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Original Article

Lean techniques and simulation-based optimization for improving wood plastic composite manufacturing

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Abstract

In this research, lean techniques were utilized in a wood plastic composite manufacturer to eliminate waste of the production system. Measurements showed the production capacity of the factory was limited and had a lot of waste in many processes, so customer demand could not be met. Improvement of the real production line would be complex and may cause interruption in production. Therefore, computer simulation was used to show the system performances before and after improvement. Lean techniques such as Eliminate, Combine, Rearrange and Simplify (ECRS), quick setup, Computer Aided Engineering (CAE), and line balancing, were employed to eliminate waste and shorten cycle time. After improving by lean techniques, the result showed very high productivity, utilization, efficiency and profit. However, the capacity still did not reach the demand target. So, Theory of Constraint (TOC) with bottleneck consideration and optimization were utilized to identify the suitable resources of the system to achieve high performances and customer satisfaction.

Keywords: lean techniques, case study, computer simulation, productivity improvement, optimization

1. Introduction

The relatively high growth of business pushes manufacturers to invest and improve their products and processes for the potential to serve an increasing demand. Lean manufacturing is one of the powerful tools widely recognized as improving the overall operational performance of a factory (Bortolotti, Boscari, & Danese, 2015). The improvement is achieved by identifying and eliminating waste within the manufacturing system (Susilawati, Tan, Bell, & Sarwar, 2015). There are many lean techniques employed in industrial applications such as Single Minute Exchange of Dies (SMED), Theory of Constraints (TOC), Kanban, Value stream mapping (VSM) etc. (Abdulmalek & Rajgopal, 2007; Almomani, Aladeemy, Abdelhadi, & Mumani, 2013; Bortolotti *et al.*, 2015; Kim, Kubota, & Yamanaka, 2008; Neha, Singh, Simran, & Pramod, 2013; Yue, Wang, Yin, Wang & Yang, 2003). Many techniques have been employed successfully in these applications. The benefits of lean manufacturing have been described by Melton (2005). Lean manufacturing practices is directly related to operational performance (Abdulmalek & Rajgopal, 2007; Fullerton, Kennedy, & Widener, 2014; Melton, 2005; Yang, Kuo, Su, & Hou, 2015).

Lean techniques can be used to get rid of unnecessary processes and wastes. ECRS (Eliminate Combine Rearrange Simplify) is a basic tool that can be preliminarily applied to reduce wastes of motion, transportation, over-processing and waiting. SMED technique can be used to reduce setup time of the production line. A systematic approach to accomplish the SMED was proposed to aid the process engineers to shorten setup time (Almomani *et al.* 2013). Computer-aided engineering (CAE) can also be used to analyze the behavior of materials and select the appropriate condition for processing that can reduce production time and defects. The flow of a production line can be smoothed by line balancing and the consideration of TOC. Masood (2006) investigated line balancing in automotive plants to reduce the total cycle time and increase machine utilization. Re-sequencing and changing tools can reduce bottlenecks and smooth the production line resulting in increase of throughput, machining utilization and productivity.

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Bottleneck resources can be identified and solved to increase the production capacity based on TOC (Goldratt, 1990; Hinckeldeyn, Dekkers, Altfeld & Kreutzfeldt, 2014; Phruksaphanrat, Ohsato & Yenradee, 2011). Applications of lean manufacturing have spanned many sectors such as the automotive industry, electronics, consumer products, etc. However, there is no evidence of work applying lean principles to wood plastic composite manufacturing. Many types of lean tools were utilized in this research based on the problems existed.

