Machine Layout Evaluation for Laminated Bamboo Manufacturing by Computer Simulation

N. Sangsai, V. Laemlaksakul

Abstract—**This research was to select the optimal machine layout for laminated bamboo manufacturing by computer simulation. The laminating process was to cut bamboo trunk as laminated piece. This process was important to total total time of production line so the computer simulation was applied to run each machine layout alternatives and gather the decided parameters. Production rate (pieces/day), total time, WIP and wait time were compared for making decision. The optimal machine layout had Production rate at 12,120- 12,390 laminated pieces/day and production line efficiency at 89.32%.**

Key-Words—**Laminated Bamboo, Machine Layout, Simulation**

I. Introduction

Currently, the manufacturing system has rapidly changed. In the past, the market demand was unlimited and there were not too various product requirements. This was called "Mass Production". The machine layout was then settled on products having high demand. However, the market demand has turned up side down at which customers require more variety of products and less demand. This is called "Mass Customization". The size of products must be determined in "Batch" in order to be flexible for production. Clearly, the manufacturing systems must adapt to "Flexible Manufacturing System (FMS)". FMS is well-suited for Mass Customization era because it can manufacture various products for small or medium batch size and for short time. The machine layout is an important factor for FMS because it can directly help production line less total time, work in process (WIP) and set up time. Finally, the business can enhance potential competitiveness and customer satisfaction [1].

The machine layout is based on 2 key parameters that are (1) the variety of products and (2) the quantity of products. If the customer requirements tend to be more various products but less quantity demand, the product layout or cellular manufacturing system (CM) should be considered [2].

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Irani [3] applied production flow analysis to machine layout. McAuley [4] used similarity coefficient value given by machine and product matrix to solve problems. King [5] and Rajamani [6] presented the developed matrix methodology for solving machine layout problems by considering weight scores for each row and column. Then the weight scores were ranked from large to small in order to group related products or machines. If the customer requirements tend to be less various products but more quantity demand, the process layout or production line system should be applied. There are also some factors to be concerned such as line balancing and economy.

Thailand has long produced bamboo furniture. Most designs are built in round-shape styles. After that the surface finishing are later done such as painting, coating.

The traditional bamboo furniture design only assembled the round shape stem bamboo together as shown in Figure 1. There was no any processing on bamboo. This could limit the styles or designs of bamboo furniture. The new bamboo furniture design turns to use the laminated bamboo instead as shown in Figure 2. The laminated bamboo can help designing furniture more styles and standardized. This research was to design the appropriate machine layout for laminated bamboo manufacturing.

Fig. 1 The traditional bamboo furniture design

Fig. 2 The modern bamboo furniture design

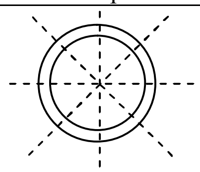
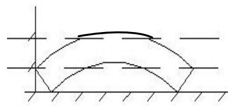
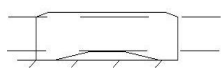
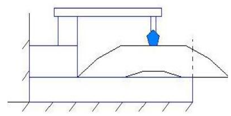
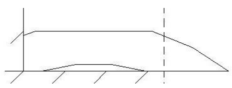
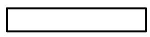
II. METHODOLOGY

Decided factors used for selecting the best machine layout for laminated bamboo manufacturing were based on these criteria; (1) production rate, (2) total time, (3) WIP and (4) wait time. The computer simulation was then constructed to compare each machine layout design. The more details for computer simulation are described in next section.

A. Modeling and Simulation

Preliminary step for laminated bamboo manufacturing study was to collect possible data related to manufacturing. The pre-processes were as follows; (1) bamboo surface finishing for cutting in laminated specimen (width x length x thickness) (2) soaking all specimen in boron compound for 24 hours [7].

Table 1
Manufacturing process for bamboo strip

Bamboo Process	Description
Splitting	
Remove 2 sides	
Planning to thickness	
1st trimmed to width	
2nd trimmed to width	
Bamboo strip	

From preliminary step, the complicated tasks for machine layout simulation were (1) surface finishing and (2) cutting into laminated pieces. The outline manufacturing flow for line A and B is shown in Figure 3.

The ARENA software was used to construct the simulation model for line *A* and *B* [8]. The production rate, total time, WIP and wait time were key factors to decide which machine layout was best appropriate.

