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(Research Article)

Flowshop scheduling problem consider makespan and breakdown machine in manufacture industry use CEGA Method (Case Study: PT X)

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Abstract

Flowshop scheduling problem (FSP) is a production scheduling consists of a set of jobs (n) executed on a number of machines (m) with the same process sequence. In 2022, PT X received a score of 97% of the target of 100% in delivery achievement. The delivery delay was caused by failure to achieve production planning. One of the main factors that causes production planning not to be achieved is the large amount of loss time which causes the machine efficiency below its standard. This research uses two scenarios, first scenario with normal conditions (does not considering breakdown machine) and the second scenario considering machine breakdown. This research discusses production scheduling using a metaheuristic method, namely the Cross Entropy-Genetic Algorithm (CEGA) method with the help of MATLAB software. CEGA simulation results show that scenario 1 produces a makespan of 40,795 minutes and scenario 2 of 53,589 minutes. Apart from that, the CEGA method can provide an efficiency value of 11.58% for scenario 1 and 16.98% for scenario 2 when compared with current production scheduling in PT X.

Keywords: Flowshop Scheduling Problem; Production Scheduling; Makespan; Breakdown Machine; Metaheuristic; CEGA

1. Introduction

Uncertainty and potential risks are one of the most important challenges in supply chain optimization [1]. The uncertainty referred to in the supply chain varies greatly, such as fluctuating demand, varying prices and varying machine breakdowns [2]. Various uncertainties in the supply chain mean that some industries are currently facing more complicated situations than before, such as demand that is difficult to predict, increasing levels of variance in customer demand and a fluctuating production environment [3]. Managers in manufacturing systems strive to increase the efficiency of the production process, but various factors and the application of different policies in an industry also influence the achievement of this goal [4]. Factors such as production scheduling, production & inventory control, maintenance planning and quality control are very important and most sustainable factors with production efficiency [5].

Flowshop scheduling is the operation of several jobs having the same process sequence along machines which are assumed to be installed in one series or for short definition is a set of m machines and a set of n jobs. Finding the optimal solution for flow shop scheduling is a difficult task and even basic problems involving several machines are considered NP-hard problems [6].

PT X is a company engaged in manufacturing with its main product is housing for the supply of automotive industries, both two-wheeled and four-wheeled. Based on customer assessment data regarding deliveries for the 2022 period, PT X received a score of 97% of the target of 100%. The delivery delay was caused by failure to achieve production

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planning. One of the main factors that causes production planning not to be achieved is the large amount of loss time which causes the machine efficiency below its standard. In production there are 3 processes sequentially, so if one process has an interruption, the next process will be interrupted, such as a part shortage or the machine in the next process will also stop, which will result in loss of productivity and will have an effect on delivery delays.

Research on flowshop scheduling problems has generally been carried out a lot. Flowshop scheduling research with the aim of minimizing makespan with several methods, namely the JJV algorithm, Palmer Method and CDS Method [7]. It was found that the JJV Algorithm and CDS Method had the same makespan objective and were smallest compared to the Palmer Method. Sambasa, et al [8] conducted research on flowshop scheduling with the aim of minimizing makespan and delays in an aviation industry with 32 jobs and 9 processes. This research succeeded in producing a schedule with makespan 18% shorter than the existing schedule.

Metaheuristic method that combines the *Cross Entropy algorithm* with the *Genetic Algorithm* with the name CEGA has developed [9]. This CEGA method is proven to produce solutions that avoid getting stuck in local areas with relatively fast computing times in research related to production scheduling with the aim of minimizing makespan.

The purpose of this research is generally to study Flowshop Scheduling Problem by considering makespan and breakdown machine using the CEGA method at PT X to get a better production scheduling with minimizing makespan.

2. Material and Methods

This research uses a quantitative approach by data analyze in the form of data and figures obtained during field studies and historical company data.

2.1. Flowshop Scheduling Problem

The Flowshop Scheduling Problem consists of two main element, a production system of "m" machines and a set of "n" jobs that will be processed on these machines [10]. All jobs must go through the same process flow starting from the first machine to the mth machine. Both flowshop and jobshop scheduling have the same goal, namely finding an optimal job sequence with existing machines to minimize job completion time.

