

Minimizing Mean Weighted Expected Tardiness by Integrating Preventive Maintenance and Production Scheduling Using Genetic Algorithm

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Abstract

Manufacturing industry that produces various plastic packaging products experience high frequency of machine breakdowns that consequently cause tardiness in completing orders. Based on importance, orders are given different weights of priorities. The earliest due date rule method that is currently used for production scheduling, is causing delays in multiple job completions, increasing average tardiness. Currently, both corrective maintenance and production scheduling are planned separately, even though both are intertwined. Given the strong correlation between the two, this study seeks to integrate preventive maintenance and production scheduling to generate production schedules that can minimize the mean weighted expected tardiness. Data processing starts by identifying machines with highest downtime value and identifying critical machine components that are causing downtimes. Based on data collection and processing, Injection Machine 650-ton has the highest down time. By calculating Preventive Maintenance, we obtain time intervals for inspection and preventive replacements for each component. Following that, orders are sorted using single machine scheduling, resulting in a mean weighted expected tardiness of 78 hours. By integrating preventive maintenance and production scheduling, the mean weighted expected tardiness resulted in 43 hours. After using genetic algorithm, the mean weighted expected tardiness further declines to 32 hours.

Keywords

corrective maintenance, preventive maintenance, production scheduling, minimizing mean weighted expected tardiness, genetic algorithm.

1. Introduction

1.1. Background

Competition in fulfilling customer demands are ever increasing in the manufacturing industry, driving company's production targets upward. Production scheduling and preventive maintenance (PM) are two subjects that have been seriously researched to support innovations and advancements in the manufacturing industry. While the two are planned and calculated in isolation, both are highly correlated. Preventive maintenances take time thus affecting the available time for production. However, undermining the importance of preventive maintenance can be detrimental as it will increase the probability of machine failures.

Typically, production schedules are often interrupted by equipment failures, which could be prevented by proper preventive maintenance. However, in order to expedite production, recommended PM intervals are often delayed. Despite the trade-offs between the two activities, they are typically planned and executed independently in real manufacturing settings even if manufacturing productivity can be improved by optimizing both production scheduling and PM planning decisions simultaneously. A vast number of studies have been conducted in these two areas in past decades. Nevertheless, almost all relevant studies considered production scheduling and PM planning as two independent problems and therefore solve them separately. Only a few studies have tried to combine both problems to solve them simultaneously. Cassady and Kutanoğlu (2003) developed an integrated mathematical model for a single machine problem with total

weighted expected tardiness as the objective function. Their model allows multiple maintenance activities and explicitly captures the risk of not performing maintenance.

In this study, the genetic algorithm procedure is successfully applied to the integrated optimization model for production scheduling and preventive maintenance planning with the total weighted expected tardiness objective function introduced by Cassady and Kutanoglu (Sortrakul, 2007). Genetic algorithm is one of the meta-heuristics that has attracted many researchers. The genetic algorithm (GA) belongs to the category of evolutionary algorithm, a class of heuristic search techniques inspired to survival-of-the-fittest Darwinian evolution principles. GA works iteratively on a population of candidate solutions for solving scheduling problems in manufacturing systems (Ławrynowicz, 2011).

Integrated models are expected to provide better savings over disjoint models. Research in integrated modeling still has great potential to further contribute to more efficient utilization of resources justified by the expected savings provided by integrated modeling. Hadidi, et al. also developed a classification scheme for problems related to production scheduling and maintenance planning and reviewed the literature related to both based on Cassady and Kutanoglu model (Hadidi, 2012).

1.2. Research Question

Through observations and interviews, it is understood that high machine downtime is negatively affecting production process, causing delays in fulfilling orders and each order is weighted differently. Currently, the company uses corrective maintenance method for machinery maintenance system, causing multiple unexpected machine breakdowns in the middle of production. The company applies earliest due date rule for scheduling, however the rule tends to exacerbate the number of job delays, further causing a high average tardiness.

1.3. Purpose of the Study

Based on the above issue, this study aims to minimize the mean weighted expected tardiness by integrating preventive maintenance and production scheduling.