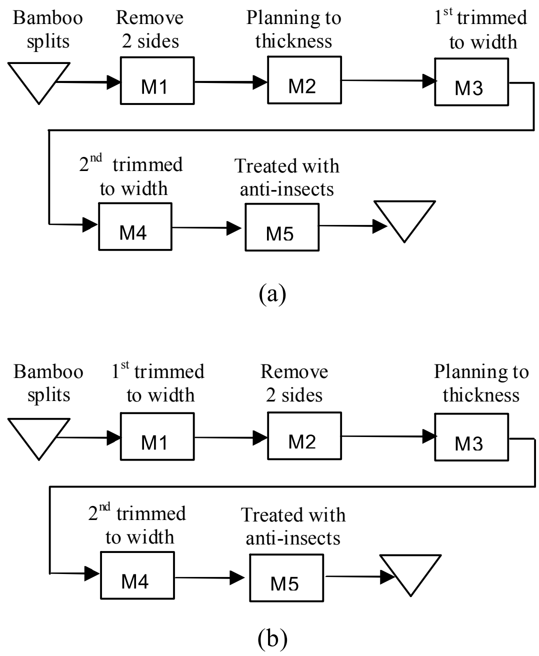


Fig. 3 Machine Layout (a) line *A* and (b) line *B*

B. Input Modeling and Data Analysis

From the preliminary step performed, the related data for simulation were as follows; (1) the original bamboo thickness before surface finishing (the bamboo thickness are different depending on its diameter) and (2) processing time varying with its thickness. All data were statistically analyzed to find its distribution and summarized in Table 2 and 3.

Table 2
The statistical distribution for each processing time in line *A*

Process	Statistical Distribution
Thickness before processing	8 + ERLA(0.996, 3): mm.
Remove 2 sides	Setup time 10 min / lot
	7 + LOGN(4.39, 4.61) : Sec./pieces
	8 + ERLA(1.61, 2) : Sec./pieces
Planning to thickness (12 mm. to 4 mm.)	Setup time 5 min / lot
	NORM(7.57, 1.94) : Sec./pieces
	7 + ERLA(1.78, 2) : Sec./pieces
	4 + ERLA(0.788, 5)) : Sec./pieces
	NORM(9.82, 1.61) : Sec./pieces
	4 + WEIB(7.68, 1.7) : Sec./pieces
	NORM(18.3, 2.79) : Sec./pieces
	16 + GAMM(4.18, 1.39) : Sec./pieces
	14 + GAMM(0.973, 6.49) : Sec./pieces
	17 + EXPO(3.45) : Sec./pieces
Trimmed to width	Setup time 3 min / lot
	20 + 40 * BETA(0.567, 1.86): Sec./pieces
Treated with anti-insects time	12 + LOGN(5.61, 3.39) Sec./pieces
	Constant 24 : hr.

Table 3
The statistical distribution for each processing time in line *B*

Process	Statistical Distribution
Thickness before processing	8 + ERLA(0.996, 3): mm.
1st Trimmed to width	Setup time 20 min / lot 12 + EXPO(16.4): Sec./pieces
Remove 2 sides	Setup time 3 min / lot NORM(33.8, 12.6): min.
Planning to thickness (12 mm. to 4 mm.)	Setup time 5 min / lot 5 + LOGN(6.88, 6.41)) : Sec./pieces 7 + ERLA(2.46, 2) : Sec./pieces 8 + 28 * BETA(0.566, 2.55) : Sec./pieces 6 + LOGN(7.55, 5.98)) : Sec./pieces 6 + LOGN(7.55, 5.98) : Sec./pieces 7 + LOGN(3.9, 3.76) : Sec./pieces 5 + LOGN(2.06, 1.52) : Sec./pieces 3 + ERLA(1.15, 4) : Sec./pieces 3 + 8 * BETA(2.52, 2.32) : Sec./pieces 4 + GAMM(3.04, 1.47) : Sec./pieces 5 + LOGN(3.56, 2.35) : Sec./pieces
2nd trimmed to width	Setup time 3 min / lot 12 + ERLA(4.54, 2) : Sec./pieces NORM(19.1, 4.5): Sec./pieces
Treated with anti-insects time	Constant 24 : hr.

