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SIMULATION FOR JEWELRY PRODUCTION PROCESS IMPROVEMENT USING LINE BALANCING: A CASE STUDY

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Abstract:
Thai jewelry is the world's leading jewelry which has gained high reputation and recognition from customers worldwide. In the past decade, jewelry have become one of the top ten export product of Thailand with the current export value of around 58,000 million baht per year which is 3.4 percent of all Thailand export products. Due to the high competition in the world market, however, Thai jewelry manufacturers needs to continue to improve their product quality as well as process efficiency in order to gain more market share. Currently, computer-aided tools have become more powerful tool in jewelry production management. They have been used to design production process, plant and workstation layout, production planning, worker's scheduling, and other decisive decision making in both high management and shop floor levels. This research demonstrates a case study of plant simulation application for jewelry production process improvement. The objective is to reduce bottlenecks and increase productivity in wax pattern and casting processes using line balancing. Various scenarios have been proposed in order to support different level of desired output rate due to the increase of demand. The results of line balancing and simulation models reduce bottlenecks. Hence, productivity is increased. The desired throughput rates are achieved with the minimum number of workers and machine in the system.

Key words: *process improvement, line balancing, simulation model, jewelry production process*

INTRODUCTION

Problem statement

The jewelry company case study produces many types of products with diversity of shapes, sizes, and characters, due to various customer requirements. Since the production process type is job shop, it is difficult for production planning manager to design production plan because of product multiplicity and demand uncertainty. This obstacle leads to unbalanced production system which causes low process efficiency. This research applies simulation tools to reduce bottlenecks and increase productivity. Simulation modeling is one of the powerful tool which could be used to analyze problems and study the behavior of production system. Theory of constraint and line balancing are taken into account in order to increase the efficiency of the process by minimizing bottlenecks and minimizing number of workstations.

Currently, the company produces many types of product such as rings, ear rings, and pendants with various shape and size according to customer specifications. Each month, the company receives a large number of orders from many customers from various regions in the world. Most of the time, patterns and shapes of the products are specified by customers. Therefore, it is not easy for the production manager to design production plan. Moreover, the company is confronting with insufficient production capacity due to the continual increase of demand. The company wants to pay attention on casting area which has highest bottlenecks and worker idle time. The casting area consists of wax pattern process and casting process. The scope of the study is the main production lines of ring, ear ring, and pendant made by aluminum and platinum which are considered critical due to the highest demand rate.

Literature review

Line balancing: The main purpose of line balancing is to assign tasks to sequence of workstations in order to minimize the delay or minimize number of workstation. Salveson [1] published the very first paper of line balancing using linear programming solution. Gutjahr and Nemhauser [2] considered the efficient algorithms to obtain solution for NP hard assembly line balancing (ALB) problems later on. In the past, many computer-efficient approximation algorithms or heuristics and exact method have been used to solve ALB problems such as Hoffman [3], Arcus [4], Raouf and El-Sayed [5], Baybars [6], and Jim and Wu [7]. Talbolet at. [8] described the use of an integer programming algorithm in order to assign tasks to work stations on an assembly line with minimum number of work stations. An article by Scholl and Becker [9] provided the state-of-the-art exact and heuristic solution procedures for simple assembly line balancing (SALB). Chutima and Olanviwatchai [10] illustrated a new evolutionary method called combinatorial optimization with coincidence algorithm (COIN) which was applied to mixed-model u-shaped assembly line balancing problems (MMUALBP) in a just-in-time production system. Avikal and Yadav [11] described the attempt of evaluating labor productivity in u-shaped line system and straight line system. They applied a critical path method (CPM) based approach for u-shaped assembly line for assigning tasks to work stations for the layout of an assembly line. Sivasankaran and Shahabudeen [12] developed three genetic algorithms for the mixed-model assembly line balancing problem to maximize the combined balancing efficiency. Zupan and Herakovic [13] proposed a case study of the optimization of the production line by using line balancing and discrete event simulation approach.

Simulation: A well establishment of simulation model could analyze alternate situations and enhance the understanding of system behavior, Maria [14]. Kadar et al. [15] showed the potential of using simulation model in supporting production planning and scheduling. They built a simulation model which constituted a coherent part of digital factory solutions. Technomatix Plant Simulation software was applied to simulate the comparison of two different production models in research of Stankovic et al. [16]. Ho [17] studied staged improvement of delivery-orientated production plan using a system dynamics (SD). In the study, a practical problem was a dynamic approach adjusting enterprise's policy for conforming of customers' needs. In addition, simulation was used to investigate the effect of changes in the shop floor on production performance through discrete event simulation. The effect on the throughput rate, labor utilization, and machine utilization were studied by Ng et al. [18]. Pröpstera et al. [19] conducted research on validation of line balancing by simulation of workforce flexibility. Their paper presented a simulation tool which simulated the aspects of worker flexibility according to the produced variants and their sequence. Furthermore, an approach validated by line balancing and resulted by simulation was introduced. Simulations have also been applied in process design and workstation optimization in manufacturing process to achieve customer demands. Management could use simulation to test all possible solutions to achieve customer demand, Sargent [20], Güçdemir and Selim [21], and Lang et al. [22].

RESEARCH METHODS

Casting phase

The casting phase is the first stage of jewelry production process. The process starts with preparing pattern for making mold of casting. Patterns are made of wax and processed by injection machine, trimming, and attaching wax to taper. Aft era pattern is finished, it will be placed into a tube, and operators will pure plaster into that tube, then the tube will be conveyed to the furnace to be melted to make a mold for metal casting. After finishing casting process, the material will be inspected and awaiting to convey to the next process. Wax pattern and casting are two main processes in casting phase. They are installed in separate rooms called wax pattern room and casting room. Figure 1 presents four workstations in wax pattern process. Figure 2 shows five workstations in casting process, respectively.