Computer simulation is used in the evaluation of system performance. It has been employed in studying many systems (Erenay, Suer, Hung, & Maddisetty, 2015; Zhang & Zhang, 2007). It can help a firm make better decisions on production systems (Ingemansson, Ylipää, & Bolmsjö, 2015). Moreover, it can be used to find the appropriate input factors to meet production orders (Padhi, Wagner, Niranjan & Aggarwal, 2013). Simulation optimization based decision support helps steel manufacturing, diamond tool production line, electronics industry and automotive manufacturers improve their production lines (Dengiz, Bektas, & Ultanir, 2006; Lin & Chen 2015; Melouk, Freeman, Miller, & Dunning, 2013; Padhi *et al.*, 2013). It can identify potential improvements in a short time frame. In this research, simulation based optimization is applied to find the appropriate resources in a wood plastic composite factory where made to order (MTO) output cannot meet demand. It can show the system performance and suggest potential improvements for the production line.

2. Lean Manufacturing

Lean manufacturing focuses on pinpointing both value and wastes, and then using tools to eliminate the wastes. Moreover, the flow of the system should be smoothed. The objective of lean is to reduce wastes. The following leans tools are applied.

2.1 ECRS (Eliminate Combine Rearrange Simplify)

ECRS is a technique employed to improve processes in operational as well as office management practices. It is one of the motion study techniques that are usually applied in productivity improvement.

2.2 Quick setup

Activities of setup operations can be classified into two categories: internal activities, which are performed while the machine is offline and therefore must be minimized because they decelerate the production, and external activities that are done, while the machine is running (Almomani *et al.*, 2013). Modifying the equipment is the most common way to convert setup activities from internal to external. The main concept is to continuously try to reduce the setup time on the machine.

2.3 CAE (Computer Aided Engineering)

Computer-aided engineering (CAE) is the broad use of computer software to aid in engineering analysis tasks. It includes Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD) and optimization. CAE is now common in design of casting and forging processes (Kim *et al.* 2008; Yue *et al.* 2003). In this research it is used to analyze the heat transfer behavior of wood plastic composite.

2.4 Production line balancing

Assembly lines are a common way to organize mass production of a standardized product. The cycle time determines how much time the stations' workers and /or machines have to fulfill their tasks before passing on the workpiece to the next station (Masood, 2006). Takt time is the time required for completions of successive units of end product (Abdulmalek & Rajgopal, 2007). It is a baseline used to eliminate over servicing. It can be calculated by finding the number of products required for a given time. In order to serve customer demand cycle time and takt time should be consistent.

2.5 Theory of constraint (TOC)

The theory of constraints (TOC) (Phruksaphanrat, *et al.* 2011) is an important tool for improving process flows. The implications of the theory are far reaching in terms of understanding the bottlenecks in a process and better managing these bottlenecks to construct an efficient process flow. It provides a tool set to increase the performance of the company through systematic bottleneck management.

3. Wood Plastic Composite Manufacturing

The case study of this research is a wood plastic composite factory, which has 2 main groups of production lines: Extrusion lines of product types Classic, Terrace, Emboss and Premium and injection line for special products. The production ratio of each type of extruded product is 43%, 30%, 14% and 13%, respectively. Extrusion lines make 70% of the production quantity, so this research focused on extrusion lines. It has high potential to increase supply by up to 30% per year. The process flow is shown in Figure 1. The production line is not a continuous process due to unbalance of processes. There is a buffer between stations. The setup times of different product groups are the same. In each day of production, only one type of product group is produced. So, in the simulation model, data of daily production for the selected model was used. Setting up the real production line is done at the beginning of each day, so set up time is excluded from the simulation model. Process standard times were collected and prepared. Different types of product have the same standard time at each station, but each product type passes different processes (from process 8 to process 10) as shown in Table 1. Demand for each day is 800 pieces. The factory operates 7.5 hours per day or 450 minutes per day. Then, the takt time is 0.56 minutes per piece.

The current standard times and takt time of extrusion lines are illustrated in Figure 2. Tasks 1-4 are in the same workstation. Rice husk, sawdust, plastic resin and additive are prepared. Tasks 5 and 6 also share a workstation. At this workstation, all materials are transferred, mixed together in a mixer and then sent to three extrusion machines (task 7). Other tasks are in separate workstations. Number of workers and machines in each station are shown in Table 1.