C. *Model Verification and Validation*

The Verification and Validation (V&V) for new production was very difficult because there was no existed production line to compare so the model was tested by running simulation as many times as possible (Figure 4). Furthermore, the data from experiences and the adjacent production lines can be helpful for V&V.[2]

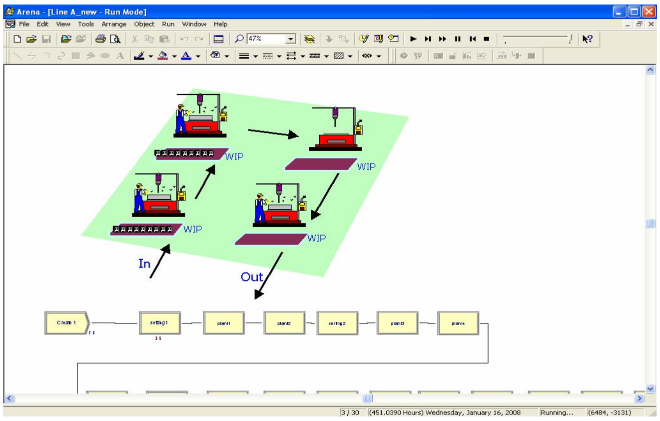


Fig. 4 The simulation program on V&V step

D. *Output Modeling*

The output from running the simulation for each machine layout design is production rate , total time, WIP and wait time. These factors were considered to compare the efficiency of each layout. The efficiency of each layout was such as the WIP area, the maximum machine Production rate and the bottlenecks of production line. When the real machine layout is implemented, the efficiency of each layout will be an important criterion to decide which layout will be the most appropriate.

III. Results

The simulation time of each machine layout was run by 30 consecutive days and each simulation run was performed 50 replications. After that the output of each machine layout was pair-wised and tested the different by t-test ($\alpha = 0.05$). The summarized data of each machine layout is shown in Table 3 and 4.

A. Production Lot Size

Simulation was run to find the optimal lot size by comparing the production line A and B. Small lot size (150 – 300 pieces/lot) yields the production rate more than large lot size (500 – 2,000 pieces/lot). Production rate from line B is higher than from line A by 5.96% but lower than from line B by 5.71% when lot size is increased to 2,000 pieces/lot.

B. Bottlenecks of production line.

In case of bottleneck, the average utilization of each machine is of interest to consider which machine or production line is in trouble.

- From production line A, there are 2 machines showing bottlenecks that are M1 and M2. The average utilization is 100% and 95% respectively. These machines are in remove 2 sides and planning to thickness processes because these machines can cut the bamboo size only one at a time. If the machine can improve as progressive cutting, its total time will definitely decrease. This points the guidelines for further improving.
- From production line B, there are 2 bottleneck machines that are M1 and M3. The average utilization is 100% and 92% respectively. These machines are in trimmed to width and planning to thickness processes as same as production line A. The work in process of production line B is less than of production line A so the production rate is also high.

C. Work in process / Total time/ Wait time

Simulation was run at different lot sizes 150, 200, 300, 500, 1,000, 1,300, 1,500 and 2,000 pieces per lot to compare work in process, total time and waiting time. Production line B yields less work in process total time and waiting time than production line A by 1.51%, 10.63% and 17% respectively. When considering small lot size (< 200 pieces/lot), work in process, total time and waiting time from production line B are less than from production line A by 1.51% 81.93% and 105.30% respectively. The optimal lot size between 100 – 200 pieces will benefit to the process.