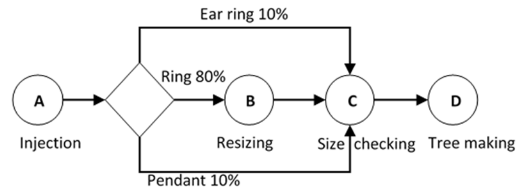


Fig. 1 Wax pattern process

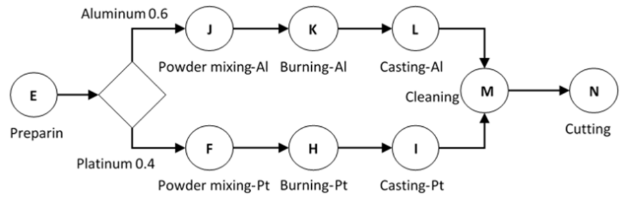


Fig. 2 Casting process

Wax pattern process has three production lines for each of three products: ring, ear ring, and pendant. Four main workstations in wax pattern process are Injection (A), Resizing (B), Size checking (C), and Tree making (D). Injection is the process of melting wax and injecting it into rubber mold. Each station in this section requires one worker, but no machine. When the injected wax cools down, it becomes 'wax pattern'. Re-sizing process is the process of adjusting the pattern size. The pattern size could be enlarged by adding wax into the pattern. It could be cut at the bottom of the shank, separated into two pieces, and then attached back by making a small wax bride at its base. The pattern size could also be reduced by cutting the bottom of the shank and then attach it back by using soldering iron. Size checking is the process of defect detection and size checking after injection. Tree making process is the process of attaching wax pattern around wax tree by using soldering iron.

Casting process has two production lines setting for each type of materials: aluminum and platinum. There are six functions with nine stations in casting process; Preparing (E), Power mixing (F, J), Burning in a furnace (H, K), Casting (I, L), Cleaning (M), and Cutting (N). Cleaning (M) and Cutting (N) stations require no machine. Burning stations (H and K) need no worker. The rest requires one worker for each station to operate with machines. Powder mixing is the process which powder is mixed and filled into flasks under vacuum and vibration to eliminate porosity. Burning is the process of burning out wax and curing investment powder to induce desired characteristics in the powder mold. Casting process requires two different types of machine: a centrifugal casting machine and a gravitational casting machine. A centrifugal casting machine is used for aluminum and platinum casting. A gravitational casting machine is used for gold casting. Cleaning process is the process of cleaning and drying materials. Cutting process is the process that cuts and trims materials from the tree. Regularly, the production operates in a 9-hour shift with 1 hour break from 8:00 a.m. to 5.00 p.m. for 30 days per month (with part time hiring on Sunday).

The objective of this study is to increase process efficiency by using line balancing and computer simulation software. The minimum number of workers and machine will be designed to increase capacity up to future demands. The study particularly focuses on casting phase of critical products; ring, ear ring, and pendant made from aluminum and platinum.

Data collection

Cycle time of each station of the process is collected by using time study method. Hypothesis testing is used to verify data. According to historical information given by plant manager, product proportion of each type is 80% of ring, 10% of ear ring, and 10% of pendant. All three types are made from 0.60 of aluminum and 0.40 of platinum. Table 1 presents the average cycle times and number of workers of each station in the current manufacturing process.

Table 1
Average cycle time and number of workers of current wax pattern process

Station	Process	Average cycle time (seconds)			Number of workers
		Ring	Ear ring	Pendant	
A	Injection	53.87	100.05	54.45	5
B	Resizing	50.56	-	-	2
C	Size checking	88.14	148.47	70.12	8
D	Tree making	33.36	21.26	20.29	6
Total		225.93	269.78	144.86	21

Currently, the average output rate of the process is approximately 800 units per day, while the company's expectation is 900 units per day on the average. If the desired output rate is 900 units per day and the utilization time is 8 hours per day (28,800 seconds per day), cycle time of each station is 28,800/900 = 32.00 seconds per unit. According to the information in Table 1, the total cycle time is 225.93 + 269.78 + 144.86 = 640.57 seconds, then the minimum number of stations in this process should be 640.57/32 = 20.0178 stations. Currently, the process has 21 workers who are assigned for 21 work stations in the process (one worker is assigned to one station). However, this calculation does not fully practical for the process because demand rate of each type of product varies and cycle time is unequal as presented in Table 1. The redesign of line balancing will be explained in the next section to minimize number of stations which is number of workers. Burning process of both aluminum and platinum takes 12 hours, which is longer than 8 hours. Generally, both two furnaces will run continuously for 12 hours. Therefore, they would be running for another 4 hours after normal shift and would not disturb normal working hours. Each station in casting process is assigned to have sufficient number of machines to ensure capacity and to avoid disruption due to the sophisticated set up. Table 2 shows machine capacity of current casting process.

Table 2
Machine capacity of current casting process

Station	Process	Machine capacity (units/day)	Available quantity	Total Capacity (units/day)	Number of Workers
F	Powder Mixing-Pt	5,400.00	1	5,400.00	1
H	Burning-Pt	320.00	3	960.00	-
I	Casting-Pt	720.00	2	1,440.00	2
J	Powder Mixing-Al	7,200.00	1	7,200.00	1
K	Burning-Al	240.00	4	960.00	-
L	Casting-Al	600.00	3	1,800.00	3
M	Cleaning	-	-	-	2
N	Cutting	-	-	-	2
Total			14		11

Al = Aluminum, Pt = platinum

Desired output rate

Since the company plans to increase production rate up to 900 units per day from current 800 units per day on average, line balancing is taken onto account to design number of stations (i.e. number of workers).In order to design process for the company forecast demands, three scenarios are proposed. Model I has a desired output rate of 900 units per day. Model II has 1,500 units per day. Model III has 2,100 units per day. As mentioned, it is assumed that one worker is assigned to one workstation and each worker can perform every task of all types of product. The minimum number of machines in casting room will also be designed for each simulation scenario. Table 3 illustrates the desired output rate for future demands.