2. Review of Related Literatures

2.1. Maintenance

Maintaining a system is usually related to maintenance actions such as repairing, replacing, overhauling, inspecting, servicing, adjusting, testing, measuring and detecting faults in order to avoid any failure that would lead to interruptions in production operations (Duffuaa et al., 2001; Ismail et al., 2009). Corrective maintenance (CM) is one of the maintenance policies by which maintenance actions, such as repair or replacement are carried out on a system to restore it to its required functioning after it has failed (Paz and Leigh, 1994). However, this policy leads to high levels of system breakdown and high repair and replacement costs, due to sudden failures that potentially can occur. Another maintenance policy, Preventive Maintenance (PM) serves as an alternative to CM (Kimura, 1997). Normally, PM is planned and performed after a specified period of time, or when a specified system has been used, in order to reduce the probability of its failure (Basri, 2017).

2.2. Scheduling

According to Baker (1974), scheduling is the process of allocating resources to choose a set of tasks in a specific period of time. Notations commonly used for scheduling are as follows (Bedworth and Bailey, 1987):

- *Processing time* (t_j)
- *Setup time* (s_j)
- *Due date* (d_j)
- *Completion time* (c_j) = $c_{t-1} + t_j$ (2.1)
- *Tardiness* is a form of *Lateness* with positive value.
 $Tardiness = (c_i - d_i) \geq 0$ (2.2)
- *Mean Tardiness* is the average of total *tardiness*.

2.3. Integrating Production and Preventive Maintenance

Cassady and Kutanoglu investigated the value of integrating production and Preventive Maintenance (PM) scheduling. This model was developed for a single machine that has increasing hazard rate, i.e. subjected to failure. Each time the machine fails, it needs a fixed time to repair. Expected number of failures can be minimised by performing preventive maintenance before the start of the job which will restore the machine to an ‘as-good-as-new’ condition. This PM will delay the start of the job by fixed time to maintain tp , nevertheless. If the machine is required to process n jobs with the objective to minimise their expected total completion times then the scheduler is required to provide simultaneously, optimal sequence and, when to perform PM’s. To represent the problem in the form of mathematical programme, a binary variable $y[i]$ is defined where $y[i] = 1$ if PM is conducted and $y[i] = 0$ if PM is not conducted. Let $P[i]$ be the processing time for job i (Cassady, 2005).

2.3.1. Determining Machine Working Age

It is assumed that delay in job processing due to machine failures can be continued without any penalty. During the production process, machines can not be stopped for preventive maintenance and only 1 failure is allowed when performing a job.

$a_{[0]}$ = machine age prior to any production and PMs

$\bar{a}_{[i-1]}$ = machine age right before a job started (or after **PM**, if any)

$a_{[i]}$ = machine age right after a job is finished

$y_{[i]}$ = 1, if PM is performed prior to a job and $y_{[i]} = 0$ if there is no **PM** prior to a job.

$$\bar{a}_{[i-1]} = a_{[i-1]} (1 - y_{[i]}) \quad i=1, 2, \dots, n \quad (2.3)$$

$$a_{[i]} = \bar{a}_{[i-1]} + p_{[i]} \quad i=1, 2, \dots, n \quad (2.4)$$

2.3.2. Machine Failures Probability Calculation

Calculation is performed to know the probability of a machine to experience failures while performing a job. The formula uses a Weibull distribution parameter according to TTF distribution of data.

$$F(p_{[i]} + \bar{a}_{[i-1]} | \bar{a}_{[i-1]}) = 1 - \exp \left[- \left(\frac{p_{[i]} + \bar{a}_{[i-1]}}{\eta} \right)^\beta + \left(\frac{\bar{a}_{[i-1]}}{\eta} \right)^\beta \right]$$

where,

Probability of machine failure:

$$\Phi_{[i]} = F(p_{[i]} + \bar{a}_{[i-1]} | \bar{a}_{[i-1]}) \quad (2.5)$$

Probability of machine performing without failure:

$$\bar{\Phi}_{[i]} = 1 - F(p_{[i]} + \bar{a}_{[i-1]} | \bar{a}_{[i-1]}) \quad (2.6)$$

Probability mass function is calculated using this equation:

$$\pi(i,k) = \Pr \{M[i] = ktr\} = \sum_{N_{i,k}} \prod_{1 \in N_{i,k}} \Phi_{[i]} \prod_{1 \in N_{i,k}} \bar{\Phi}_{[i]} \quad (2.7)$$