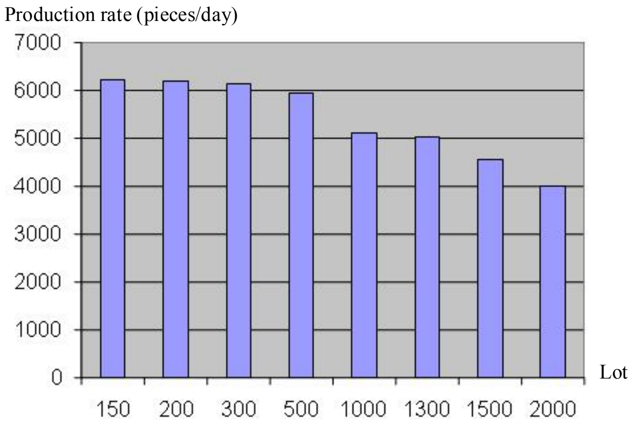


Fig. 5 Production rate (pieces/day) at different lot sizes of production line A

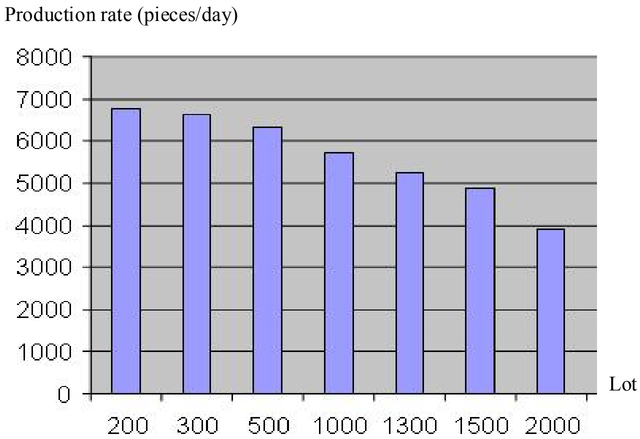


Fig. 8 Production rate (pieces/day) at different lot sizes of production line B

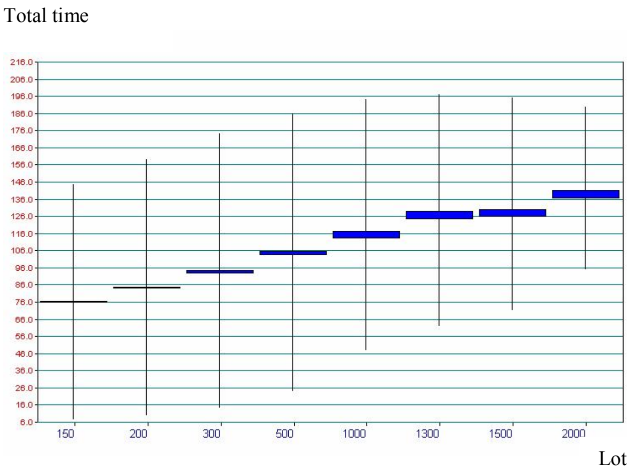


Fig. 6 Total time at different lot sizes of production line A

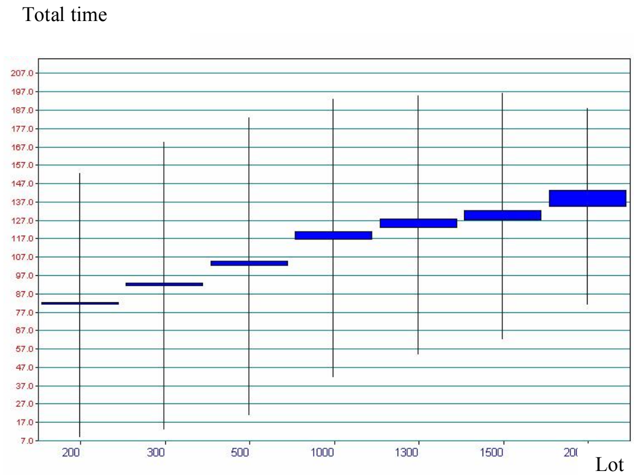


Fig. 9 Total time at different lot sizes of production line B

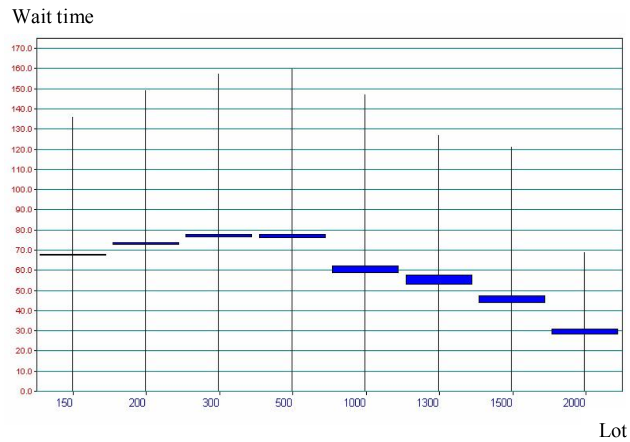


Fig. 7 Waiting time at different lot sizes of production line A

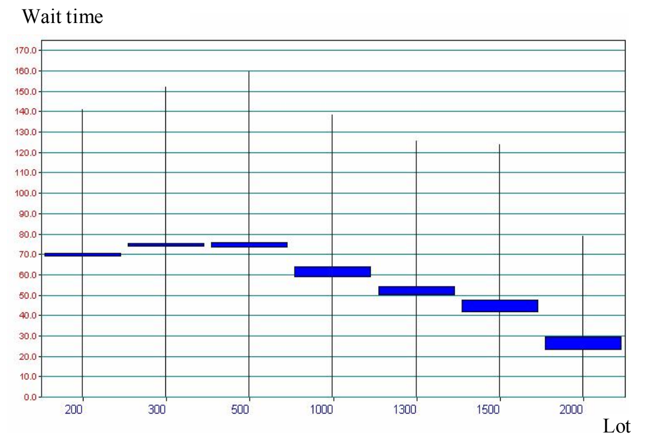


Fig. 10 Waiting time at different lot sizes of production line B

Table 4
Work in process and utilization of machines in line A

Lot	WIP (pieces)	Utilization			
		M1	M2	M3	M4
150	7,934	1	0.991	0.275	0.161
200	10,578	1	0.988	0.268	0.159
300	15,868	1	0.983	0.262	0.153
500	26,446	1	0.972	0.247	0.148
1000	52,892	1	0.944	0.223	0.127
1300	68,760	1	0.927	0.211	0.124
1500	79,338	1	0.916	0.194	0.112
2000	105,784	1	0.889	0.166	0.096

Table 5
KPI of each lot size in line A (Adding more machines in bottlenecks)

Lot	Total time (min./pieces)	Wait time (min./pieces)	WIP. (pieces)	Prod. rate (pieces/day)
150	48.041	39.402	8,669	12,390
200	64.007	52.63	11,559	12,327
300	81.079	64.277	17,338	12,120
500	98.003	69.997	28,897	11,467
1000	117.401	62.036	57,794	10,033
1300	126.355	54.519	75,132	9,143
1500	133.795	51.065	86,691	8,850
2000	146.442	36.31	115,588	7,400

Table 6
Utilization of machines in line A (Adding more machines in bottlenecks)

Lot	Utilization			
	M1	M2	M3	M4
150	1.00	0.99	0.54	0.33
200	1.00	0.98	0.53	0.32
300	1.00	0.97	0.51	0.31
500	1.00	0.96	0.49	0.29
1000	1.00	0.91	0.44	0.25
1300	1.00	0.89	0.42	0.23
1500	1.00	0.87	0.39	0.22
2000	1.00	0.83	0.34	0.19

D. Productivity Improvement

The simulation run for laminated bamboo manufacturing can benefits as;

- Combining the processes

The right and left cutting process can be combined into one process in order to use the same machine. The efficiency of production line A increased from 57.93% to 77.23%.