Table 3
The amount of each product for different desired output rates of three simulation scenarios

Product	Material	Proportion	Desired output rate (units/day)		
			Model I: 900	Model II: 1,500	Model III: 2,100
Ring (80%)	Al (0.6)	48%	432.00	720.00	1,008.00
	Pt (0.4)	32%	288.00	480.00	672.00
Ear ring (10%)	Al (0.6)	6%	54.00	90.00	126.00
	Pt (0.4)	4%	36.00	60.00	84.00
Pendant (10%)	Al (0.6)	6%	54.00	90.00	126.00
	Pt (0.4)	4%	36.00	60.00	84.00
Total		100%	900.00	1,500.00	2,100.00

SIMULATION MODEL

As discussed earlier, casting phase has two processes; wax pattern and casting. This section presents the calculation of number of workers and machines for both processes.

Three scenarios for targets of average 900, 1,500, and 2,100 units per day are considered.

Model I: Target = 900 units/day

Model I is set to produce product up to the amount of 900 units per day on average. Utilization time is 8 hours per day (28,800.00 seconds per day). Therefore, takt time is 28,800.00 seconds per day/900.00 units per day = 32.00 seconds per unit. The average proportion of product of ring, ear ring, and pendant is 80:10:10. Therefore, the utilization time for 80% ring is 23,040.00 seconds per day, 10% ear ring is 2,880.00 seconds per day, and 10% pendant is 2,880.00 seconds per day.

Model I – Wax pattern process

From data in Table 2, takt time can be calculated as shown below.

$$Takt\ time = \frac{Available\ utilized\ time}{Desired\ output\ rate}$$

Takt time of 80% ring is (23,040.00 seconds/day) ÷ (720.00 units/day) = 32.00 seconds/unit. Takt time of 10% ear ring is (2,880.00 seconds/day) ÷ (90.00 units/day) = 32.00 seconds/unit. Takt time of 10% pendant is (2,880.00 seconds/day) ÷ (90.00 units/day) = 32.00 seconds/unit. Table 4 presents the real cycle time to finish one unit of product at each work station. For example, a ring requires 53.87 seconds in work station A (Injection process). To be able to produce product to meet demand, cycle time must be less than or equal to takt time. Therefore, workstation A should have at least 1.683 workers or 2 workers (cycle time/takt time = 53.87/32 = 1.683). Minimum number of workers of other workstations are also calculated and shown in Table 4.

Table 4

Number of workers without proportion calculation at wax pattern process of Model I

Product	Station	Process	Cycle time (sec.)	Takt time (sec./unit)	Number of workers	
					Calculation	Round
Ring	A	Injection	53.87	32.00	1.683	2
	B	Resizing	50.56	32.00	1.580	2
	C	Size checking	88.14	32.00	2.754	3
	D	Tree making (TM)	33.36	32.00	1.043	2
Ear ring	A	Injection	100.05	32.00	3.127	4
	C	Size checking	148.47	32.00	4.640	5
	D	Tree making	21.26	32.00	0.664	1
Pendant	A	Injection	54.45	32.00	1.702	2
	C	Size checking	70.12	32.00	2.191	3
	D	Tree making	20.29	32.00	0.634	1
Total			640.57		20.018	25

Since proportion of product varies, therefore the number of workers should also be calculated based on this proportions shown in Table 5. Number of workers is decreased to 11 from 21.

Table 5

Number of workers calculated by proportion at wax pattern process of Model I

Station	Process	Ring (80%)	Ear ring (10%)	Pendant (10%)	Total	Round
A	Injection	2x0.8 = 1.6	4x0.1 = 0.4	2x0.1 = 0.2	2.20	3
B	Resizing	2x0.8 = 1.6	-	-	1.60	2
C	Size checking	3x0.8 = 2.4	5x0.1 = 0.5	3x0.1 = 0.3	3.20	4
D	Tree making	2x0.8 = 1.6	1x0.1 = 0.1	1x0.1 = 0.1	1.80	2
Total						11

Model I – Casting process

Number of workers without proportion calculation is calculated as shown in Table 6. Table 7 illustrates number of workers calculated by proportion. Table 8 presents number of machines calculated by proportion at casting process.

Table 6

Number of workers without proportion calculation at casting process of Model I

Product	Station	Process	Cycle time (sec.)	Takt time (sec./unit)	Number of workers	
					Calculation	Round
Ring-Al	J	Mixing	4.00	32.00	0.125	1
	L	Casting	59.62	32.00	1.863	2
	M	Cleaning	10.03	32.00	0.313	1
	N	Cutting	12.22	32.00	0.382	1
Ring-Pt	F	Mixing	3.20	32.00	0.100	1
	I	Casting	44.19	32.00	1.380	2
	M	Cleaning	10.03	32.00	0.313	1
	N	Cutting	12.21	32.00	0.382	1
Ear ring-Al	J	Mixing	4.00	32.00	0.125	1
	L	Casting	59.62	32.00	1.863	2
	M	Cleaning	10.03	32.00	0.313	1
	N	Cutting	12.30	32.00	0.384	1
Ear ring-Pt	F	Mixing	3.20	32.00	0.100	1
	I	Casting	44.19	32.00	1.381	2
	M	Cleaning	10.03	32.00	0.313	1
	N	Cutting	12.50	32.00	0.391	1
Pendant-Al	J	Mixing	4.00	32.00	0.125	1
	L	Casting	59.62	32.00	1.863	2
	M	Cleaning	10.03	32.00	0.313	1
	N	Cutting	12.26	32.00	0.383	1
Pendant-Pt	F	Mixing	3.20	32.00	0.100	1
	I	Casting	44.19	32.00	1.381	2
	M	Cleaning	10.03	32.00	0.313	1
	N	Cutting	12.58	32.00	0.393	1