2.3.3. Completion Time Calculation

Completion time calculation is as follows:

$$c_i = tp \sum_{i=1}^i y_{[i]} + \sum_{i=1}^i p_{[i]} + M_{[k]} \quad (2.8)$$

with:

c_i = completion time

tp = inspection time

$y_{[i]}$ = PM decision variable

$p_{[i]}$ = processing time for a job

$M_{[i]}$ = time needed for repairment during failures

2.3.4. Tardiness Calculation

This calculation is performed to know the delay of a job from the set due date. The equation for tardiness is as follows:

$$\Theta_{i,k} = \max(0, c_{i,k} - d_i) \quad (2.9)$$

where,

$c_{i,k}$ = job completion time

d_i = job due date

The equation for expected tardiness is as follows:

$$E(\Theta)_{[i,k]} = \Theta_{i,k} \pi_{i,k} \quad (2.10)$$

2.3.5. Objective Function Calculation

The objective function is to minimize mean weighted expected tardiness by identifying PM and job sequence:

$$\frac{\sum_{i=1}^n w_{[i]} E(\theta_{[i]})}{n} \quad (2.11)$$

where,

$w_{[i]}$ = rate of importance of i job

n = number of *job*

2.4. Genetic Algorithm

Genetic algorithm is a searching technique and optimization technique that mimics the process of evolution and the changes of genetic structures of a living being. The main principle of the way genetic algorithm works is inspired by natural selection process and genetics principles (Arkeman, 2012).

The stages of genetic algorithm are as follows: (Arkeman, 2012).

- **Chromosome Representation**

The first step in obtaining genetic algorithm is to encode a proposed solution into a form of chromosome representation.

- **Evaluation of Fitness Function and Objective Function**

Genetic algorithm functions by determining the effectiveness of a chromosome in resolving a problem. Measurement is done using fitness function.

- **Tournament Selection**

Tournament selection follows the following steps; (1) Randomly selecting two chromosomes from a population; (2) Comparing fitness values between the two chromosomes; and (3) Selecting the chromosome with a lesser fitness value.

- **Partially Mapped Crossover (PMX)**

PMX was first introduced by Goldberg dan Lingle (1985). PMX technique can be seen as an improvement from two-point crossover, which is an improvement technique to avoid illegal chromosomes. A modified PMX technique is as follows ; (1) Taking a pair of parent chromosome derived from selection process; (2) Determining random two-point crossovers in each of the chromosomes; (3) Performing crossover for the two chromosomes using PMX rule; (4) As a result of the crossover, there are 2 new chromosomes and inserted into the next population.

- **Swap Mutation**

Swap mutation technique will pick two positions in each chromosome randomly. Those two position then swapped.



Figure 1. Swap Mutation

3. Research Methodology

The research begins with preliminary research and literature studies and based on problem identification, research objectives can be determined. Next is data collection for data processing and analysis needs. Data processing starts by identifying machines with highest downtime value and identifying critical machine components that are causing downtimes. Based on data collection and processing for the critical machine components, we calculate Preventive Maintenance to obtain time intervals for inspection and preventive replacements for each component. Next, based on job orders using single machine scheduling with minimum mean weighted expected tardiness, we integrate the preventive maintenance calculation and the production scheduling result and then by using genetic algorithm, we obtain the job schedule. The objective function of the study is to get the minimum mean weighted expected tardiness. Figure 2 below shows flow chart of the research.

