LEAN MANUFACTURING APPROACH WITH PARTICLE SWARM OPTIMIZATION-LINE BALANCING

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ABSTRACT

Manufacturing lead time must be evaluated when production can't meet the target. In lean manufacturing, waste in production line is prohibited and it must be eliminated so it can shorten the length of production time. This research is to identify and to reduce the waste in order to achieve the target of production. Waste identification used value stream mapping and process activity mapping. In order to achieve the target, lean manufacturing approach is conducted by balancing the line using Particle Swarm Optimization (PSO), evaluating work system using process flow chart and outsourcing the process.
Keywords: *lean manufacturing, line balancing, particle swarm optimization, flow process map, outsourcing*

1. INTRODUCTION

Lean manufacturing is an approach to identify and eliminate the waste using any improvement and development. Lean focuses on identification and elimination of non value added activities in design, manufacture, service and supply chain management according to customer (Jones and Womack, 2000). Lean manufacturing approach use Value Stream Mapping and Process Activity Mapping as tools to identify waste. Manufacturing lead time and production cycle effieciency are the performance indicator for lean manufacturing approach.

In fabrication stage, the process follows the precedence network and work element in the precedence network represent the movement of raw material: processing and assembly the part to produce finished good. Balancing the work load in the line becomes the first thing to do. Line balancing can minimize the idle time of a line, which is determined by the longest operation. It also distributes work element evenly to workstation so the use of equipment can be maximized (Baroto, 2002).

2. LITERATURE

Lean manufacturing is a method for eliminating the waste in every sector (i.e. operator activity, inventory, time needed, and manufacturing scope) to become more responsive to customer need with only producing quality product in effective and economic way (Womack, 1990). Perfomance indicator for lean manufacturing is manufacturing lead time. Manufacturing Lead Time (MLT) is total time required in producting end item which include setup time (S), queue time (Q), wait time (W), operation time (O) and move time (M) (Fogarty, 1991).

Tools in lean manufacturing are value stream mapping and process activity mapping. Value Stream Mapping is an improvement tools in lean manufacturing to visualize the production process, represent the raw material and the information flow. The objective is to identify the waste in VSM and take an action to eliminate it (Rother and Shook, 1999). According to Jones and Womack (2000), VSM is a visual current mapping of information and material flow which is used to prepare the future mapping with the better performance and method. VSM is also effective to represent and communicate the process in an organization (Taylor, 2005). Steps for implementing VSM according to Singh (2013) are selecting critical product family, preparing current state mapping, analyze current state mapping, preparing future state mapping, and analyze the result. Process activity mapping is one of the common seven tools of mapping. It maps detail activities, help to understand the flow process, identify the waste, identify the possibility of rearrange the process efficiently, and identify the flow improvement of value added. This mapping shows the physical and information flow, time needed for activities, distance, and inventory product fo each activities. Activities are easily identified because there are five classifications for activities such as operation, transportation, inspection, delay and storage. And also detail activities can be grouped to VA, NVA and NNVA. Steps for making process activity mapping are analyze each process first, identify existing waste, consider to change process sequence, consider to make better flow, consider only to every important flow process.

Particle Swarm Optimization (PSO) is a meta-heuristic inspired by swarm which is introduced by Eberhart dan Kennedy in 1995. PSO algorithm search for the best solution from every problem and renew every particle set which is called swarm, just to find the optimal solution. Steps for particle swarm optimization-line balancing (Baykasoğlu, 2012) are:

1. Initialisation, determine cycle time (*c*) and number of work station (*m*) achieved:
   $c = lower\ bound(LB = \max\{t_{max}, t_{sum}/m\})$ (1)
2. Generate random initial swarm using particle position and velocity.
   $x_{i,j}^{0} = x_{min} + r_1(x_{max} - x_{min})$ (2)
   $v_{i,j}^{0} = v_{min} + r_2(v_{max} - v_{min})$ (3)
   Maksimum and minimum value of *x* and *v* is determined, x_{min}=0,0 and x_{max}=4,0, and v_{min}=-4,0 and v_{max}=4,0; r_1 & r_2 are uniform random number between (0,1); *j* is dimension or number of job (*j*=1,…,*D*), *Ns*=1**j* with *Ns* is number of particle.
3. Determine permutation:
   $\pi_i^0 = [\pi_{i1}^0, \pi_{i2}^0, \dots, \pi_{in}^0]$ (4)
   i=1,2,…,*Ns.* It uses smallest position value (SPV).
4. Evaluate each particle in the swarm using objective function f_i^0. Where *i*=1,2,…,*Ns.* Then determine:
   $P_i^0 = X_i^0$ (5)
   $P_i^0 = [P_{i1}^0 = X_{i1}^0, P_{i2}^0 = X_{i2}^0, \dots, P_{in}^0 = X_{in}^0]$
   together with the best value, f_i^{pbest} for *i*=1,2,…*Ns.*
5. Determine *pbest* (*global best*) in all swarm, f_l=min{f_i^0} with position X_l^0. Set global best to
   $G^0 = X_l^0$ (6)
   $G^0 = [g_1 = x_{l,1}, g_2 = x_{l,2}, \dots, g_n = x_{l,n}]$
   with the best value, f^{gb}=f_l.
6. Renew iteration with *t*=*t*+1
7. Renew velocity of particle:
   $v_{ij}^t = w^{t-1}v_{ij}^{t-1} + c_1 r_1 (P_{ij}^{t-1} - x_{ij}^{t-1}) + c_2 r_2 (g_j^{t-1} - x_{ij}^{t-1})$ (7)
   Inersia weight $w^t = w^{t-1} * \beta$, with β = 0.95 and w^t = 0.9, while c_1 is cognitif parameter and c_2 is social parameter of, 2 and 1,5, respectively.
8. Renew position using:
   $x_{ij}^t = x_{ij}^{t-1} + v_{ij}^t$ (8)
9. Determine permutation:
   $\pi_i^0 = [\pi_{i1}^0, \pi_{i2}^0, \dots, \pi_{in}^0]$ (9)
   With *i*=1,2,…,*Ns.* It uses smallest position value (SPV).
10. Renew personal best by evaluating each particle using permutation to check whether the *pbest* is develop or not using equation:
    $f_i^t < f_i^{pbest}$ (10)
    With *i*=1,2,…,*Ns.* Renew *pbest* as P_i^t=X_i^t and f_i^{pbest}=f_i^t.
11. Renew global best by determining minimum value from *pbest*:
    $f_l = \min\{f_i^0\}$ (11)
    With *i*=1,2,…,*Ns.* If $f_i^t < f^{gb}$ then renew global best as G^t=X_l^t and f^{gb}=f_l^t.
12. If number of work is station achieved in best particle, renew cycle time like determined before and continue to 7.

Notation:

i	=	particle
c	=	cycle time
n	=	index of activity
V	=	activity {1,…,*n*}
m	=	number of work station
WS	=	work station {1,…,*m*}
t_i	=	operation time
t_{sum}	=	total operation time
Ns	=	number of particle (swarm size)
$x_{i,k}$	=	current position of particle
$x_{i,k}^{pbest}$	=	best position of each particle
$v_{i,k}$	=	current velocity

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t = index of iteration number

3. METHODOLOGY

In lean manufacturing approach, we use value stream mapping and Process activity mapping to search the possibilty of improvement in the shop. The result of improvement show that there are three steps of improvement: Balancing the line, work system improvement and outsourcing the process. The first improvement is to balance the line. Workload of each workstation is balancing using Particle Swarm Optimization (PSO) algorithm from (Baykasoğlu, 2012). The second improvement is rearranging the work element using flow process map. The last is outsourcing the process to minimize the time in the first process.

4. RESULT

This research is conducted in manufaturing company which produces stainless steel and aluminium products. The product is aluminimum ladder alpha type with the process that can be seen in Figure 1.