2.2. Metaheuristic

Metaheuristics is a computational approach to finding optimal or near-optimal solutions to an optimization problem by trying iteratively to improve candidate solutions by paying attention to the limits of the quality of the solution [11]. The metaheuristic method approach uses a special and interactive algorithm that produces a global solution that is close to optimal. The metaheuristic approach is more applicable to real problems that involve large amounts of input data and produces fast calculations.

2.3. Cross Entropy-Genetic Algorithm (CEGA)

The CEGA algorithm is a metaheuristic method resulting from a hybridization of the Cross Entropy (CE) and Genetic Algorithm (GA). The CE algorithm itself is a fairly new method that can produce quite optimal results with relatively shorter computing times [12]. Meanwhile, the GA algorithm is a metaheuristic method that can avoid the possibility of optimal solutions being trapped in local optimal areas but takes longer computing time. In this CEGA algorithm, the CE method is used as the basic rule and GA is used only at the sample generation stage, namely in the crossover and mutation stages.

3. Results and discussion

3.1. Conceptual Model

The conceptual model is a consolidated model that is concise and precise to explain the research objectives. A conceptual model is a non-software simulation of a computer simulation model that explains the objectives, inputs, outputs, assumptions and simplifications of the model [13].

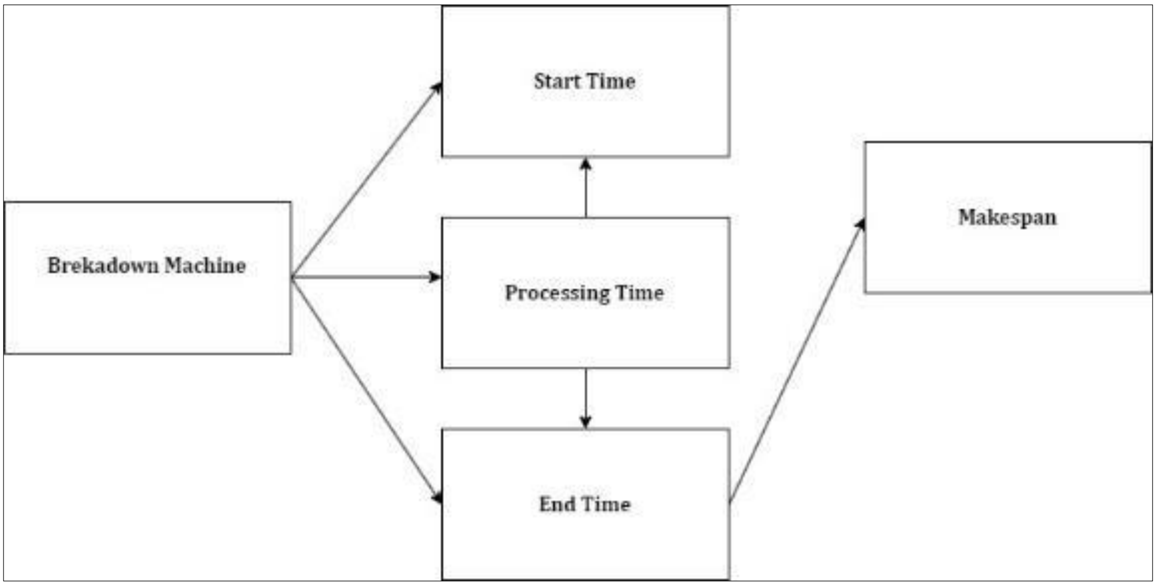

Figure 1 Conceptual Model for Flowshop Scheduling Problem with Makespan and Breakdown Machine

There are three main parameters in Flowshop Scheduling (Lee & Loong (2017) such as start time, process time and end time. Start time is the time when a job starts to be carried out, if the job is carried out on the first machine then the start time is 0. Processing time is the time needed to complete the job in that process. Finish time is the time when the job has been completed in the process. Generally, the main goal of the Flowshop Scheduling Problem is to increase competitive advantage by minimizing makespan or minimizing the total completion time where a job has completely completed all processes. In this research, we want to consider the uncertainty factor, namely breakdown machine, where if a machine suddenly breaks down, it will disrupt the process time, which will then change the finish time for that process and the start time for the next process, then it will end up increasing the total completion time or *makespan*.

3.2. Data Collection

3.2.1. Product Description

Product that will be the object of this research is part of spare part called spark plug. The spark plug is an important part to support all parts of the spark plug whose function is the entry groove when installing the spark plug in the vehicle. There are electrodes at the bottom of the housing, so current can flow through the machine to the centre electrode through the gap. The spark plug size that will be studied is M 14 x 1.50 with 16 domestic parts that will be studied. This product category was chosen because it is a fast moving product in the company, so the delivery of these goods is the main focus in achieving the delivery fulfilment target.