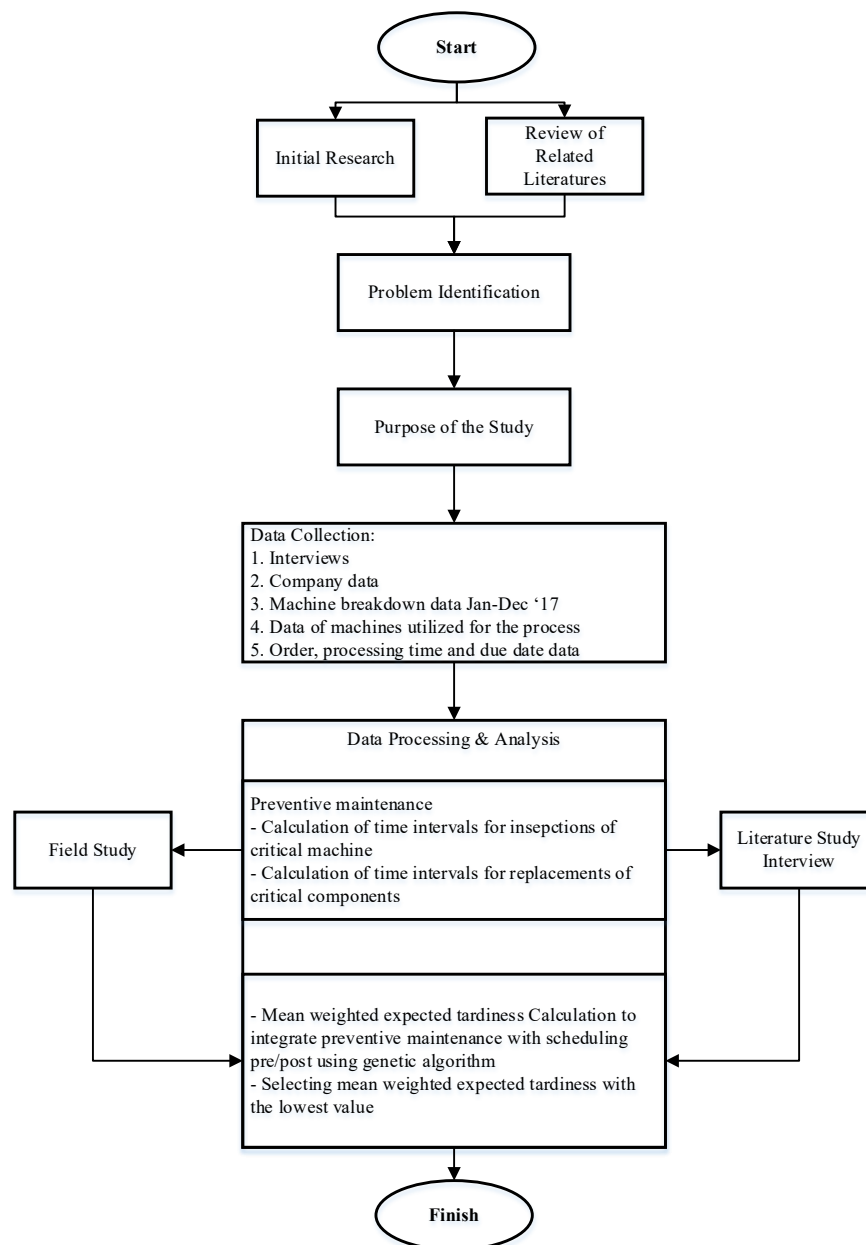


Figure 2. Research Flowchart

4. Results & Discussions

4.1. Determining Time Intervals for Inspection and Component Replacement for Critical Machines

Injection Machine 650-ton is chosen as the machine with highest downtime based on January – December 2017 total downtime data for injection machines. The decision to choose a critical component is based on the component downtime and all components in the injection machines are critical component, with total downtime of 121.667 hours.

A reduction in the frequency of machine failures (increasing machine reliability) is still achievable by performing inspections within a certain time interval. Based on calculation, we can derive that the inspection time interval is every 78 hours. However, intervals for critical components replacements vary and that timing will be used in the analysis to integrate PM with scheduling.

Table 1. Time Intervals for Component Replacements – Injection Machine 650 Ton

Machine	Critical component	Age Replacement (hours)
Injection 650 Ton	Heater	661
	Limit Switch	794
	Magnetic Contractor	2036
	Nozzle	162
	Piston Injector	795
	PU Pipe	1209

4.2. Job Sequencing

There are 6 types of products that are produced by Injection Machine 650 ton where each product is notated as order or job. Each job is categorized based on weight of importance that is determined by the company. There are 3 categories based on priority. In this case, all jobs have the same weight, which is 1. Job sequencing is then done using several scheduling rules with the objective of minimizing mean weighted tardiness. The selected job sequence is then integrated with PM activities.

The following is an example of calculating production scheduling based on the rules of Shortest Processing Time (SPT). The order of jobs based on SPT is job 2, job 1, job 6, job 4, job 5 and job 3.

Table 2 Mean Weighted Tardiness Calculation using SPT Rule

Job	Completion Time	Due Date	Tardiness	Weight
2	44.324	72	0	1
1	109.504	144	0	
6	191.904	288	0	
4	270.571	168	102.571	
5	402.811	384	18.811	
3	582.21	264	318.21	
Mean Weight Tardiness (hours)				73.265

Next is the calculation of production scheduling for the 6 jobs based on the rules of Earliest Due Date (EDD) and Weighted Shortest Processing Time (WSPT). The sequence of jobs obtained using SPT and WSPT is same. Mean tardiness is obtained by averaging total tardiness = $(0 + 0 + 0 + 102,571 + 18,811 + 318.21) / 6 = 73,265$ hours. The following is a summary of job sequencing using different scheduling rule. The chosen sequence is the sequence that resulted in the smallest mean weighted tardiness value, the sequence of jobs based on SPT and WSPT (Job 2 - 1 - 6 - 4 - 5 - 3).