Table 7
Number of workers calculated by proportion at casting process of Model I

Station	Process	Ring		Ear ring		Pendant		Number of Workers	Round
		Al (48%)	Pt (32%)	Al (6%)	Pt (4%)	Al (6%)	Pt (4%)		
F	Powder mixing-Pt	-	1x0.32	-	1x0.04	-	1x0.04	0.40	1
H	Burning-Pt	-	-	-	-	-	-	-	-
I	Casting-Pt	-	2x0.32	-	2x0.04	-	2x0.04	0.76	1
J	Powder mixing-Al	1x0.48	-	1x0.06		1x0.06	-	0.60	1
K	Burning-Al	-	-	-	-	-	-	-	-
L	Casting-Al	2x0.48	-	2x0.06	-	2x0.06	-	1.20	2
M	Cleaning	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
N	Cutting	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
Total									7

Table 8
Number of machines calculated by proportion at casting process of Model I

Station	Machine	Machine capacity (units/day)	Available quantity	Total capacity (units/day)	Desired output rate (units/day)	Number of required machines
F	Powder mixing-Pt	5,400	1	5,400	900x0.4=360	1
H	Burning-Pt	320	3	960	900x0.4=360	2
I	Casting-Pt	720	2	1,440	900x0.4=360	1
J	Powder mixing-Al	7,200	1	7,200	900x0.6=540	1
K	Burning-Al	240	4	960	900x0.6=540	3
L	Casting-Al	600	3	1,800	900x0.6=540	2
Total			14		900	10

Model II: Target = 1,500 units/day

Model II – Wax pattern process

Following the same steps of previous section, takt time, number of workers, and number of machines of Model II can be calculated as shown below. Takt time of 80% ring is (23,040.00 seconds/day) ÷ (1,200 units/day) = 19.20 seconds/unit. Takt time of 10% ear ring is (2,880.00 seconds/day) ÷ (150 units/day) = 19.20 seconds/unit. Takt time of 10% pendant is (2,880.00 seconds/day) ÷ (150 units/day) = 19.20 seconds/unit. By changing cycle time from 32.00 to 19.20 seconds per unit, number of workers in wax pattern process calculated by proportion of Model II is calculated and shown in Table 9.

Table 9
Number of workers calculated by proportion at wax pattern process of Model II

Station	Process	Ring (80%)	Ear ring (10%)	Pendant (10%)	Total	Round
A	Injection	3x0.8 = 2.4	6x0.1 = 0.6	3x0.1 = 0.3	3.30	4
B	Resizing	3x0.8 = 2.4	0	0	2.40	3
C	Size checking	5x0.8 = 4.0	8x0.1 = 0.8	4x0.1 = 0.4	5.20	6
D	Tree making	2x0.8 = 1.6	2x0.1 = 0.2	2x0.1 = 0.2	2.00	2
Total		15				

Model II – Casting process

The number of workers in casting process of Model II calculated by proportion, which cycle time is changed from 32.00 to 19.20 seconds per unit, could be found as shown in Table 10. Number of machines are shown in Table 11.

Table 10
Number of workers calculated by proportion at casting process of Model II

Station	Process	Ring		Ear ring		Pendant		Number of workers	Round
		Al (48%)	Pt (32%)	Al (6%)	Pt (4%)	Al (6%)	Pt (4%)		
F	Powder mixing-Pt	-	1x0.32	-	1x0.04	-	1x0.04	0.40	1
H	Burning-Pt	-	-	-	-	-	-	-	-
I	Casting-Pt	-	3x0.32	-	3x0.04	-	3x0.04	1.20	2
J	Powder mixing-Al	1x0.48	-	1x0.06	-	1x0.06	-	0.60	1
K	Burning-Al	-	-	-	-	-	-	-	-
L	Casting-Al	4x0.48		4x0.06		4x0.06		2.40	3
M	Cleaning	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
N	Cutting	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
Total									9

Table 11
Number of machines calculated by proportion at casting process of Model II

Station	Machine	Machine capacity (units/day)	Available quantity	Total capacity (units/day)	Desired output rate (units/day)	Number of required machines
F	Powder mixing-Pt	5,400	1	5,400	1,500x0.4 = 600	1
H	Burning-Pt	320	3	960	1,500x0.4 = 600	3
I	Casting-Pt	720	2	1,440	1,500x0.4 = 600	1
J	Powder mixing-Al	7,200	1	7,200	1,500x0.6 = 900	1
K	Burning-Al	240.00	4	960.00	1,500x0.6 = 900	3
L	Casting-Al	600	3	1,800	1,500x0.6 = 900	2
Total			14		1,500	11

Model III: Target = 2,100 units/day

Model III – Wax pattern process

Takt time of 80% ring is (23,040.00 seconds/day) ÷ (1,680.00 units/day) = 13.71 seconds/unit. Takt time of 10% ear ring is (2,880.00 seconds/day) ÷ (210.00 units/day) = 13.71 seconds/unit. Takt time of 10% pendant is (2,880.00 seconds/day) ÷ (210.00 units/day) = 13.71 seconds/unit. By following steps in previous section, but changing cycle time from 32.00 to 13.71 seconds per unit, and considering product proportion, number of required workers in wax pattern process of Model III are calculated and described in Table 12.

Table 12

Number of workers calculated by proportion at wax pattern process of Model III

Station	Process	Ring (80%)	Ear ring (10%)	Pendant (10%)	Total	Round
A	Injection	4x0.8 = 3.2	8x0.1 = 0.8	4x0.1 = 0.4	4.40	5
B	Resizing	4x0.8 = 3.2	0	0	3.20	4
C	Size checking	7x0.8 = 5.6	11x0.1 = 1.1	6x0.1 = 0.6	7.30	8
D	Tree making	3x0.8 = 2.4	2x0.1 = 0.2	2x0.1 = 0.2	2.80	3
Total		20				

Model III – Casting process

Number of workers for casting process is illustrated in Table 13. Number of machines is shown in Table 14.

Furnace for aluminum is not sufficient in the case of desired output rate of 2,100 units per day. To achieve this target, the company should acquire two more furnaces for aluminum.

