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***Research paper***



# Implementation of Learning Effect Scheduling on SME's Injection Moulding Machine

**Didit Damur Rochman*, Asep Anwar, Ucu Nugraha, Usi Putri**

*Faculty of Engineering, Widyatama* University, Indonesia
**Corresponding author E-mail: Didit@widyatama.ac.id*

**Abstract**

This study conducted on SME company in Bandung which have problem on machine scheduling. Current method that company use to schedule job and machine using simple FCFS method which resulting increase inventory and tardiness cost. We proposed machine scheduling with learning effect that developed in the previous research. Using repeat order data, we obtain 20 job that company regularly produce, we calculate scheduling with proposed method and result are 1.71% and 1.81% improvement that FCFS method that company use. Implementation step we proposed to company owner and future work to include quality and time deterioration.

***Keywords***: *machine scheduling; learning effect.*

## 1. Introduction

SME in Indonesia characterized by lack education whether the owner as manager or down to operator[1]. This condition makes survivability of the company low because lack understanding in cost optimization as part of gaining competitive advantage. Current business environment challenge every part of organization from SME to MNC to act fast to responds every customer needs and constantly reconfigure their capabilities to support today or tomorrow environment [2]. To increase dynamic capabilities as part gaining competitive advantage, companies need to learn best practice industry to imitate, assimilate even better to create better method to manage.

This study on single SME company at Bandung which produce specialty plastics textile industry spare parts. Currently, the owner act as multiple function ranging from procuring material, production planning and products marketing. These condition make the company using production management method by "common sense", as simple as they can without cost production optimizing. Declining in customer orders, high inventory material cost, and high product rework cost make this company rethink again about production planning execution on machine scheduling.

Using make to order production methods, the company accepts a variety of product order with different specifications. Not all new products that produce by the company, but repeated orders are received quite a lot. Currently, the machines owned are single injection molding machine with a capacity of 150 tons, a lathe and milling to make metal dies. All order received by company using first come first serve (FCFS) rules to produce the product as customer orders. Problem arise with these rules are delay on delivery for some new design customer order. But, repeat order from customer make processing time decrease because of learning effect applied to machine operator. The operator that involve in producing product will have experience as learning that automatically will improve production process time and quality.

In [3] emphasize the importance of scheduling decision making because of the nature of resource and objectives are different across organization. As mentioned before learning effect on production spare parts at this company occur because of repeat orders. Learning effect on machine scheduling introduced by [4] where job $J_j$ at r position depend on iteration of production the same product with learning curve coefficient which same for every product.

$$p_j r = p_j r^a \quad (1)$$

In [5] come with more learning effect scheduling model with different dispatching rules and different learning curve for every product [6]. In [7] conclude that single machine with learning effect as polynomial solvable as far as single machine problem. In [8] proposed beside learning effect that happened, learning deterioration also occur in case machine or resource have problem. In [9] come with addition release time as every job come with different time as part of processing time.

This study aims to introduce machine scheduling with learning effect as alternative on traditional FCFS that use by company currently and the improvement between them. The implementation of scheduling method on this company main criteria that we employ are simplicity and fast time to obtain solution without using specific software. These criteria lead us to use [4, 9] model as proposed method to machine scheduling in the company.

## 2. Methodology

To focus research and to answer research question above we make research steps as shown on Figure 1. We define the problem as company currently using simple FCFS scheduling and need to improve. After problem defined we conduct literature review on machine scheduling and specially on learning effect on processing time.

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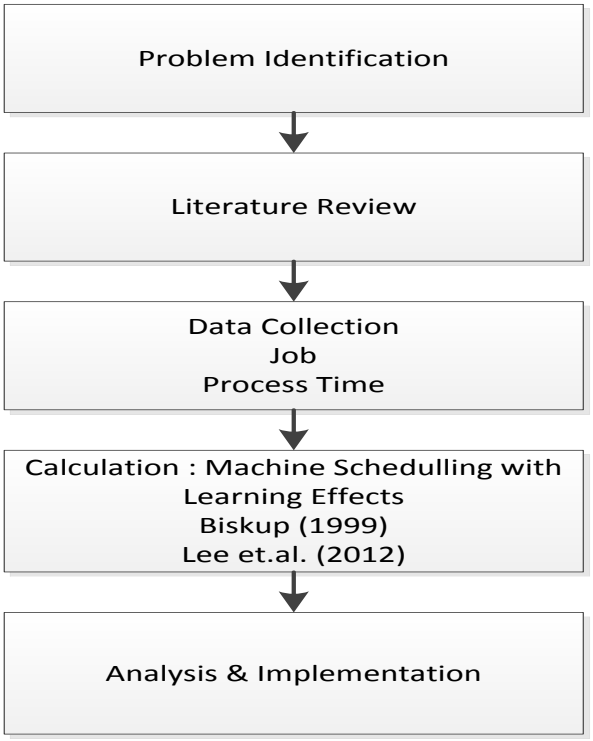