Table 3 Summary of Job Sequence

Schedulling rule	Job sequence	Mean Weighted Tardiness (Hours)	Makespan (Hours)
SPT	2-1-6-4-5-3	73.265	582.21
EDD	2-1-4-6-3-5	77.959	
WSPT	2-1-6-4-5-3	73.265	

The results of job sequences based on scheduling results are illustrated in the following Gantt Chart in figure 3 and figure 4. The sequence of jobs based on EDD rules is Job 2 - 1 - 4 - 6 - 3 - 5 while jobs based on SPT and WSPT rules are Job 2 - 1 - 6 - 4 - 5 - 3 resulting in the same makespan value which is equal to 582.21 hours.

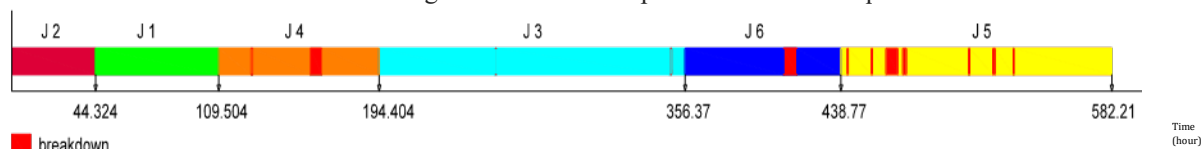


Figure 3. Gantt Chart of the Job Sequence using EDD

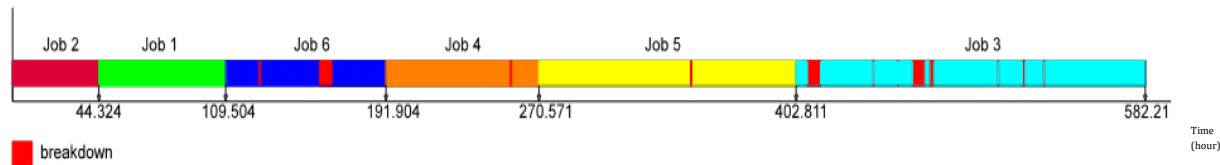


Figure 4. Gantt Chart of the Job Sequence using SPT and WSPT

The chosen job sequence is then used as a basis to be integrated with Preventive Maintenance activities.

4.3. Integrating Preventive Maintenance

The calculation is performed to know the best timing to perform preventive maintenance and job scheduling.

4.3.1. Machine Working Age Calculation

Machine can not be interrupted with any preventive maintenance activities when it is currently performing a job (non-preemptive). Hence, PM can only be performed prior to any job. The calculation of the machine working age will consider the optimum machine inspection time interval, which is 78 hours. Moreover, estimating machine working time also considers interval for component replacements, which is 162 hours (nozzle component).

Table 4. Calculation of machine working time

i	job	$a_{[i-1]}$	$y(i)$	$\bar{a}_{[i-1]}$	p_i (hours)	PM tp (hours)	C_i (hours)
1	2	0	0	0	44.324	0	44.324
2	1	44.324	0	44.324	65.18	0	109.504
3	6	109.504	1	0	75.4	1	185.904
4	4	75.4	0	75.4	77.9	0	263.804
5	5	153.3	1	0	131.54	1	396.344
6	3	131.54	1	0	160.5	1	557.844

$y_{[i]}$ is a notation for PM activities. $y_{[i]} = 1$ if all PM is performed prior to a job and $y_{[i]} = 0$ if there is no PM prior to a job. The decision to perform PM is according to the below criteria:

1. If the value of $a_{[i-1]}$ has exceeded the limit of optimum inspection interval (78 hours), then PM is to be performed prior to the next job.
2. If the value of $a_{[i-1]}$ has not exceeded 78 hours, but the value of $a_{[i-1]} + p_i$ has exceed the minimum time interval for replacement (162 hours), then PM still is to be performed prior to the next job. This is performed when the machine working age has not exceeded the time interval limit of component replacement to avoid component wear out that will in turn cause machine breakdown.