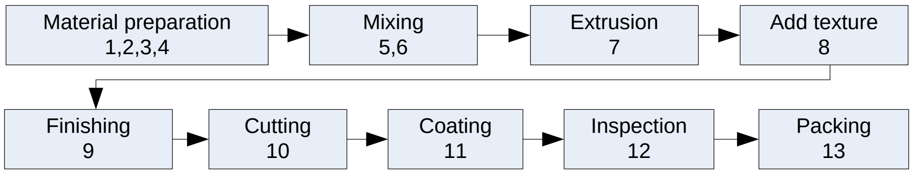

Figure 1. Flow process of the extrusion line.

Table 1. Different processes of product groups.

Task	Type					
	Classic	Terrace	Emboss	Premium	No. of workers	No. of machine (Task)
1-4	•	•	•	•	4	1 (1)
5,6	•	•	•	•	2	1 (6)
7	•	•	•	•	6	3
8	-	•	-	•	4	1
9	-	-	•	•	4	1
10	-	-	•	-	4	1
11	•	•	•	•	6	1
12	•	•	•	•	2	-
13	•	•	•	•	2	-

• pass that station.

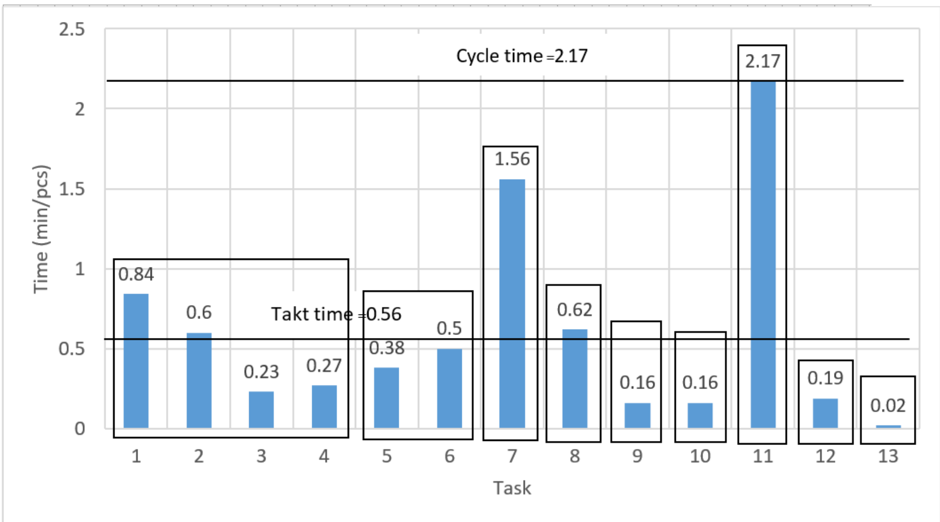

Figure 2. Cycle time and takt time before improvement.

There are totally 9 workstations. In Figure 2, it can be seen that takt time is much lower than cycle time, which means that the factory cannot produce enough products for customers. Moreover, the production lines are unbalanced. Cycle time of tasks 1, 2, 7, 8, and 11 need to be improved. Moreover, some tasks may be able to combine to the same station after improvement.

4. Improvement by Lean Techniques and Simulation based Optimization

Wastes occur in many processes of the production line causing long production lead time and set up time. Waiting time also exists in some processes. Lean techniques and simulation based optimization are employed for solving these problems in order to reduce cycle time of the processes, which have cycle time more than takt time. Firstly, lean techniques are used to eliminate wastes in these production lines. However, the extrusion lines still cannot meet customer demand. So, additional resources are determined based on bottleneck machines in order to sufficiently serve customer demand. Then, simulation is used to evaluate and optimize the appropriate number of machines. The profit and cost of investment are calculated to select the best alternatives for the factory.