- Adding more machines in Bottlenecks

When adding more machines in production line A and B (by simulation approach), the efficiency of production line A and B is higher from 57.93% to 66.26% and 79.32% to 86.24% respectively. Furthermore, production rate of each production line is at 93.27% and 89.32% respectively.

Table 7
Work in process and utilization of machines in line B

Lot	WIP (pieces)	Utilization			
		M1	M2	M3	M4
150	-	-	-	-	-
200	10,421	1	0.950	0.982	0.395
300	15,632	1	0.962	0.973	0.383
500	26,053	1	0.960	0.957	0.367
1000	52,106	1	0.928	0.916	0.328
1300	67,738	1	0.894	0.891	0.303
1500	78,159	1	0.892	0.875	0.293
2000	104,212	1	0.878	0.834	0.249

Table 8
KPI of each lot size in line B (Adding more machines in bottlenecks)

Lot	Total time (min./pieces)	Wait time (min./pieces)	WIP. (pieces)	Prod. rate (pieces/day)
150	-	-	-	-
200	57.706	45.822	12,814	13,273
300	77.609	60.171	19,221	13,100
500	96.733	67.966	32,035	12,417
1000	119.066	62.192	64,069	10,600
1300	128.607	54.665	83,290	9,663
1500	135.196	50.421	96,104	9,100
2000	147.615	33.557	128,138	7,000

Table 9
Utilization of machines in line B (Adding more machines in bottlenecks)

Lot	Utilization			
	M1	M2	M3	M4
150	-	-	-	-
200	1.00	0.94	0.98	0.78
300	1.00	0.96	0.97	0.75
500	1.00	0.95	0.94	0.72
1000	1.00	0.92	0.89	0.62
1300	1.00	0.91	0.85	0.58
1500	1.00	0.91	0.83	0.53
2000	1.00	0.88	0.78	0.45

IV. CONCLUSIONS

Laminated bamboo manufacturing process is important to the production line and total time. The efficient machine layout for this process will improve production rate and reduce manufacturing cost. Computer simulation was considered to help making decision which machine layout alternatives will be the most efficient or how many machines should have in the selected layout. The important parameters given by computer simulation in this research were production rate, total time, WIP and wait time. The machine layout *B* was the best following to all parameters. The new laminated bamboo manufacturing process should rely on machine layout *B*.

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