3.2.2. Production Flow Process

There are 3 processes in Spark Plug:

- Forming Process

The forming process is a process where a material undergoes plastic deformation to obtain the desired size, shape, and/or changes in physical and chemical properties or in short, forming is the process of forming a raw material.

- Machining Process

Machining is a manufacturing process that removes material in a controlled manner to produce the required part. This process uses several cutting tools such as chisels, drills and drills to cut some parts of the body to form other parts.

- Welding Rolling

This stage consists of two processes and there is also a complementary material, namely nickel wire. At the welding stage, there is a process of welding nickel material onto the body housing to form a part then the rolling process will continue namely forming threads.

- *Processing Time*

Processing time is a calculation of the processing time required for each job and each machine. The secondary data obtained is run rate data in or machine capacity in units of pcs/minute. Processing time can be calculated using the following formula:

$$Processing\ Time = \frac{Average\ Order\ Quantity\ (pcs)}{Run\ Rate\ (\frac{pcs}{minute})}$$

There will be 2 types of processing time will calculated, the first verse is processing time with normal condition or without consider breakdown machine and the second verse is processing with consider breakdown machine using the following formula:

$$Processing\ Time = \frac{Average\ Order\ Quantity\ (pcs)}{Run\ Rate\ (\frac{pcs}{minute}) \times (1 - \%\ Breakdown\ Machine)}$$

Table 1 Processing Time Result without Breakdown Machine

Part	Processing Time		
	M1	M2	M3
1	2,437	5,392	11,480
2	642	1,419	6,246
3	2,341	5,178	5,178
4	2,006	4,438	4,882
5	1,532	3,389	3,728
6	262	580	2,551
7	939	2,078	2,078
8	348	770	1,640
9	570	1,262	1,388
10	41	91	432
11	159	352	387
12	150	332	332
13	44	98	98
14	25	55	55
15	4	10	21
16	156	346	14

Table 2 Processing Time Result with Breakdown Machine

Part	Processing Time		
	M1	M2	M3
1	2,659	10,942	12,615
2	700	2,881	6,574
3	2,553	10,508	5,450
4	2,188	9,006	5,491
5	1,671	6,878	4,193
6	286	1,177	2,685
7	1,025	4,217	2,187
8	380	1,563	1,802
9	622	2,560	1,561
10	45	185	213
11	174	714	436
12	164	674	349
13	48	198	103
14	27	111	58
15	5	20	23
16	171	702	809

3.3. CEGA Method

3.3.1. CEGA Parameter Test

A good combination of parameters can be carried out by testing with 30 replications on the sparseness parameters (ρ) and smoothing coefficient (α). De Boer in Budiman [9] revealed that the optimal α value is 0.4; 0.5; 0.6; 0.7 and 0.8 and the optimal ρ value is 0.02; 0.03 and 0.04, so parameter tests will be carried out with this range of values.