Determining time interval for component replacement is helping to decide PM activities to not exceed component replacement timing. This is performed to avoid any breakdown caused by component failure. Sample calculation is as follows:

For $i \rightarrow 1$

$$\bar{a}_{[1-1]} = a_{[1-1]} (1 - y_{[1]}) = 0 (1 - 0) = 0$$

$$a_{[1]} = \bar{a}_{[1-1]} + p_{[1]} = 0 + 44,324 = 44,324$$

Machine working age prior to performing a job is zero hour. The first job to be processed according to the sequence is job 2. This first job (job 2) requires 44.324 hours, hence machine working age post processing job 2 is 44.324 hours. The second job (job 1) requires 65.18 hours.

Machine working age after processing job 2 and job 1 is 109.504 hours. Machine working age prior to the third job has exceeded 78 hours, which is the optimum interval for inspection. Therefore, PM needs to be performed prior to the third job. Machine working age calculation for the next job is performed using the same method. If you apply the same machine working age calculation, you can conclude that PM is performed prior to job 6, 5 and 3.

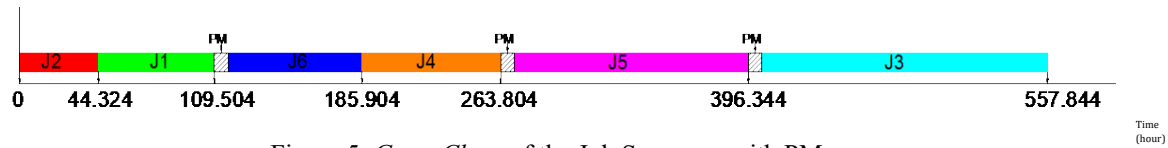


Figure 5. Gantt Chart of the Job Sequence with PM

Based on the above gantt chart, we can conclude that the completion time to complete all jobs and PM activities is 557.844 hours.

4.3.2. Probability Mass Function Calculation

This calculation aims at knowing the probability of failure when performing a job with the integration of PM into the schedule.

$$F(p_{[i]} + \bar{a} [i - 1] | \bar{a} [i - 1]) = 1 - \exp \left[- \left(\frac{p_{[i]} + \bar{a} [i - 1]}{\eta} \right)^{\beta} + \left(\frac{\bar{a} [i - 1]}{\eta} \right)^{\beta} \right]$$

$$\Phi_{[1]} = 1 - \exp \left[- \left(\frac{44,324+0}{93} \right)^{0,95934} + \left(\frac{0}{93} \right)^{0,95934} \right] = 0,3881$$

Probability mass function is calculated using the following equation:

$$\pi(i,k) = \Pr \{M[i] = ktr\} = \sum_{Ni,k} \prod_{1 \in Ni,k} \Phi_{[i]} \prod_{1 \in Ni,k} \bar{\Phi}$$

Value of $M_{[k]}$ is time for repair when breakdown happens.

$$t_r = MTTR = 0,9591$$

In this calculation, we calculate the time required for repair when breakdown happens k times. Sample of calculation:

$$M_{[0]} = \text{Time for repair without any breakdown (k=0)} = 0 \times 0,9591 = 0$$

$$M_{[1]} = \text{Time for repair if breakdown happens 1 time (k=1)} = 1 \times 0,9591 = 0,9591$$

4.3.3. Completion time Calculation

The calculation *completion time* is a time between job start $t=0$ until job finished.

$$c_{i,k} = tp \sum_{i=1}^i y_{[i]} + \sum_{i=1}^i p_{[i]} + M_{[k]}$$

$$tp = 1 \text{ hour}$$

completion time job 2 if machine failure 1 time, is (k=1) 110,463 hours

$$C_{2,1} = tp \sum_{i=1}^2 y_{[i]} + \sum_{i=1}^2 p_{[i]} + M_{[1]} = \{1(0+0)\} + (44,324+65,18) + 0,9591 = 110,463$$

4.3.4. Tardiness Calculation

The calculation is performed to know the delay of completing a job from the set due date.

$$\Theta_{i,k} = \max (0, c_{i,k} - d_i)$$

Sample of calculation:

$$\Theta_{2,1} = \max (0, c_{2,1} - d_2) = \max \{0, (110,4631 - 144)\} = 0$$

4.3.5. Objective Function Value Calculation

The objective function of this study is to calculate the mean weighted expected tardiness. The addition of the word “weighted” is to portray the different priority of each job as determined by the company. Expected tardiness is the expected value of job delays by considering the probability of breakdown with the existence of PM activities. Expected tardiness is the accumulated value of probability of delays.