4.1 Improvement by lean techniques

Lean techniques are used to improve extrusion lines as follows:

ECRS

- The first task is filtering rice husk**.** Currently, an overhead crane is used to transport material, but it takes a very long time. So, a forklift truck is considered for use. Material are transported for 34 units of product each time. Transportation time can be reduced from 0.84 to 0.13 min/unit.
- The second task of material preparation is drying**.** Process time of this task can be eliminated by indicating the specification of low material moisture from the supplier.
- Tasks 12 and 13 are inspecting and packing, which can be combined into the same workstation. Workers and time can also be reduced by eliminating movement.

Quick setup

- Task 4 is weighing. Currently, workers waste a lot of time in preparing and weighing, so all materials will be well prepared at store before starting the process.
- Task 5 is the process of transporting rice husk, sawdust, plastic resin and additive to the mixing machine, which takes a lot of time due to use of a conveyor. So, the crane could be used instead to reduce transport time.
- The crane is available in the factory and used in other processes**.** Time of movement per unit (6 meters long of the product) could be reduced from 0.38 to 0.17 min/pieces**.** 30 pieces of materials were move each time.

CAE

- Task 7 is extrusion. There are 3 extrusion machines. The mixed material is heated until it becomes fluid at 150 ^{o}C. Then, it is passed through a die and cooled by water until it becomes solid. The temperature of the extruded product surface is about 120 ^{o}C. The product in 6 meters lengths is transferred and cooled at room temperature, then cut into pieces. Calculation of heat transfer and fluid dynamics by CAE was used to determine the range of cooling at room temperature. It was found that 4 meters is long enough for reducing the temperature of the product. The average temperature of the product between 4 to 6 meters long is 118.68 ^{o}C. The cycle time can be reduced from 4.67 to 3.11 min. So, cycle time of this task can be reduced from 1.56 to 1.04 min. Task 7 the cycle time is still higher than takt time, so machines should increase from 3 to 6 machines to reduce the cycle time to 0.52 min. Calculation from CAE is shown in Figure 3.

Line balancing

- After improvement by lean techniques, line balancing is finalized by increasing capacity and smoothing task time at each work station. The numbers of machines for tasks 7, 8 and 11 are increased from three to six, one to two and one to four respectively. Then, cycle time for each station can be shown in Figure 4. However, these numbers are approximate numbers without considera-tion of variations**.** So, Simulation was needed to find the suitable number of machines in each station.

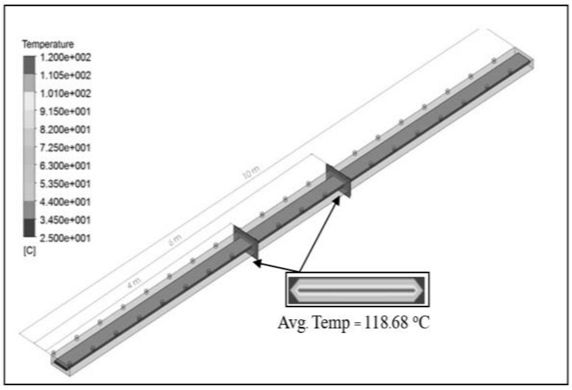

Figure 3. Calculation of product heat transfer behavior in task 7.

4.2 Performance analysis via computer simulation

Standard times of all processes were measured and calculated. Statistical tests such as independence, homo-geneity, stationarity and goodness of fit were tested for all processing times and moving times, which are shown in Table 2.

Independence is proved by using scatter plots and run tests. Homogeneity can be checked by visually inspecting the distribution to see if it is more than one mode. Stationarity is to determine that the data should not change with time. The goodness of fit is checked by Kolmogorov-Smirnov method. These data are used in simulation models.