Table 13

Number of workers calculated by proportion at casting process of Model III

Station	Process	Ring Al (48%)	Ring Pt (32%)	Ear ring Al (6%)	Ear ring Pt (4%)	Pendant Al (6%)	Pendant Pt (4%)	Number of workers	Round
F	Powder mixing-Pt	-	1x0.32	-	1x0.04	-	1x0.04	0.40	1
H	Burning-Pt	-	-	-	-	-	-	-	-
I	Casting-Pt	-	4x0.32	-	4x0.04	-	4x0.04	1.60	2
J	Powder mixing-Al	1x0.48	-	1x0.06	-	1x0.06	-	0.60	1
K	Burning-Al	-	-	-	-	-	-	-	-
L	Casting-Al	5x0.48		5x0.06		5x0.06		3.00	3
M	Cleaning	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
N	Cutting	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
Total									9

Table 14

Number of machines calculated by proportion at casting process of Model III

Station	Process	Ring Al (48%)	Ring Pt (32%)	Ear ring Al (6%)	Ear ring Pt (4%)	Pendant Al (6%)	Pendant Pt (4%)	Number of workers	Round
F	Powder mixing-Pt	-	1x0.32	-	1x0.04	-	1x0.04	0.40	1
H	Burning-Pt	-	-	-	-	-	-	-	-
I	Casting-Pt	-	4x0.32	-	4x0.04	-	4x0.04	1.60	2
J	Powder mixing-Al	1x0.48	-	1x0.06	-	1x0.06	-	0.60	1
K	Burning-Al	-	-	-	-	-	-	-	-
L	Casting-Al	5x0.48		5x0.06		5x0.06		3.00	3
M	Cleaning	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
N	Cutting	1x0.48	1x0.32	1x0.06	1x0.04	1x0.06	1x0.04	1.00	1
Total									9

RESULTS AND DISCUSSIONS

Number of workers and machines calculated in Simulation model section using line balancing are used as initial parameters of each simulation model in this section. Each model has a wax pattern process and casting process frame separately. Both frames are interfaced and run continuously for 30 days. In case that simulation results by the initial inputs do not meet the desired output, parameters are manually increased one by one to find the results which could meet targets.

Model I: Target = 900 units/day

Figure 3 presents work station layout in simulation program of Model I. The left frame is wax pattern room. The purple area is station A-Injection, yellow is B-Resizing, green is C-Size checking, and orange is D-Tree making. The gray area on the left side is mold storage which is movable and on the right is Quality control (QC) station. The right frame is casting room. The yellow area is stations F, J-Powder mixing, pink is H, K- Burning, orange is I, L-Casting, blue is M-Cleaning, and green is N-Cutting. Number of workers from line balancing calculation is 7 and from simulation after manually adjusted is 9. Number of machines from line balancing is10 which is equal to simulation result. Figure 4 shows the run results of each type of product for 30 days. The total throughput is 30,000.00 units per month, which is 1,000.00 units per day on the average (See Table 15 and 16). Figure 5 illustrates utilization for each station. There is no blocking (yellow code) in this model which shows that the process runs smoothly. The green codes are working and the gray ones are waiting.

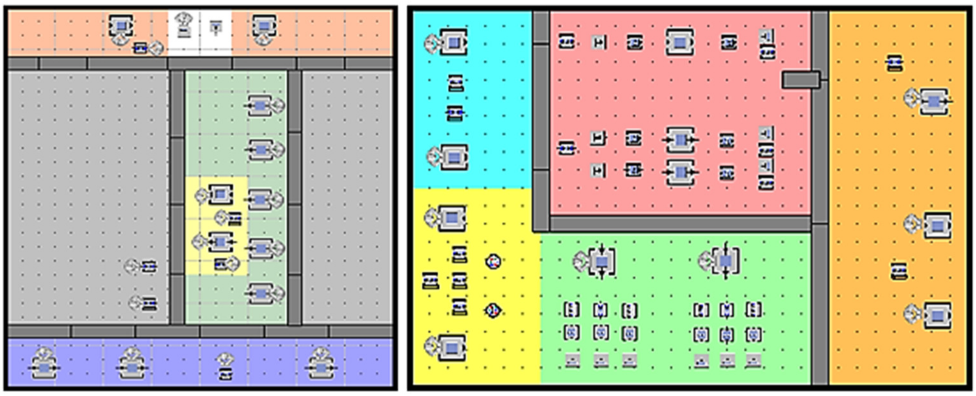
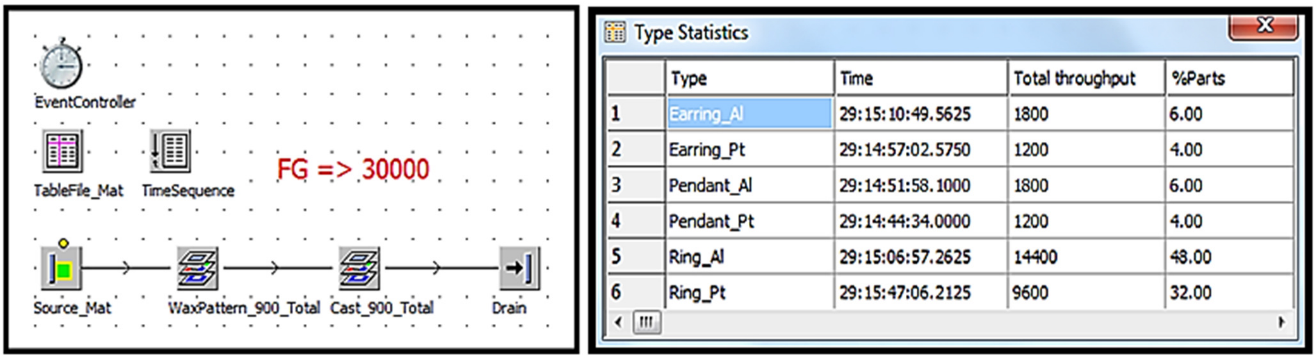