Table 5. Mean Weighted Expected Tardiness Calculation

job	Expected Tardiness	Weighted Expected Tardiness
2	0	0
1	0	0
6	0	0
4	85,7238	85,7238
5	10,2138	10,2138
3	161,4953	161,4953
objective function value		42,9055

- Expected Tardiness = $\sum_{k=0}^i \theta_{[i,k]} \pi_{[i,k]}$

Example:

$$E\theta_{[1]} = \sum_{k=0}^1 \theta_{[1,1]} \pi_{[1,1]} = 0 (0,6119) + 0 (0,3881) = 0$$

- Calculation of Weighted Expected Tardiness

$$\text{Weighted expected tardiness} = w_{[i]} E(\theta_{[i]})$$

where: $w_{[i]}$ is the weighted value of each job.

Example:

$$w E(\theta_{[1]}) = w_1 E(\theta_{[1]}) = 1 \times 0 = 0$$

- Mean weighted expected tardiness = $\frac{\sum_{i=1}^n w_{[i]} E(\theta_{[i]})}{n}$

$$= \frac{0+0+0+85,7238+10,2138+161,4953}{6} = 42.9055 \text{ hours.}$$

4.4. Genetic Algorithm

4.4.1. Coding

Coding is the process to code or form a chromosome structure. A chromosome consists of smaller units called genes. In this study, genes are the jobs being performed, and the chromosome is the job sequence.

4.4.2. Population Initialization

In this particular case study, a population consists of 10 chromosomes. Initial population $P(0)$ consists of chromosomes that are randomly generated using random integer using matlab R2013a software.

4.4.3. Fitness Value Evaluation

Fitness value is calculated for each chromosome that is under evaluation. The fitness value in this study is the mean weighted expected tardiness. Fitness calculation for each chromosome is calculated by integrating PM and scheduling.

4.4.4. Selection

Chromosome then is selected to become parent for the next generation. In this study, the chosen method for selection is the tournament selection. Example of the tournament selection for generation-0 to select parents for population 1:

1. Choose chromosome 2 and chromosome 3.
2. Fitness value chromosome 2 is 157.1037. Compared to fitness value chromosome 3, which is 88.6869.
3. Choose chromosome 3, because it's deemed to be more fit (having a lower fitness value). After chromosome 3 is chosen to become a mother (one of the parent), then the same steps are repeated to choose the chromosome of the father.

4.4.5. Reproduction

- Elitism**

Two chromosomes with the best fitness value from the previous generation will automatically survive to the next generation. This concept of reproduction is called elitism. The elite count value of this study is 2 chromosomes.

- Crossover**

In this study, the crossover chance used in 0.8. This value means that it is expected that 80% of the population formed in the next generation is the result of crossovers of the previous generation. The crossover technique used is a modified Partially Mapped Crossover (PMX). Example of the PMX process for chromosomes that are taken from generation 0:

Chromosom 6 :	Parent 1	3	5	6	2	1	4
Chromosom 7 :	Parent 2	4	1	3	5	6	2
	Child 1	4	5	6	2	1	3
	Child 2	3	1	4	5	6	2

Figure 6. PMX Crossover

The selection process presented a pair of chromosomes: Chromosome 6 and Chromosome 7. The two are then crossed over on job 3 and 4.

• Mutation

The chance for mutation is 0.1. In this case, the mutation process happens after the crossover and called mutation embedded within crossover. The initial process of mutation is to raise a randomly generated number (between 0 – 1) for as many chromosomes that have been generated in the crossover process. The random number is generated using a random generator function in matlab 2013a software. If the number randomly generated is less than 0.1, then mutation is performed in that chromosome. Example of a swap mutation in the second generation of chromosome 2:

Chromosom 7 (Second generation)	1	5	4	2	3	6
Mutation result	1	6	4	2	3	5

Figure 7. 2nd Generation's 7th chromosome Swap Mutation

Mutation that happens in the second generation of chromosome 7 is in job 5 and job 6. In this mutation process, gene 5 and gene 6 exchanged. The following table 4.5 is the result of genetic algorithm method, from the initial generation up until the second generation.