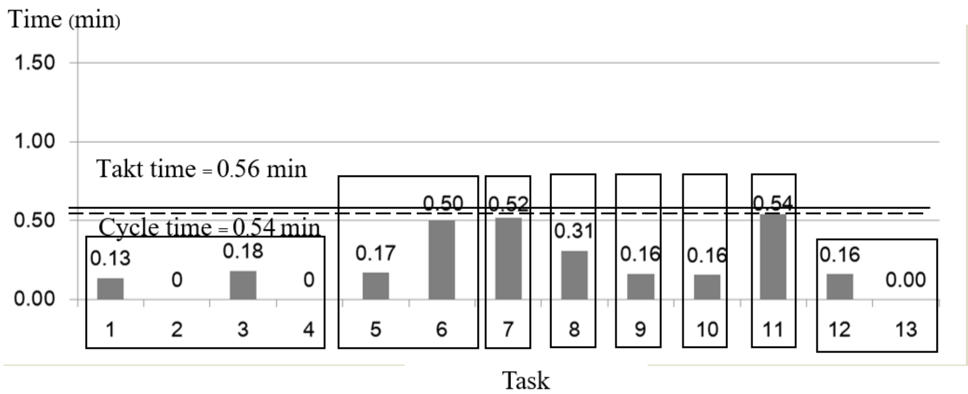

Figure 4. Cycle time and takt time after improvement by lean techniques.

Table 2. Standard times and statistical distributions.

No.	Description	Std. Time (min/pcs)	Goodness test	Lot size/ m/c	P-value	Parameter for each production lot size
1	Filter rice husk	0.84	Logistic	34	0.998	(27.8,0.88)
2	Oven rice husk	0.60	Constant.	34	-	20.4
3	Spin plastic	0.23	Extreme Value	15	0.992	(4.02,0.383)
4	Weigh	0.27	Weibull	15	0.992	(3.54,1.43,1.08)
5	Carry all components	0.38	Beta	30	0.996	(9.65,12.9,2.83,2.51)
6	Mix	0.50	Constant.	30	-	15
7	Extrude	1.56	Constant.	1	-	1.56
8	Add pattern to the surface	0.62	Triangular	4	0.997	(1.06,2.09,1.87)
9	Trim	0.16	Normal	8	0.859	(1.36, 0.186)
10	Cut	0.16	Beta	8	0.850	(1.07,1.48,1.7,1.42)
11	Coat	2.17	Beta	1	0.978	(1.45,2.69,2.18,1.56)
12	Inspect	0.19	Gamma	12	0.944	(-2.61,378,1.31e-2)
13	Pack	0.02	Triangular	12	0.333	(0.198,0.287,0.22)

Four models were constructed using Promodel software (Harrell, Ghosh, & Bowden, 2012). The first model was the existing production line for evaluating the current performance as shown in Figure 5 (Model 1). The second model was the proposed model based on lean improvement without adding any machine (Model 2) because the factory may not ready to invest. The third model was the adjustment of resources based on bottlenecks (Model 3) and the last model was the simulation based optimization model (Model 4).

The existing model was verified by checking programming code, testing the output, watching animation and tracing and debugging. Moreover, validation was done by comparing the real quantity of produced products with the simulation results. The current average production capacity is 169 pcs/day. Average production capacity from simulation

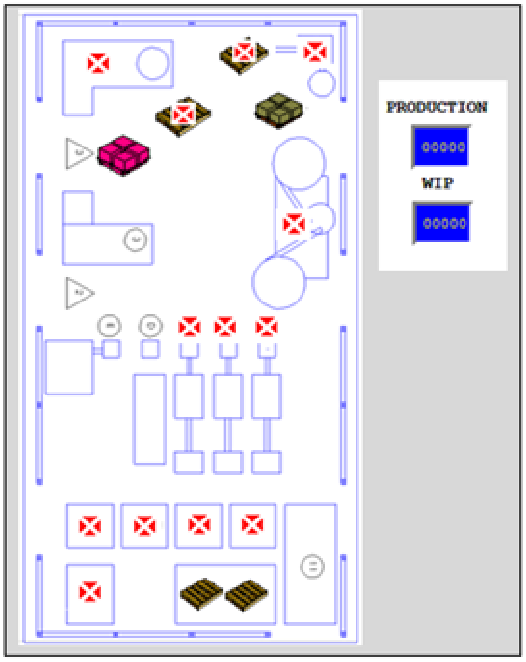

Figure 5. Simulation model of the wood plastic composite industry.