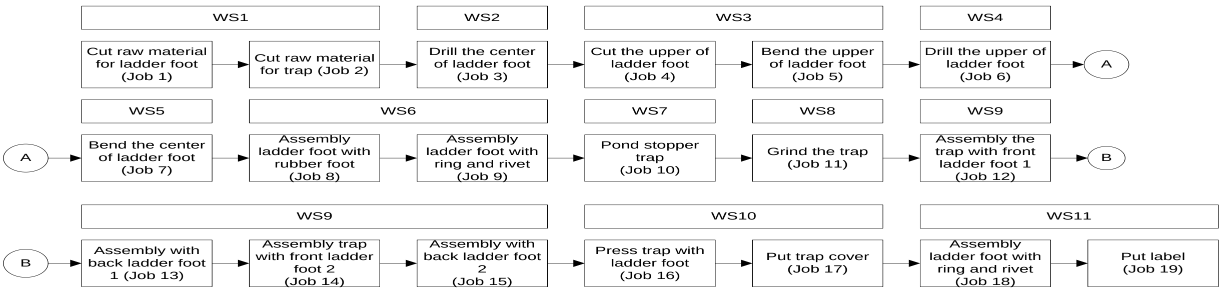


Figure 1. Process of aluminum ladder

Production time is 2791.99 detik, without setup time for preparation.

Manufacturing Lead Time = Setup (S) + Queue (Q) + Waiting (W) + Operation (O) + Move (M)

Manufacturing Lead Time = 1080 + 0 + 413.37 + 1836.48 + 542.14 = 3871.99 second

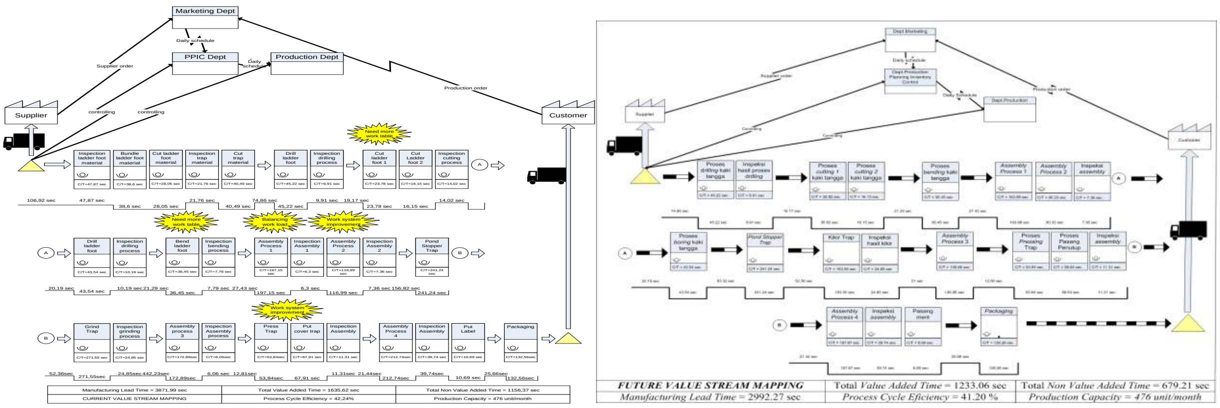


Figure 2. Value Stream Mapping Current (left) and Future (right)

Then the process mapping activity is made to search where the waste are. The summary of waste based on process mapping activity before and after steps of improvement can be seen in table 1. Waste is classified and each of improvement is elaborate.

Table 1. Summary for waste elimination

No	Type of Waste	Workstation	Work Element	Before (sec)	After (sec)
1	Waiting	WS7	Waiting for cutting raw material trap	93,5	40,49
		WS9	Waiting for the process from WS6	319,9	289
2	Transportation	WS1	Take raw material trap	42,66	0
		WS3	Transfer from WS2	19,17	10,17
		WS5	Transfer from WS4	21,29	15,12
3	Over processing	WS1	Inspection raw material trap	21,76	0
		WS3	Inspection ladder foot (after drill and bend process)	14,02	0
		WS4	Inspection ladder foot (after boring)	10,19	0
		WS5	Inspection ladder foot (after bending)	7,79	0
		WS6	Inspection assembly of ladder foot with rubber	6,3	0
		WS9	Inspection assembly	6,06	0
4	Motion	WS6	Take ladder foot	25,77	0
			Take rubber	20,77	8,57
			Take ring and rivet	37,71	4,7
		WS9	Take ladder foot	16,21	11,16
		WS10	Take cover trap	22,3	13,03
		11	Take hing and hing nail	35,27	10,4