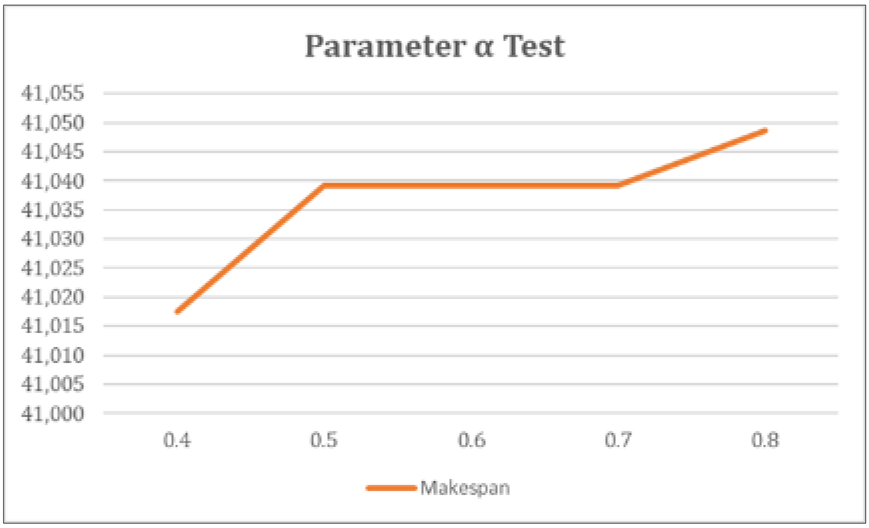

Figure 2 Parameter α Test Result

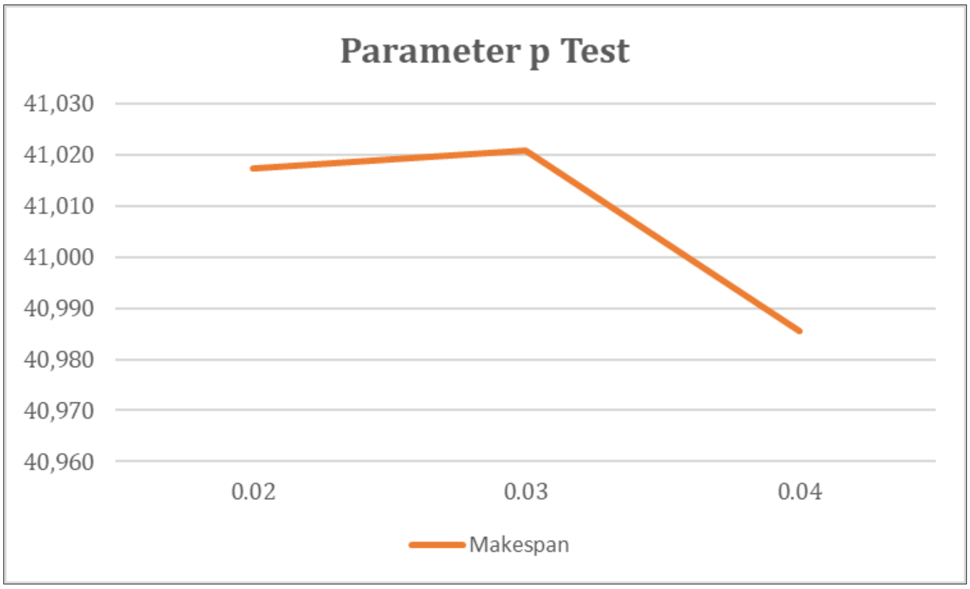

Figure 3 Parameter p Test Result

Based on Figure 2 it shows that α = 0.4 produces the minimum average value of the objective function so that 0.4 is chosen as the α that will be used for simulations with the CEGA algorithm. Meanwhile, based on Figure 3, it shows that a value of þ = 0.04 can produce the minimum objective function value compared to the value of ρ for other parameters, so in this research will use α = 0.4 and þ = 0.04 for the simulation.

3.3.2. Input and Output Definition

The purpose of this research is to get a production scheduling sequence with minimized makespan results. The input used in this research is processing time matrix (W) in minutes where the rows represent the jobs or parts to be worked on and the columns represent the processes or machines that are passed. The output in this research is a schedule consisting of job sequence (X) and makespan (C).

3.3.3. Parameter Initialization

At this stage, the parameters required for the CEGA method are input, such as the number of samples (N), smoothing coefficient (α), sparseness parameter (ρ), crossover parameter (P_{ps}) and stopping tolerance (β). Reference to parameter test result that has calculated in 3.3.1, here are parameters that used in this research:

- The number of samples (N) is n3, the number of jobs in this study is 16 jobs, so the sample generated is 4,096 samples
- The sparseness parameter (p) uses a value of 0.04
- The smoothing coefficient (α) uses a value of 0.4
- The crossover parameter (P_{ps}) uses a default value of 1
- Stopping tolerance (β) uses a default value of 0.0001

3.3.4. Initial Random Sample Generation

The initial random sample generation use the “randperm” command function in MATLAB, this function aims to generate random scheduling or job sequences and the numbers that come out are positive integers. The following is an example of 3 samples that generated.

$$X_1 = 15 - 11 - 6 - 10 - 9 - 8 - 13 - 2 - 14 - 12 - 5 - 3 - 7 - 16 - 1 - 4$$

$$X_2 = 10 - 6 - 2 - 12 - 15 - 5 - 4 - 14 - 7 - 1 - 8 - 13 - 11 - 9 - 3 - 16$$

$$X_3 = 10 - 12 - 6 - 2 - 7 - 16 - 14 - 11 - 13 - 15 - 3 - 9 - 5 - 8 - 1 - 4$$

3.3.5. Objective Function Calculation

This research has the objective function of knowing the job sequence in the form of production scheduling with minimized makespan. The following is a sample objective function calculation for X1-X3. This objective function calculation is carried out on the entire sample that has been generated.

