Comparison makespan for eksisting, LPT, CEGA and PSO

| No | Method | Job Sequence | Makespan (Minutes) | Efficiency |
|----|--------|--------------|-------------------|------------|
| 1  | Existing | 1-2-3-4-5    | 9117              |            |
| 2  | LPT     | 5-4-3-2-1    | 8394              | 7.94%      |
| 3  | CEGA    | 5-1-4-3-2    | 8394              | 7.94%      |
| 4  | CEGA    | 5-4-1-3-2    | 8394              | 7.94%      |
| 5  | PSO     | 5-2-1-4-3    | 8394              | 7.94%      |

LPT Efficiency = \( \frac{\text{Makespan Existing Method} - \text{Makespan LPT Method}}{\text{Makespan LPT Method}} \times 100\% \)

= \( \frac{9117 - 8394}{9117} \times 100\% = 7.94\% \)
5. Conclusion

Based on the calculation through the heuristic method and the metaheuristic one, the minimum makespan has been achieved for the parallel machine scheduling in this research which is the 8394 minutes. The heuristic and the metaheuristic have shown their best performances. Since the metaheuristic algorithm such as CEGA and PSO have complicated procedure, for the managerial practising, the application of LPT method is recommended.

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