**Fig. 1:** Research Steps

Learning effect come from reality if we do something repeat or frequently, we got experience to get better. The terminology of learning curve in [9] first reported in 1939 by Wright where production increase but production time decrease. Mathematical function of learning curve as follows:

$$Y = KX^{n} \quad (2)$$

where Y = direct labor hours to produce Xth unit, K = direct labor hours to produce first unit, X = cumulative number units, n = $(\log\emptyset/\log 2)$ = learning index and $1-\emptyset$ = progress ratio.

In [4] introduce machine scheduling with learning effect with objective minimize earliness (E), tardiness(T) and completion time (C) penalty (α, β, θ) with model to find schedule S:

$$E_i = \max\{0, d - C_i\} \quad (3)$$

$$T_i = \max\{0, C_i - d\} \quad (4)$$

$$f(S) = \sum_{i=1}^{n}(\alpha E_i + \beta T_i + \theta C_i) \quad (5)$$

$$\gamma_r = \min\{(r-1)\alpha + (n-r+1)\theta, (n-r+1)(\beta+\theta)\} \quad (6)$$

Let $X_{ir}$ as decision variable to process job I at r position, and simplification on α, β, θ and rth position in sequence S.

$$f(S) = \sum_{i=1}^{n}\gamma_r P_{[r]} \quad (6)$$

Solving this sequence, using integer programming as follow:

$$\text{minimize} \sum_{i=1}^{n}\sum_{r=1}^{n}\gamma_r p_{ir} X_{ir} \quad (7)$$

$$\text{Subject to} \sum_{i=1}^{n} Xir = 1, \quad r = 1, \dots, n, \quad (8)$$

$$\sum_{r=1}^{n} Xir = 1, \quad i = 1, \dots, n,$$

$$X_{ir} \in \{0,1\}\, i, r = 1, \dots, n.$$

To solve the equation above, we use software Lingo Version 11. Another method that we will use heuristics algorithm from [9], which develop from NEH algorithm [10] as follow:

**Stage I:**

Set J = {$J_1$, $J_2$, ... , $J_n$};
For l ← 1 to n do
  Choose job Ji with min{ri + $p_{il}^{a}$} from J and place it on the l th position.
  Delete job Ji from J.
end
Output S = ($J_{[1]}$, $J_{[2]}$, ... , $J_{[n]}$);

**Stage II:**

Set S 0 = ($J_{[1]}$, −, ... , −) where the first job is from S;
For l ← 2 to n do
  Select the l th job from S and insert it in l possible positions in the current partial sequence $S^0$.
  Among the l partial sequences, select the one with a minimum $C_{[l]}$ as the current partial sequence $S^0$.
end
Output S 0;

**Stage III:**

For k ← 1 to n − 1 do
For i ← k + 1 to n do
  Create a new sequence S 1 by interchanging jobs in the i th and the k th positions from S 0.
  Replace $S^0$ by $S^1$ if the value of the makespan of $S^1$ is less than that of $S^0$;
end
end
Output $S_0$;

In [9] noted that complexity of this heuristic algorithm is $O(n^3)$. Analysis carried on improved efficiency of proposed solution, compared to FCFS method that company currently use, and implementation consist steps to implement scheduling method at company.

## 3. Results and Analysis

Data collection employed using interview, observation and gathering production data archive. There are 20 repeat orders that company produce as shown on Table 1.