model is 168.5 pcs/day with standard deviation 3.41 (Model 1). The result from t-test showed that simulation result is not different from the real production result with 0.05 significant level. So, simulation model can be used to represent the real production line. The hypotheses are

$$H_0 : \mu = 169$$

$$H_1 : \mu \neq 169$$

$$t_0 = \frac{y - \mu_0}{s/\sqrt{n}} = \frac{168.50 - 169}{3.41/\sqrt{30}} = -0.803 \qquad (1)$$

$$t_{crit} = t_{\alpha/2,n-1} = t_{0.025,29} = 2.045.$$

So, $-t_{crit} < t_0 < t_{crit}$ or $-2.045 < -0.803 < 2.045$.

Then, it can be concluded that the quantity from the model is not different from the quantity from the real production line at significant level of 0.05.

The objective of the simulation was to compare the performance of these four models. Performance measures were production per day, productivity, average utilization, cost per day and profit per day. The simulation models were run 30 times. (Calculating at 0.05 significance level), assuming 100% of yield. The current production line (Model 1) can produce 168.5 pieces per day with 0.66 pieces per hour per man. Currently there are 34 workers. Average utilization is 22.22% with 27.29% line efficiency. The total cost per day is 207,543 Baht, and the profit, 23,639 per day.

The second model is the production which improved by lean without adding any machine. After simulation, the result of the lean model (Model 2) showed that the production could be increased 8.49% to produce 184.13 pieces per day with 0.72 pieces per hour per man. Average utilization can increase to 23.66%. However, line efficiency is reduced to 26.77 due to reduction of production time in each station except the bottleneck machine. Cost per day is not increased, but profit per day is improved 91%. But, this capacity would not satisfy the customer demand, which is 800 pieces per day.

After improving by lean techniques, line balancing was analyzed. The numbers of machines for tasks 7, 8 and 11 should increase from three to six, one to two and one to four respectively**.** Then, takt time and cycle time after improving is shown in Figure 4 if additional machines is added**.** From the figure, the production line should be able to meet customer demand because cycle time is lower than takt time, however in the real world problem, there are a lot of variations. So, simulation model was used to show the performance of the production line by increasing capacity further until reaching the customer demand.

4.3 Increasing capacity further

Line balancing was used to analyze the production line**.** Minimum number of workstations by calculation was 5 workstations. However, with some limitations of processes the number of workstations becomes 8 workstations. Some machines need to be added in order to increase the capacity of the production line. There are 6 types of machines that affect the production**.** So, the suitable number of machines for each workstation was analyzed.

Cost of production for each workstation was calculated from initial cost, operating cost, production cost (labor cost and overhead cost), maintenance cost and salvage value. Time value of money was also considered for these costs at 10% interest rate per year. They were converted to annual worth. Then annual worth was transformed into daily cost. The daily costs for each station for X_1 to X_7 are 4,770, 14,405, 47,440, 8,618, 8,439, 8,387 and 6,004 Baht, respectively. Average revenue after excluding material cost per piece is 1,372 Baht. Fixed cost per day is 14,600 Baht. So, the profit equation can be represented by

$$\text{Profit} = (1{,}372 \times TP) - (14{,}600 + 4{,}770X_1 + 14{,}405X_2 + 47{,}440X_3 + 8{,}618X_4 + 8{,}439X_5 + 8{,}387X_6 + 6{,}004X_7) \quad (2)$$

TP is the total production per day
X_1 is the number of filter machines
X_2 is the number of mixers
X_3 is the number of extrusion machines
X_4 is the number of texture making machines
X_5 is the number of finishing machines
X_6 is the number of cutting machines
X_7 is the number of coating machines

4.3.1 Bottleneck analysis

The computer simulation was used to find the possible solution for the target demand, according to determination of bottleneck machine in each stage. The possible boundaries of each variable were, $1 \le X_1 \le 3$, $1 \le X_2 \le 2$, $3 \le X_3 \le 10$, $1 \le X_4 \le 4$, $1 \le X_5 \le 3$ and $1 \le X_6 \le 4$, $1 \le X_7 \le 6$. After simulating each time, the bottleneck was defined, then one more machine was added to increase the capacity of that workstation. These steps were repeated until the production reached 800 pieces per day.