Table 3 Objective Function Calculation

Sample	Job Sequencing	Makespan (minutes)
X1	15-11-6-10-9-8-13-2-14-12-5-3-7-16-1-4	41,197
X2	10-6-2-12-15-5-4-14-7-1-8-13-11-9-3-16	40,961
X3	10-12-6-2-7-16-14-11-13-15-3-9-5-8-1-4	40,849

3.3.6. Define Elite Sample

Based on the results of previous parameter tests, the þ value used is 0.04 and N is 16. To determine the elite sample by multiplying the þ value and the number of jobs:

$$N_e = 0.04 \times 16 = 0.64 = 1$$

The result for the elite sample was 0.64, which was then rounded to 1. The selected elite sample was the one that had the smallest objective function value among the samples generated so that the calculated objective function value would be ranked first from smallest to largest value.

Table 4 Objective Function Result for Elite Sample

Sample	Job Sequencing	Makespan (minutes)
X3	10-12-6-2-7-16-14-11-13-15-3-9-5-8-1-4	40,849
X2	10-6-2-12-15-5-4-14-7-1-8-13-11-9-3-16	40,961
X1	15-11-6-10-9-8-13-2-14-12-5-3-7-16-1-4	41,197

The value X3 has the smallest objective function value so CX3 will be the elite sample.

3.3.7. Elite Sample Weighting

The elite sample weighting is obtained from the results of the objective function from the previous iteration, due to number of elite samples is 1 in previous iteration so the weight used is also the same as the elite sample value.

3.3.8. Linear Fitness Ranking (LFR)

The LFR value obtained will be used to select parents in the crossover stage. The following is the LFR calculation formula:

$$LFR_{(I(N-i+1))} = F_{max} - (F_{max} - F_{min}) \times \left(\frac{(i-1)}{(N-1)}\right)$$

$$F_{max} = \frac{1}{C(1)}$$

$$F_{min} = \frac{1}{C(N)}$$

Table 5 Linear Fitness Ranking Calculation Result

Sample	Job Sequencing	LFR
X3	10-12-6-2-7-16-14-11-13-15-3-9-5-8-1-4	0,00002470
X2	10-6-2-12-15-5-4-14-7-1-8-13-11-9-3-16	0,00002449
X1	15-11-6-10-9-8-13-2-14-12-5-3-7-16-1-4	0,00002427

3.3.9. Elitism

Elitism has purpose to keep samples that have the best value or those that have the smallest objective function value. In this calculation sample X3 is a sample that will experience elitism.

3.3.10. Cross-Over Parent Selection

The crossover mechanism used is a roulette wheel where the first parent is selected from the elite sample while the second parent is selected from the overall sample generated.

3.3.11. Cross-Over Mechanism

The crossover principle used in this research is 2-point order crossover. This stage will generate a random value, if the random value is smaller than the previously selected crossover parameter then the two parents will crossover and vice versa, if the random value is greater then there will be no crossover.

Table 6 Crossover Result

Sampel	Random Value	Judgement
X3 = 10-12-6-2-7-16-14-11-13-15-3-9-5-8-1-4	0,2281	crossover
X1 = 15-11-6-10-9-8-13-2-14-12-5-3-7-16-1-4	0,2555	crossover

3.3.12. Termination Criteria Check

The stopping criterion can calculated by difference between the I mutation parameter and the i+1 mutation parameter. If the absolute result exceeds the beta value then will do iteration, conversely if the absolute value is smaller then the iteration will stop.

$$\varepsilon = |0{,}4 - 1| = 0{,}6 \geq 0{,}0001$$

The absolute result produced is still greater than the stopping characteristic value, so it is necessary to do iteration.

3.3.13. Mutation

Table 7 Mutation Result

Sampel	Random Value	Judgement	Result
X3 = 12-7-6-10-2-16-14-11-13-15-3-9-5-8-1-4	0,230	Mutation	X3 = 12-7-13-10-2-16-14-11-6-15-3-9-5-8-1-4
X1 = 15-11-6-2-10-9-8-13-14-12-5-3-7-16-1-4	0,167	Mutation	X1 = 15-11-14-2-10-9-8-13-6-12-5-3-7-16-1-4

The mutation mechanism used in this research is swapping mutation. The mutation parameter value reference to previous parameter test is 0.4. Mutation begins by generating random numbers for each sample that has been previously crossed. If the random number is smaller than the mutation parameter, the sample do mutation.