Fig. 3 Simulation frames of wax pattern and casting processes of Model I



	Type	Time	Total throughput	%Parts
1	Earring_Al	29:15:10:49.5625	1800	6.00
2	Earring_Pt	29:14:57:02.5750	1200	4.00
3	Pendant_Al	29:14:51:58.1000	1800	6.00
4	Pendant_Pt	29:14:44:34.0000	1200	4.00
5	Ring_Al	29:15:06:57.2625	14400	48.00
6	Ring_Pt	29:15:47:06.2125	9600	32.00

Fig. 4 Throughput and results of interfaced wax pattern and casting processes of Model I

Table 15

Result comparisons of calculations and simulations of Model I, II, and III

Process	Station	Process	Current		Model I: 900				Model II: 1,500				Model III: 1,200			
			Worker	M/C	Worker		M/C		Worker		M/C		Worker		M/C	
					Cal.	Sim	Cal.	Sim	Cal.	Sim.	Cal.	Sim	Cal.	Sim.	Cal.	Sim
Wax pattern	A	Injection	5	-	3	3	-	-	4	4	-	-	5	6	-	-
	B	Resizing	2	-	2	2	-	-	3	3	-	-	4	4	-	-
	C	Size checking	8	-	4	5	-	-	6	6	-	-	8	9	-	-
	D	Tree making	6	-	2	2	-	-	2	2	-	-	3	3	-	-
Total			21	-	11	12	-	-	15	15	-	-	20	22	-	-
Casting	F	Powder mixing-Pt	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	H	Burning out-Pt	-	3	-	-	2	2	-	-	3	3	-	-	3	3
	I	Casting-Pt	2	2	1	1	1	1	2	2	1	1	2	2	2	2
	J	Powder mixing-Al	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	K	Burning out-Al	-	4	-	-	3	3	-	-	3	3	-	-	6	6
	L	Casting-Al	3	3	2	2	2	2	3	3	2	3	3	4	3	3
	M	Cleaning	2	-	1	2	-	-	1	2	-	-	1	2	-	-
	N	Cutting	2	-	1	2	-	-	1	2	-	-	1	2	-	-
Total			11	14	7	9	10	10	9	11	11	12	9	12	16	16

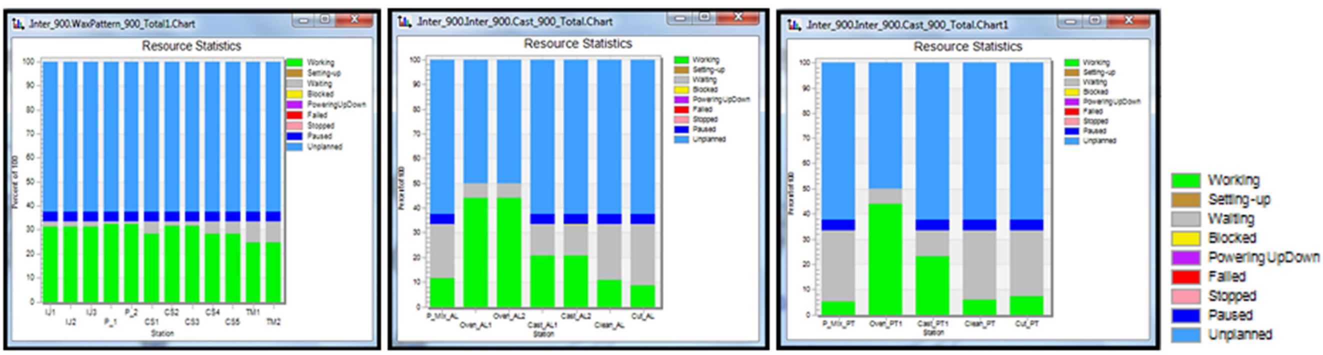


Fig. 5 Utilization of interfaced wax pattern and casting processes of Model I

Table 16

Simulation results of interfaced wax pattern and casting processes of Model I, II and III

	Product	Material	Avg. Throughput (units/day)		Proportion (%)	
			Target	Simulation	Target	Simulation
Model I	Ring (80%)	Al (0.6)	432.00	14,400/30 = 480.00	48.00	48.00
		Pt (0.4)	288.00	9,600/30 = 320.00	32.00	32.00
	Ear ring (10%)	Al (0.6)	54.00	1,800/30 = 60.00	6.00	6.00
		Pt (0.4)	36.00	1,200/30 = 40.00	4.00	4.00
	Pendant (10%)	Al (0.6)	54.00	1,800/30 = 60.00	6.00	6.00
		Pt (0.4)	36.00	1,200/30 = 40.00	4.00	4.00
	Total		900.00	30,000/30 = 1,000.00	100.00	100.00
Model II	Ring (80%)	Al (0.6)	720.00	23,040/30 =768.00	48.00	48.00
		Pt (0.4)	480.00	15,760/30 = 512.00	32.00	32.00
	Ear ring (10%)	Al (0.6)	90.00	2,880/30 = 96.00	6.00	6.00
		Pt (0.4)	60.00	1,920/30 = 64.00	4.00	4.00
	Pendant (10%)	Al (0.6)	90.00	2,880/30 = 96.00	6.00	6.00
		Pt (0.4)	60.00	1,920/30 = 64.00	4.00	4.00
	Total		1,500.00	48,000/30 = 1,600.00	100.00	100.00
Model III	Ring (80%)	Al (0.6)	1,008.00	31,980/30 = 1,066.00	48.00	48.19
		Pt (0.4)	672.00	21,120/30 = 704.00	32.00	31.83
	Ear ring (10%)	Al (0.6)	126.00	3,390/30 = 133.00	6.00	6.01
		Pt (0.4)	84.00	2,640/30 = 88.00	4.00	3.98
	Pendant (10%)	Al (0.6)	126.00	3,390/30 = 133.00	6.00	6.01
		Pt (0.4)	84.00	2,640/30 = 88.00	4.00	3.98
	Total		2,100.00	66,360/30 = 2,212.00	100.00	100.00

Model II: Target = 1,500 units/day

Figure 6 presents work station layout in simulation program of Model II. Number of workers from line balancing calculation is 9 and from simulation is 11. Number of machines from line balancing is 11 and from simulation result is 12.

