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Original Article

Modifying production line for productivity improvement: A Case Study of Vision Lens Factory

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Abstract

This study aimed to modify the plastic vision lens production line CR39 in order to improve its productivity. Work study and line balancing techniques were employed in order to improve the bottleneck point in the manufacturing process. Standard time was measured. The result shows that productivity increased by 1,257 pieces per day and labor productivity increased from 82 to 88 pieces per man-hour. However, this improved production capacity was still below the target capacity. Therefore three additional alternatives were proposed. A simulation model was employed in order to analyze these alternatives. The results found that, by using the lowest unit production cost scenario, additional labor and machines were added into the bottleneck point of the production line. The productivity was then increased by 7,738 pieces per day or a 44% improvement, which reached the target productivity, and the average resource utilization was 89%, which satisfied the objectives.

Keywords: productivity, simulation, work study, utilization, line balance, WIP

1. Introduction

Thailand is now considered one of the largest vision lens production bases in the world. Seven main manufacturers operate their production facility in Thailand and are responsible for 22% of global demand. Last year the proportion of basic product business to value-added product businesses was 65:35. In this period of economic crisis and intense price competition, customers tend to use basic products more than value-added products; however, vision lenses are essential to customers with common eyes problems. Moreover, vision lenses are needed to be replaced overtime due to changes in eyesight. Compared to contact lenses or laser eye surgery, vision lenses are also more economical. Nowadays, the demand for glass lenses continuously falls since customers tend to use plastic lenses more. As a result, there has been a major increase in demand for plastic lenses. For our case study, the company of interest produces various types of both glass and plastic lens, e.g. single vision lens, bifocal lens, and progressive additional lens. Most of the manufacturing capacity aims to serve the export market. Since plastic lens demand is on the increment, the company has attempted to increase the manufacturing capacity of plastic lenses by using the concept of waste reduction manufacturing and effective allocation of resources. In this study, the focus is on the CR39 model (Plastic Lens Casting). This CR39 model is the main product of the plastic lens manufacturing line and also has the highest sales volume. As a consequence of government policy, the minimum wage rate

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has increased, so the company is forced to carefully manage labor cost and economic investment. Therefore, this study aims to improve the efficiency of the production line by using work study and also applying the line balancing concept to the bottleneck of the production line. Three different alternatives for improving the manufacturing process are proposed. ARENA software is employed to simulate and analyze these alternatives. Performance indicators are compared to obtain the optimal result.

2. Literature Review

2.1 Work study

Work study can be divided into method study and work measurement. It is used to systematically study and improve human working methods by considering all factors that affect the working efficiency and conditions. After the job of interest has been selected, time study can be examined by 1) recording all information about the job, 2) breaking the job down into elements, 3) examining those elements and determining the sample size, 4) recording the time to perform each element using a stop-watch, 5) assessing the speed of working, 6) converting the observed time to basic time, 7) determining the allowances, and 8) determining the standard time.

Shuang *et al.* (1997) improved the bottleneck process in a lamp assembly line using the basic concepts of work study, ECLS, and line balancing. The result shows the improvement for both product and operator. The reduction in production time resulted in better productivity. Khalid and Saleh (2011) studied the manufacturing process in the automobile industry both before and after the improvement had been made, by using an operation process chart. The bottleneck of the process was selected to study and improve in order to increase manufacturing capacity. ARENA software was employed to select the suitable option.

Resnick and Zanotti (1997) incorporated ergonomic concepts in the design of a manufacturing process in order to improve productivity. Equipment weight, distance of movement, and working from heights were factors to be considered. The results show that all three factors had significant impact on the standard time. This means that the design of the manufacturing process does have an impact on productivity.

2.2 Line balancing

Keytack (1997) proposed the concept of expert line balancing system (ELBS). The study shows that by combining two or more jobs and workstations in order to eliminate unnecessary jobs and reduce time between machines, an improved productivity of the production line can be achieved. By using the line balancing concept, decision makers can determine a suitable system for their workload. This also results in maximum total efficiency and productivity as shown in Figure 1.