**Table 1:** Repeat Order Products and Processing Time

| No. | Products | Processing Time (Hours) | Demands (pcs) |
|---|---|---|---|
| 1 | Bobbin Cape | 0,0333 | 1.000 |
| 2 | Impeler □230mm | 0,0833 | 400 |
| 3 | Impeler □300mm | 0,0500 | 400 |
| 4 | Nozzel Spray | 0,0500 | 1.000 |
| 5 | Cones □□□mm | 0,0083 | 50.000 |
| 6 | Cones □□□mm | 0,0083 | 50.000 |
| 7 | Siku | 0,0083 | 5.000 |
| 8 | Bobbin Holder 1 | 0,0500 | 1.500 |
| 9 | Bobbin Holder 2 | 0,0500 | 1.500 |
| 10 | Bobbin Holder 3 | 0,0500 | 500 |
| 11 | Spalator 1 | 0,0333 | 5.000 |
| 12 | Spalator 2 | 0,0333 | 5.000 |
| 13 | Dudukan Rak Meja | 0,0167 | 60.000 |
| 14 | Flag Holder | 0,0167 | 20.000 |
| 15 | Tutup Mesin Tenun | 0,0833 | 500 |
| 16 | Adjustable Support 1 | 0,0833 | 300 |
| 17 | Adjustable Support 2 | 0,0333 | 300 |
| 18 | Adjustable Support 3 | 0,0083 | 300 |
| 19 | Hanger | 0,0833 | 1.000 |
| 20 | Pantex | 0,0083 | 100.000 |

To measure learning curve and learning factor coefficient, we make observation on Bobin Cape's process time as shown on Table 2.

**Table 2:** Bobbin Cape Processing Time

| Bobbin Cape | | | |
|---|---|---|---|
| No. | Process Time (Hour) | No. | Process Time (Hour) |
| 1 | 0,0250 | 16 | 0,0238 |
| 2 | 0,0247 | 17 | 0,0237 |
| 3 | 0,0242 | 18 | 0,0238 |
| 4 | 0,0245 | 19 | 0,0233 |
| 5 | 0,0243 | 20 | 0,0237 |
| 6 | 0,0248 | 21 | 0,0237 |
| 7 | 0,0243 | 22 | 0,0233 |
| 8 | 0,0240 | 23 | 0,0233 |
| 9 | 0,0240 | 24 | 0,0237 |
| 10 | 0,0243 | 25 | 0,0233 |
| 11 | 0,0242 | 26 | 0,0235 |
| 12 | 0,0240 | 27 | 0,0237 |
| 13 | 0,0243 | 28 | 0,0235 |
| 14 | 0,0237 | 29 | 0,0233 |
| 15 | 0,0233 | 30 | 0,0232 |
| Average | | | 0,0239 |

Calculation of learning factor coefficient using in (2) for 1000 unit Bobin Cape as X and cycle time 0.0238 hours and 0.025 hour to produce first product, then we can calculate as follow:

$$T = C + ((X-1) \times \text{cycle time})$$
$$T = 23{,}84 \text{ hour}$$

Based on the above steps, it can be determined the calculation of the level of learning which is mathematically the log10% LC value, which is as follows:

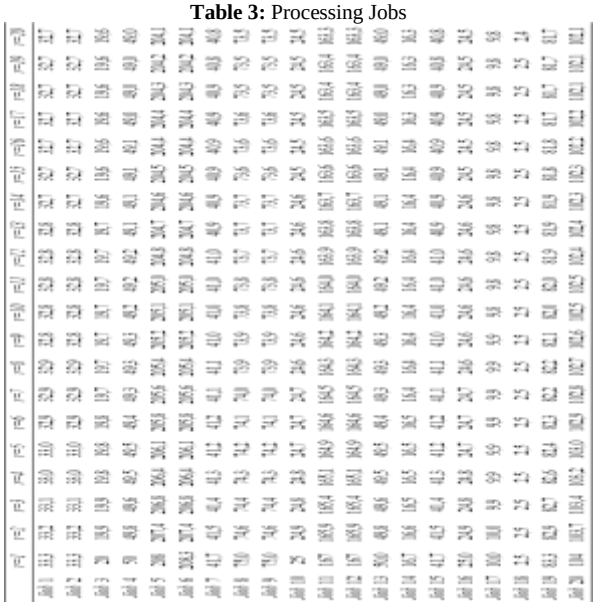
$$\log T = \log C + (n)\log X + \log X$$
$$(n) = -0{,}0068$$

where T = Total Processing Time = 23.84 hours, C = The first unit processing time = 0.025 hours and X = Number of products that have been produced = 1000 pcs.

$$S = \frac{\log \%LC - 2}{\log 2}$$
$$\log 10\%LC = 99{,}53\%$$

Based on these calculation, we assumed that every job has same learning factor 99.53%. Then, calculation process time under learning factor using in (1), we have process time matrices.