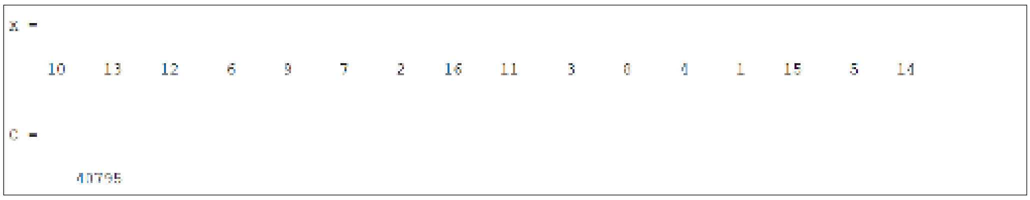

Figure 4 CEGA Simulation Result for Scenario 1

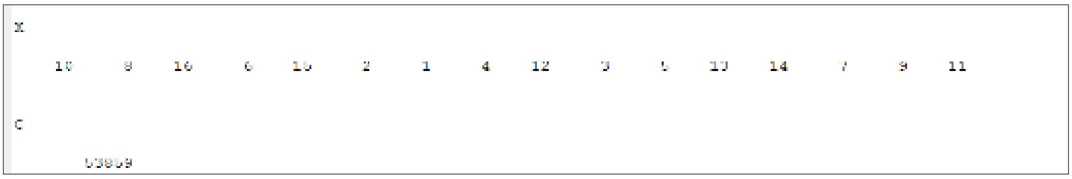

Figure 5 CEGA Simulation Result for Scenario 2

Table 8 CEGA Result

Scenario	Job Sequencing	Makespan (minutes)
Scenario 1 (Normal Condition)	10-13-12-6-9-7-2-16-11-3-8-4-1-15	40,795
Scenario 2 (Consider Breakdown Machine)	10-8-16-6-15-2-1-4-12-3-5-13-14-7-9-11	53,859

3.4. Efficiency Calculation

Table 9 Efficiency Achievement Result for Existing Condition with CEGA Method

Scenario	**Existing Condition**		***CEGA***		**% Efficiency**
	Job Sequencing	Makespan (minutes)	Job Sequencing	Makespan (minutes)	
Scenario 1 (*Normal Condition without Breakdown Machine*)	5-4-6-2-9-11-3-12-14-1-10-15-7-13-8-16	46,140	10-13-12-6-9-7-2-16-11-3-8-4-1-15	40,795	11.58%
Scenario 2 (*Consider Breakdown Machine*)	5-4-6-2-9-11-3-12-14-1-10-15-7-13-8-16	64,875	10-8-16-6-15-2-1-4-12-3-5-13-14-7-9-11	53,859	16.98%

Efficiency is calculated to show how good the CEGA method solution is in the case of production scheduling. Currently PT does not have production scheduling, it tends to be done based on manifest priorities released by customers so that work on existing jobs tends to be rando. Efficiency can calculated with following formula:

$$Efficiency = \frac{Makespan_{existing} - Makespan_{CEGA}}{Makespan_{existing}} \times 100\%$$

It was found that for scenario 1 with normal conditions without considering the machine breakdown it could produce an efficiency value of 11.58%, which means that the CEGA method was successful in producing a production sequence with better makespan minimization compared to existing conditions. In scenario 2, with the condition of considering machine breakdown, it can produce an efficiency value of 16.98% respectively which means that the CEGA method has succeeded in producing a production sequence with better makespan minimization compared to existing conditions, so it can be concluded that the CEGA method can provide more efficient production scheduling performance when compared to existing conditions.

4. Conclusion

The results of the research showed that CEGA method can be used in flowshop production scheduling with a purpose to minimize makespan. In PT X case study, CEGA method an efficiency value of 11.58%, which means that the CEGA method was successful in producing a production sequence with better makespan minimization compared to existing conditions. In scenario 2, with the condition of considering machine breakdown, it can produce an efficiency value of 16.98% .

Compliance with ethical standards

Conflict of interest statement

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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