The capacity of the production line had to be increased by considering the bottleneck machine or constraint of the system from the highest WIP station after simulation. In each step the bottleneck machine was determined by the result from computer simulation until the total production quantity exceeded 800 pieces per day as shown in Table 3. For example, after improvement by lean, the bottleneck was defined. It was machine 7. So, one more of machine 7 was added to the simulation model. The model was run and found that the production quantity could increase from 184.3 units per day to 366.77 units per day. In conclusion the factory should have 1 each of filter machine, finishing machine and cutting machine, 2 mixers, 7 extrusion machines, 2 texture making machines and 5 coating machines to satisfy high customer demand.

Then, the performance of the system would be increased. Production per day would increase to 810.13 pieces, sufficient for customer demand. Productivity, average utilization and efficiency would be enhanced to 2.29, 65.01% and 44.03%, respectively. Cost per day would be increased to 114% from the current cost, but profit per day would improve 2722% (Model 3).

Table 3. Determination of decision variable based on bottleneck machines.

Determination of bottleneck (Task)	X_1 (1)	X_2 (6)	X_3 (7)	X_4 (8)	X_5 (9)	X_6 (10)	X_7 (11)	Production per day
Before improve	1	1	3	1	1	1	1	168.50
Improve by lean without adding machines	1	1	3	1	1	1	**1**	184.13
Add X_7	1	1	3	1	1	1	**2**	366.77
Add X_7	1	1	**3**	1	1	1	3	383.57
Add X_3	1	1	4	1	1	1	**3**	509.73
Add X_7	1	1	**4**	1	1	1	4	510.60
Add X_3	1	1	**5**	1	1	1	4	594.73
Add X_3	1	1	6	1	1	1	**4**	596.17
Add X_7	1	**1**	6	**1**	1	1	5	596.20
Add X_2, X_4	1	2	**6**	2	1	1	5	735.10
Add X_3	1	2	7	2	1	1	5	810.13
Optimization	1	2	8	2	1	1	6	**963.13**

Note: **Bold** number means bottleneck machine.

4.3.2 Optimization

Promodel software has built-in optimization tool, which is called SimRunner (Harrell, Ghosh, & Bowden, 2012). It uses evolutionary algorithms to solve problems. The objective function and constraints were set as follows.

$$\text{Max Profit} = (1{,}372 \times TP) - (14{,}600 + 4{,}770X_1 + 14{,}405X_2 + 47{,}440X_3 + 8{,}618X_4 + 8{,}439X_5 + 8{,}387X_6 + 6{,}004X_7)$$

Subject to

$$1 \le X_1 \le 3,$$
$$1 \le X_2 \le 2,$$
$$3 \le X_3 \le 10,$$
$$1 \le X_4 \le 4,$$
$$1 \le X_5 \le 3,$$
$$1 \le X_6 \le 4,$$
$$1 \le X_7 \le 6.$$
$$X_1, X_2, X_3, X_4, X_5, X_6, X_7 \ge 0$$

The objective was to maximize profit under the possible boundaries of each variable. Experiments were run until the optimal solution was found as shown in Figure 6.

The solution from SimRunner (Model 4) showed that the factory should have 1 each of filter machine, finishing machine and cutting machine, 2 mixers, 8 extrusion machines, 2 texture making machines and 6 coating machines. For this optimal solution maximizing profit, all of performance measures were higher than other models though the number of machines was increased more than the bottleneck model and production capacity was 20% more than target demand with 144% additional cost, however the profit would improve 3348%. Performance measures of each model are shown in Table 4.