**Table 3:** Processing Jobs



Calculation of earliness and tardiness penalty with 5% annual interest rate for inventory cost, small rework cost about 0.1% per hours because failed product can reprocess as raw material. Result of calculation in hours cost as shown in Table 4.

**Table 4:** Earliness and Tardiness Penalty

| *Job* | Nama Produk | *Demand (pc)* | Harga | Inventori (Rp/Jam) | *Rework Cost* (Rp/jam) | Gamma 1 | Gamma 2 |
|---|---|---|---|---|---|---|---|
| 1 | Bobbin Cape | 1.000 | Rp17.000 | Rp99 | Rp708 | 0 | 14.167 |
| 2 | Impeler Ø230mm | 400 | Rp30.000 | Rp70 | Rp500 | 70 | 9.500 |
| 3 | Impeler Ø300mm | 400 | Rp37.500 | Rp88 | Rp625 | 176 | 11.250 |
| 4 | Nozzel Spray | 1.000 | Rp3.000 | Rp18 | Rp125 | 53 | 2.125 |
| 5 | Cones Ø30mm | 50.000 | Rp750 | Rp219 | Rp1.563 | 878 | 25.000 |
| 6 | Cones Ø20mm | 50.000 | Rp550 | Rp161 | Rp1.146 | 805 | 17.188 |
| 7 | Siku | 5.000 | Rp350 | Rp10 | Rp73 | 61 | 1.021 |
| 8 | Bobbin Holder 1 | 1.500 | Rp20.000 | Rp176 | Rp1.250 | 1.229 | 16.250 |
| 9 | Bobbin Holder 2 | 1.500 | Rp20.000 | Rp176 | Rp1.250 | 1.404 | 15.000 |
| 10 | Bobbin Holder 3 | 500 | Rp20.000 | Rp59 | Rp417 | 527 | 4.583 |
| 11 | Spalator 1 | 5.000 | Rp300 | Rp9 | Rp63 | 88 | 625 |
| 12 | Spalator 2 | 5.000 | Rp1.000 | Rp29 | Rp208 | 322 | 1.875 |
| 13 | Dudukan Rak Meja | 60.000 | Rp750 | Rp263 | Rp1.875 | 3.160 | 15.000 |
| 14 | Flag Holder | 20.000 | Rp120 | Rp14 | Rp100 | 183 | 700 |
| 15 | Tutup Mesin Tenun | 500 | Rp9.000 | Rp26 | Rp188 | 369 | 1.125 |
| 16 | Adjustable Support 1 | 300 | Rp12.000 | Rp21 | Rp150 | 316 | 750 |
| 17 | Adjustable Support 2 | 300 | Rp6.000 | Rp11 | Rp75 | 169 | 300 |
| 18 | Adjustable Support 3 | 300 | Rp1.000 | Rp2 | Rp13 | 30 | 38 |
| 19 | Hanger | 1.000 | Rp16.000 | Rp94 | Rp667 | 1.685 | 1.333 |
| 20 | Pantex | 100.000 | Rp40 | Rp23 | Rp167 | 445 | 167 |

Then, calculate $\gamma_r$ using in (6) to obtain positional weight every job on r positions and save as excel file to include in Lingo software. Using Lingo software will generate schedule based on in (7) as shown in Figure 2.

```
model:
SETS:
job/1..20/:g;
run/1..20/;
ITR(job,run):Xir, pir;
ENDSETS

DATA:
pir = @OLE('D:\pjr.xlsx','_pir');
g = @OLE('D:\pjr.xlsx','_g');
ENDDATA

MIN=@sum(run(r):@sum(job(i):g(i)*pir(i,r)*Xir(i,r)));
@for(run(r):@sum(job(i):Xir(i,r))=1);
@for(job(i):@sum(run(r):Xir(i,r))=1);

@for(job(i):@for(run(r):@BIN(Xir(i,r))));
END
```

**Fig. 2:** Schedule positional weight of job

Schedule we obtain from Lingo is summarized as Table 5 with makespan 1412.3 hours.