Improvement #1 (Particle Swarm Optimization Algorithm)

Iteration 0 (t=0)

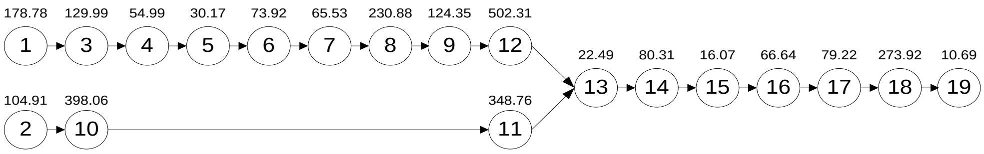
1. Cycle time (c) = lower bound (LB = max {621.18, 2791.99/11}) = 621.18 second.
   Number of workstation (m) = total operation time/cycle time = 5 WS (second).
2. Step 2-step 4 for i=1

Table 2. Step 2-step 4 for i=1

i=1										
j	1	2	3	4	5	6	7	8	9	10
r1	0.2546	0.1005	0.8055	0.7789	0.0820	0.3241	0.8815	0.3661	0.3375	0.5431
r2	0.6326	0.4617	0.5208	0.8747	0.6187	0.5385	0.6340	0.4831	0.9097	0.9301
$x^0_{i,j}$	1.0185	0.4020	3.2219	3.1155	0.3278	1.2964	3.5259	1.4644	1.3498	2.1723
$v^0_{i,j}$	1.0607	-0.3068	0.1661	2.9975	0.9498	0.3082	1.0718	-0.1353	3.2777	3.4411
$\pi^0_{i,j}$	7	3	14	13	1	8	16	10	9	11
$P^0_{i,j}$	1.0185	0.4020	3.2219	3.1155	0.3278	1.2964	3.5259	1.4644	1.3498	2.1723

j	11	12	13	14	15	16	17	18	19
r1	0.9831	0.1977	0.9904	0.0857	0.2458	0.1384	0.8260	0.5815	0.9895
r2	0.3596	0.2167	0.2233	0.0756	0.3716	0.8884	0.8590	0.2753	0.3137
$x^0_{i,j}$	3.9322	0.7909	3.9614	0.3426	0.9832	0.5538	3.3042	2.3261	3.9579
$v^0_{i,j}$	-1.1228	-2.2660	-2.2136	-3.3955	-1.0276	3.1073	2.8717	-1.7972	-1.4902
$\pi^0_{i,j}$	17	5	19	2	6	4	15	12	18
$P^0_{i,j}$	3.9322	0.7909	3.9614	0.3426	0.9832	0.5538	3.3042	2.3261	3.9579
f^{pbest}_i	607.51								

Sequencing for workstation is based on the precedence network (Figure 2).



Workstation	Total time (second)
1	442,77
2	355,23
3	593,58
4	429,07
5	607,51
6	363,83

Figure 2. Precedence network of aluminium ladder

Table 1. Current Sequencing for workstation

WS1					WS2		WS3			WS4		WS5				WS6		
1	4	5	2	6	8	9	10	3	7	11	14	12	13	15	16	17	18	19

3. Result of cycle time with t=0 for step 5.

i	f^{pbest} (second)	*i*	f^{pbest} (second)	*i*	f^{pbest} (second)	*i*	f^{pbest} (second)
1	607,51	6	606,40	11	598,72	16	599,73
2	603,10	7	621,18	12	591,44	17	600,77
3	591,44	8	612,70	13	621,18	18	607,51
4	591,44	9	621,18	14	607,51	19	606,4
5	607,51	10	606,40	15	591,44		

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The cycle time is 591.44 sec, so the next iteration can't have the value of cycle time above 591.44 sec.