Figure 7 shows the run results of each type of product for 30 days. The total throughputs 48,000.00 units per month, which is 1,600.00 units per day on the average (See Table 15 and 16). Figure 8 illustrates utilization for each station. There is no blocking.

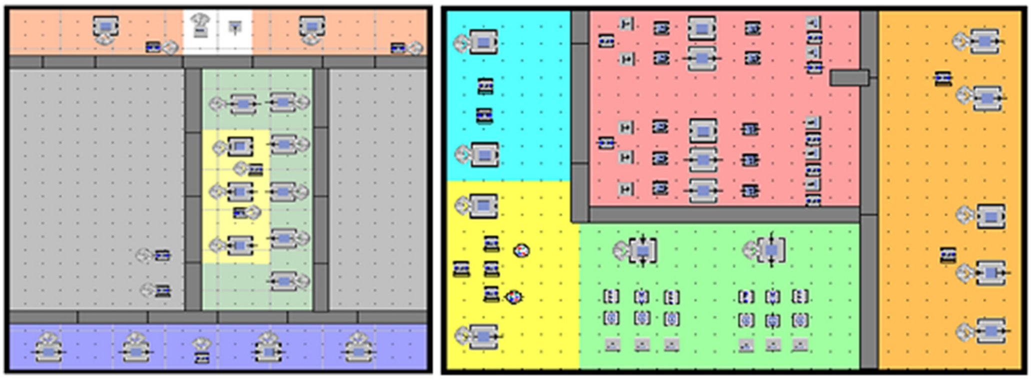


Fig. 6 Simulation frames of wax pattern and casting processes of Model II

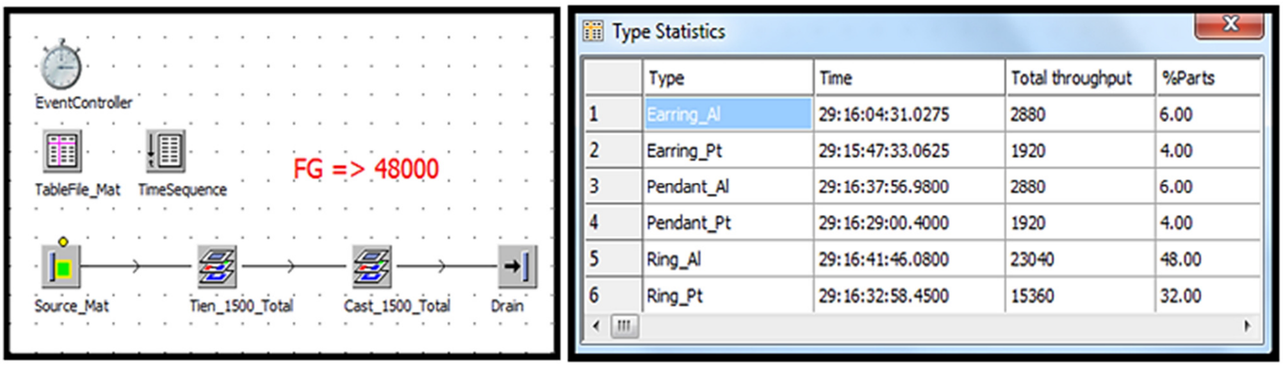


Fig. 7 Throughput and results of interfaced wax pattern and casting processes of Model II

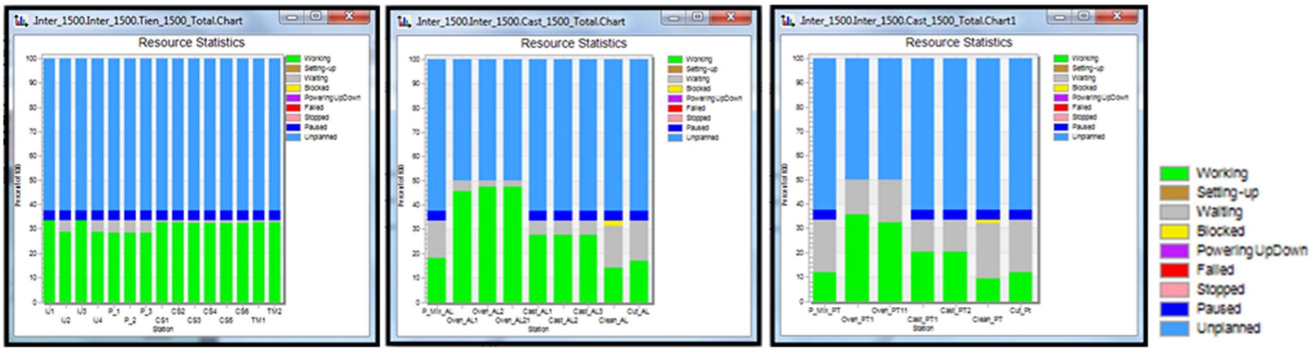


Fig. 8 Utilization of interfaced wax pattern and casting processes of Model II

Model III: Target = 2,100 units/day

Figure 9 illustrates work station layout in simulation program of Model III. Number of workers from line balancing calculation is 9 and from simulation is 12. Number of machines from line balancing is 16 which is equal to simulation result. Station B-Resizing is expanded to the left side of station C-Size checking. The mold storage in the gray area have to be slightly moved to the left side of the room. Figure 10 shows the run results of each type of product for 30 days. Total throughput is 66,360.00 units per month, which is 2,212.00 units per day on the average (See Table 15 and 16).

Figure 11 illustrates utilization for each station. There is no blocking.

Table 15 shows that the number of workers and machines from simulation results which are adequate to achieve the desired throughout rate are a little bit different from the numbers calculated from line balancing. This is because there are blocking and waiting in the system in simulation models. Table 16 presents throughputs of three models. It could be concluded that each simulation model setting presented in this section could produce throughput rate up to the desirable level with the minimum number of workers or workstations.