**Table 5:** Job Schedule

| Variable | Job | Run | Process Time (Hours) |
|---|---|---|---|
| X11 | 1 | 1 | 33.33 |
| X182 | 18 | 2 | 2.49 |
| X173 | 17 | 3 | 9.93 |
| X24 | 2 | 4 | 33.02 |
| X75 | 7 | 5 | 41.21 |
| X46 | 4 | 6 | 49.39 |
| X147 | 14 | 7 | 16.45 |
| X38 | 3 | 8 | 19.72 |
| X169 | 16 | 9 | 24.63 |
| X1010 | 10 | 10 | 24.61 |
| X1111 | 11 | 11 | 163.97 |
| X1512 | 15 | 12 | 40.97 |
| X2013 | 20 | 13 | 102.37 |
| X1214 | 12 | 14 | 163.70 |

| | | | |
|---|---|---|---|
| X815 | 8 | 15 | 73.63 |
| X916 | 9 | 16 | 73.60 |
| X1917 | 19 | 17 | 81.74 |
| X1318 | 13 | 18 | 49.03 |
| X619 | 6 | 19 | 204.20 |
| X520 | 5 | 20 | 204.13 |
| Makespan | | | 1412.13 |

Using heuristic algorithm form [9] and assumption release time = 0, we obtain schedule as shown on Table 6.

**Table 6:** Heuristic Algorithm Job Schedule

| Job | Run | Process Time (Hours) |
|---|---|---|
| 18 | 1 | 2.50 |
| 17 | 2 | 9.95 |
| 14 | 3 | 16.54 |
| 3 | 4 | 19.81 |
| 10 | 5 | 24.73 |
| 16 | 6 | 24.70 |
| 2 | 7 | 32.90 |
| 1 | 8 | 32.87 |
| 7 | 9 | 41.05 |
| 15 | 10 | 41.02 |
| 4 | 11 | 49.19 |
| 13 | 12 | 49.16 |
| 8 | 13 | 73.70 |
| 9 | 14 | 73.67 |
| 19 | 15 | 81.81 |
| 20 | 16 | 102.22 |
| 11 | 17 | 163.49 |
| 12 | 18 | 163.42 |
| 5 | 19 | 204.20 |
| 6 | 20 | 204.13 |
| Makespan | | 1411.06 |

## 4. Discussion

FCFS scheduling that currently employed by company as shown on Table 7 with makespan 1436.67 hour to complete all job.

**Table 7:** FCFS Schedule

| Job | Products | Process Time (Hour) |
|---|---|---|
| 1 | Bobbin Cape | 33,33 |
| 2 | Impeler □230mm | 33,33 |
| 3 | Impeler □300mm | 20 |
| 4 | Nozzel Spray | 50 |
| 5 | Cones □□□mm | 208,33 |
| 6 | Cones □□□mm | 208,33 |
| 7 | Siku | 41,67 |
| 8 | Bobbin Holder 1 | 75 |
| 9 | Bobbin Holder 2 | 75 |
| 10 | Bobbin Holder 3 | 25 |
| 11 | Spalator 1 | 166,67 |
| 12 | Spalator 2 | 166,67 |
| 13 | Dudukan Rak Meja | 50 |
| 14 | Flag Holder | 16,67 |
| 15 | Tutup Mesin Tenun | 41,67 |
| 16 | Adjustable Support 1 | 25 |
| 17 | Adjustable Support 2 | 10 |
| 18 | Adjustable Support 3 | 2,50 |
| 19 | Hanger | 83,33 |
| 20 | Pantex | 104,17 |
| Makespan | | 1436,67 |

Comparing solution from [4] model with makespan 1412.13 hour and in [9] heuristic algorithm makespan 1411.06, improvement we have 24.54 hour and 25.61 hour. In term percentage proposed solution give 1.74% and 1.81% improvement. In [9] heuristic algorithm gives better makespan improvement than [4].

Implementation step that we proposed to the company owner to use proposed method as follow:

1- Redesign and better archiving routing sheet for every product that customer order to overcome repeat order.
2- Creating MS Excel template to calculate schedule using proposed method.
3- Training and assistance to company owner to use excel template.

## 5. Conclusion

Future work to be address in implementation scheduling with learning effect are to include quality aspect which impacted by learning effect, deterioration time because repeat order come after long time customer not ordering same products, and creating simple application to help other company or academics to solve this type scheduling.

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