Table 6. Generation - 0

	No.	Cromosom	Fitness Value	Description
Generation 0	1	126345	66.1153	Parent
	2	534621	157.1037	Parent
	3	156243	88.6869	Parent
	4	612534	82.8916	Parent
	5	145623	71.7246	Parent
	6	356214	147.6977	Parent
	7	413562	89.6265	Parent
	8	362415	113.6767	Parent
	9	653124	151.5415	Parent
	10	214536	57.2542	Parent
Average value			102.63	
Minimum value			57.25	

Stopping criteria for genetic algorithm in this study is the number of generations. Generation will stop when it has reached the 60th generation (MaxGen = 60). This study uses a matlab 2013a software for calculating the genetic algorithm. The calculation has arrived at its lowest objective function of 32.0623 hours at the 12th generation. Job sequence that resulted in the lowest mean weighted expected tardiness is 2-1-4-6-5-3 with PM activities performed prior to job 4, 5, dan 3. There is a decrease in mean weighted expected tardiness using genetic algorithm from 42.9055 hours to 32.0623 hours.

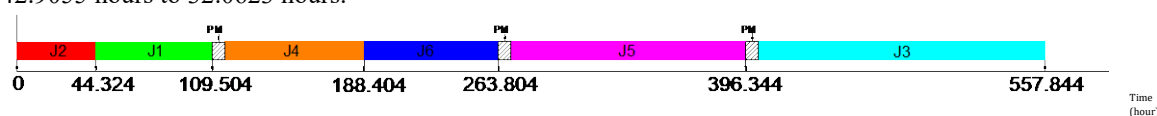


Figure 8. Job Sequence Gantt Chart integrating preventive maintenance with scheduling using genetic algorithm

Table 7. Mean Weighted Expected Tardiness Summary

Priority Rule	Job sequence & PM	Mean Weighted Expected Tardines (Hours)	Mean Weighted Tardines (Hours)	Makespan (Hour)
EDD	J2-J1-J4-J3-J5	-	77,959	582,21
SPT & WSPT	J2-J1-J6-J4-J5-J3	-	73,265	
SPT & WSPT	J2-J1-PM-J6-J4-PM-J5-PM-J3	42,9055	-	557,844
GA	J2-J1-PM-J4-J6-PM-J5-PM-J3	32,0623	-	

Calculation of the company's mean weighted tardiness at the initial stage was 77.959 hours (using EDD scheduling rule and without any PM, causing breakdowns). The integration of PM into job scheduling using genetic algorithm resulted in a mean weighted expected tardiness of 32.0623 hours.

We arrive at a lower mean weighted expected tardiness post scheduling using genetic algorithm and integrating preventive maintenance work due to a lower probability of breakdowns, hence the weighted average of expected tardiness also decreases.

5. Conclusions

Injection Machine 650-ton is the most critical machine with largest downtime percentage of 18%, machine inspection time interval of 78 hours and component replacement time interval of 162 hours (nozzle component). The current job scheduling method using EDD priority (job sequence 2-1-4-3-6-5) without any preventive maintenance (PM) causes average delays of 77.959 hours.

Integrating job scheduling with preventive maintenance resulted in job sequence of 2-1-6-4-5-3 and PMs prior to job number 6, 5 and 3. PM is determined by considering time intervals for machine inspection, component replacement with the least time interval and non-preemptive production process. Post integration, we arrive at a *mean weighted expected tardiness* of 42.9055 hours. Mean weighted expected tardiness decreases by 44.9% by integrating job scheduling and preventive maintenance.

Integrating scheduling with PM using genetic algorithm with job sequence 2-1-4-6-5-3 and PM prior to job number 4, 5, and 3 resulted in the mean weighted expected tardiness of 32.0623 hours. Using genetic algorithm, mean weighted expected tardiness further decreases by 25%.

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Biography

Sumiharni Batubara is a lecturer in the Department of Industrial Engineering, Faculty of Industrial Technology, Trisakti University, Jakarta, Indonesia. She received her Bachelor's Degree in Industrial Engineering from Institut Teknologi Bandung in 1980 and completed her Master's Degree in Industrial Engineering and Management from Institut Teknologi Bandung in 1989. Now, she is the Coordinator for Production Planning and Inventory Control Module and Industrial Manufacturing Design Module. Her research interest is in production planning and inventory control, scheduling, and lean manufacturing.