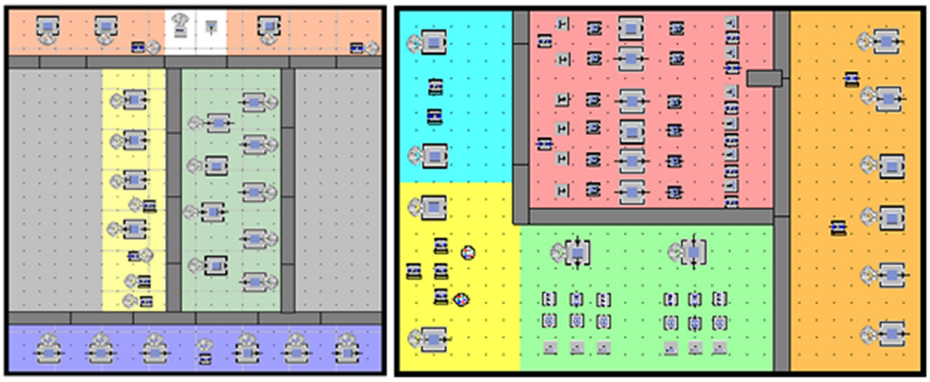
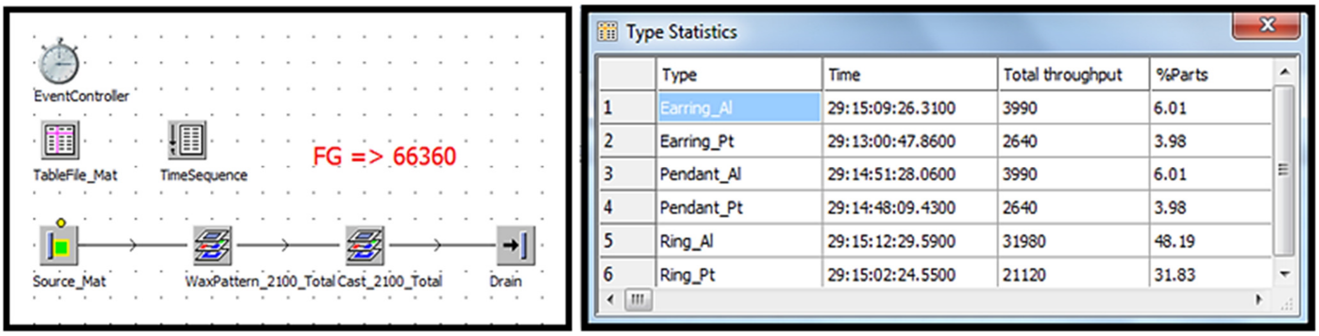


Fig. 9 Simulation frames of wax pattern and casting processes of Model III



	Type	Time	Total throughput	%Parts
1	Earring_Al	29:15:09:26.3100	3990	6.01
2	Earring_Pt	29:13:00:47.8600	2640	3.98
3	Pendant_Al	29:14:51:28.0600	3990	6.01
4	Pendant_Pt	29:14:48:09.4300	2640	3.98
5	Ring_Al	29:15:12:29.5900	31980	48.19
6	Ring_Pt	29:15:02:24.5500	21120	31.83

Fig. 10 Throughput and results of interfaced wax pattern and casting processes of Model III

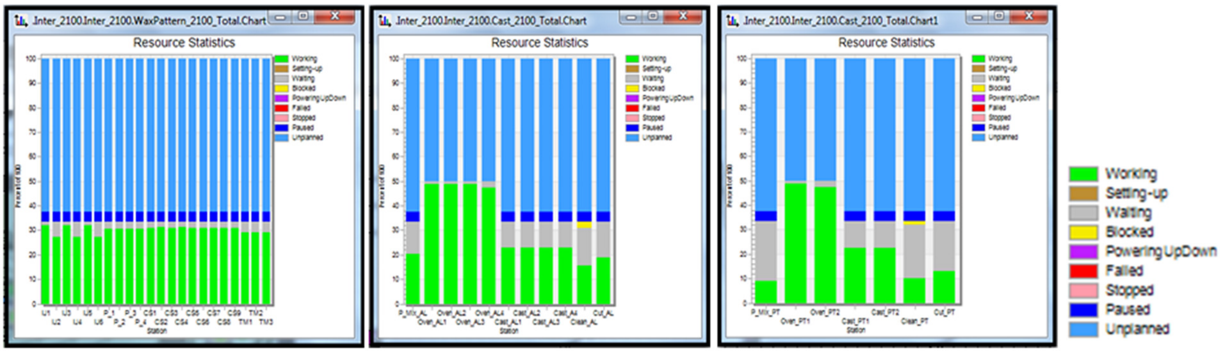


Fig. 11 Utilization of interfaced of wax pattern and casting processes of Model III

CONCLUSION

This research proposed simulation models with the use of line balancing method to solve the bottleneck problem and design minimum number of workers and machines in wax pattern process and casting process for the case study of jewelry manufacturing company. The study started with preliminary study of the current process. Information and necessary data were collected from the production plant. The sampling of one-month-period data collection was performed to collect cycle times. Takt time was then calculated by the factory desired throughput rate. Line balancing theory was applied to in order to determine the minimum number of workers and machines in three alternative models. Model I is set to have throughput target of average 900 units per day. Model II has average target of 1,500 units per day and Model III has average target of 2,100 per day. The desire output rate are designed for the higher future demand according to the company's goal. The minimum, number of workers for each station for wax pattern process and casting process are manually calculated by using line balancing method. Then simulation models are created to simulate the process with number of workers and number of machines from line balancing in order to retrieve the predicted results. The performance of each model is measured by an average number of throughputs per day and workers utilizations. All simulation models show the pleasant results which could reach target with the minimum number of workers. There are a few different amount of workers between calculation and simulation due to the blocking and waiting in the system. It is shown that simulation results not only predetermine amount of average throughput of the modified process but also provide workers utilizations in the system. This research could clearly demonstrate the methods to find alternative solutions by using a simulation program with line balancing for jewelry production plant.

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