Iteration 1 (t=1)

1. Inersia weight (β)=0.95 dan wt = 0.9; c1 is cognitive parameter and c2 is social parameter 2 and 1,5, respectively.
   $w^1 = w^0 * \beta$; $0.9 = w^0 * 0.95$; $w^0 = 0.9473$

2. Cycle time for t=1 for step 5.

i	f_i^{pbest} (detik)	i	f_i^{pbest} (detik)
1	540.87	11	591.44
2	582.62	12	591.44
3	591.44	13	540.87
4	582.53	14	539.65
5	591.44	15	533.38
6	591.44	16	591.44
7	591.44	17	589.31
8	564.37	18	591.44
9	591.44	19	582.6
10	560.35		

The result of Cycle time is 533.38 second. The next iteration for t=2, the cycle time must be lower than 533.38 second.

Step 1 Particle Swarm Optimization (PSO) Algorithm

- Sequence changes into:
  1-3-4-5-7-8-9-6-2-10-11-12-13-14-15-16-17-18-19
- The number of work station is decreasing from 11 to 6.
  The following table is job sequence in each workstation

Table 1. Job sequence in each workstation

Workstation	Job
WS1	1-3-4-5-7
WS2	8-9-6-2
WS3	10
WS4	11
WS5	12-13-14-15
WS6	16-17-18-19

Stopping rule for line balancing using PSO is obtained when the cycle time result the same value for 10 times.

Improvement #2 PSO+PAP

Increasing output is 67 unit/month
Processing time decrease to 306.98 sec.
Operation time is 2318.38 sec.

Improvement #3 (PSO + PAP + Outsourcing)

The job of cutting process were moved to another division (fabrication division to powder coating) because there is no restriction for the process to be done in other place. The effect of the elimination of job are:

- Operation time decrease to 1912.27 sec for 1 unit product.
- The increasing of output is 150 unit/month.

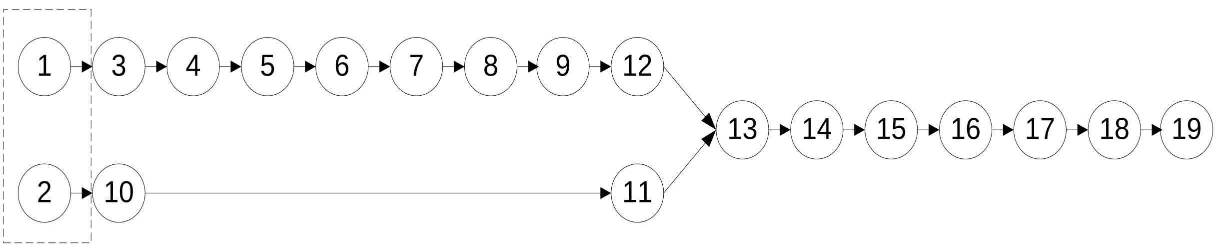

Figure 1. Improvement #3

The value of Process Cycle Efficiency decrease according to value added time and total lead time. Waste elimination is obtained due to the shorten of operation time. And the future value stream mapping in figure 2 show the effect of this research.

Table 1. Result

	Current	I	II	III
Number of Workstations	11	6	6	6
Line efficiency	40,86%	80,22%	74,40%	62,34%
Improved Efficiency	-	39,36%	33,54%	21,48%
Cycle time (second)	621,18	-	-	511,20
Processing time	2791,99	-	-	1912,27
Output (unit)	326 unit	360	393	476
Improved Output (unit)	0	34	67	150

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5. CONCLUSION

In this research, it is obtained that the production target achievement is increased by 150 units/month than the achievement before, which is 326 units/month to 476 units/month. It is shown by the decreasing of production time for about 879.72 seconds than the production time before, which is 3871.99 seconds to 2992.27 seconds. This results shows that the improvements bring good value in order to achieved the production target.

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