5. Conclusions

In this research, the production lines of a wood plastic composite manufacturer were improved and balanced by lean techniques. Currently the production capacity of the factory is limited and has a lot of waste in many processes. Lean techniques, ECRS, quick setup, Computer Aided Engineering (CAE), were used to improve the current production. After running the improved simulation model of lean without adding machines (Model 2), it was shown that the production capacity could be increased 8.49%. This would increase a profit by 91% per day and the factory would not have to invest more. Some bottleneck machines were added in the simulated production system to eliminate constraints of the system (Model 3). The results from that simulation model showed that production quantity could be increased 381%, which would serve the target demand. Profit per day would also be very much higher with a gain of 2722% from the current situation, though, cost per day would increase about 114% from the current cost. The optimization model by SimRunner (Model 4) resulted is the best solution achieving profit increase of 3348%. The SimRunner model gave even better

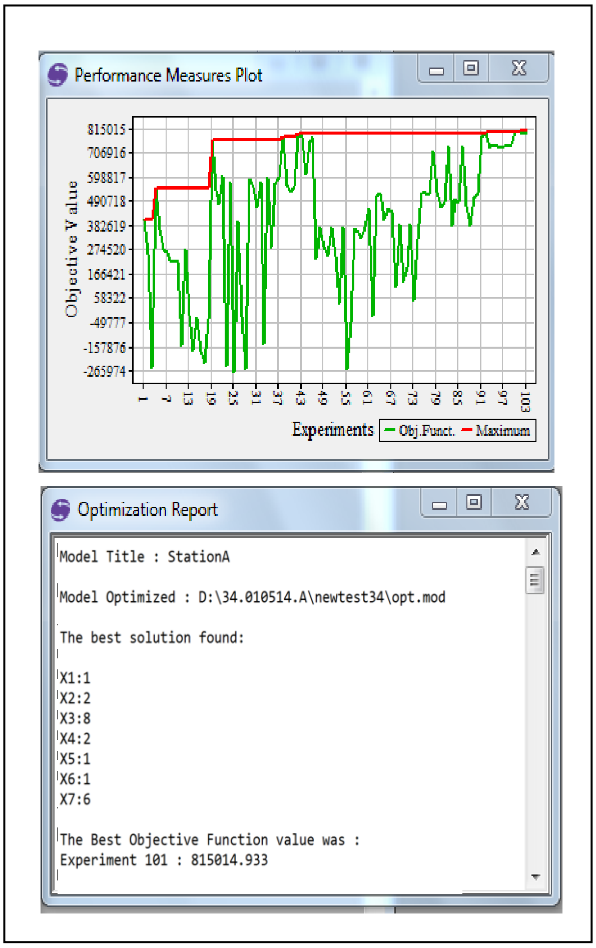

Figure 6. Simulation result from SimRunner.

Table 4. Performance measures of each model.

Model	Production quantity per day	Productivity	Average Utilization (%)	Line efficiency (%)	Cost per day	Profit per day
1. Factory	168.50	0.66	22.22	27.29	207,543	23,639
2. Lean without adding machines	184.13 (8.49%)	0.72 (174%)	23.66 (6%)	26.77 (-2%)	207,543 (0%)	45,083 (91%)
3. Bottleneck	810.13 (381%)	2.29 (247%)	65.01 (29%)	44.03 (26%)	444,342 (114%)	667,156 (2722%)
4. Sim.Opt.	963.13 (472%)	2.52 (282%)	64.01 (27%)	64.43 (85%)	506,404 (144%)	815,010 (3348%)

(% increased compared with the current model, Model 1) performances than the simulation determined by bottlenecking machines. The information provided by the simulations would support management decisions and motivate the organization to implement solutions to limitations in order to obtain the desired results of increased production and higher profit. Simulation based optimization can also be applied to other production lines.

After the simulations models were suggested to the company, the company implemented some of lean techniques and added an extrusion machine and two coating machines. Currently, the productivity and line efficiency of the production line have been increased about 90% and 60%, respectively.

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