2.3 Just-in-time

Just-in-time (JIT) is a production system that strives to eliminate production waste and non-value added activities in order to improve material and parts management. JIT is simply the production of materials, parts or finished goods to meet their demand exactly on time, with the required levels of quality and quantity. By implementing JIT, the in-process inventory and its associated costs can be reduced. One important element of JIT is to produce in small lot size (or ideally one piece per lot). This system also increases production flexibility to improve customer satisfaction. Different lot size production directly affects inventory and lead time. Small lot production results in reduced inventory and reduced lead time.

Raymond (2010) improved work flow in a semiconductor production line using small lot size. The result shows a significant reduction in production lead time. This improvement concept can be applied in other production line with short lead time and high production volume. That is the batch size is adjusted to smaller lot size in order to reduce the lead time and increase the throughput. Hadi *et al.* (2005) proposed a U-type plant layout. Many production lines use straight-line production along with a just-in-time system. Duran *et al.* (2008) studied the effects of the line balancing problem in assembly lines, the production system, and the continuous development of man and machines.

2.4 Simulation

Savsar and Al-Jawini (1995) studied the just-in-time production system using a simulation technique. The simulated model analyzed the system with different levels of

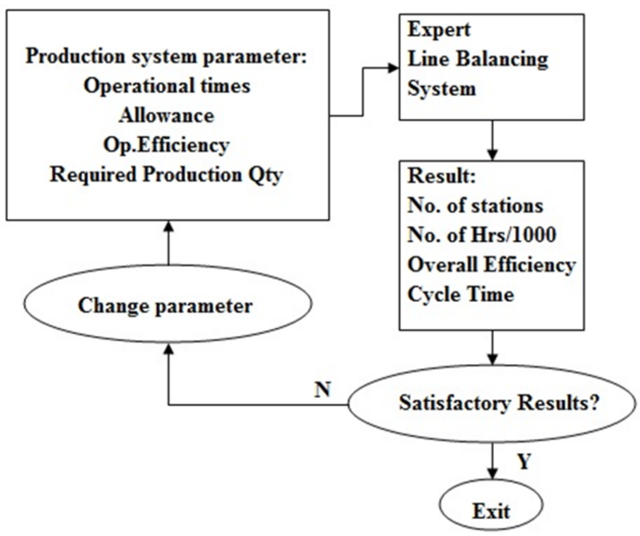

Figure 1. Flow chart of an expert line balancing system (ELBS).

various factors, such as processing time, Kanban size, customer demand, the length of the production line, and operation policy. The objective was to study the effects of these factors on operation performances, such as throughput rate, WIP, and station utilization. The result showed that processing time and customer demand significantly affects throughput rate and station utilization. Moreover, by using different Kanban policies, the system also yields different throughput rates, WIP, and station utilization. The simulated model was also used to compare a push and pull system under the same conditions. However, a pull system always outperforms push a system regarding the WIP level. Andrew (2008) used simulation to study the bottleneck point in a production line. ARENA12 software was employed to simulate an intermittent production system in order to find the appropriate WIP level and optimal production design and to reduce the problem at the bottleneck process.

3. Case Study

Plastic lens CR39 is divided into finished lenses and semi-finished lenses. Finished lenses are lenses with finished optical surfaces on the front and back of the lens and are completed to meet the requirements of a prescription (Figure 2). Semi-finished lenses are lenses with an unfinished back surface and require an RX lab for surfacing or finishing according to each individual customer's need. The manufacturing process of plastic lens CR39 is illustrated in Figure 3.

Based on the data collection in a plastic lens CR39 production line the average production capacity per day (overtime is not included) at some stations does not reach the target of 25,000 pieces per day (1 shift/8 hrs/day) as shown in Figure 4. It can be seen that the bottleneck processes are the assembly and filling stations. Both departments use process layout by placing different machines in different locations as shown in Figure 5.

Both stations are job shop productions with large batch sizes. This means that a lot of time is wasted in the transportation of WIP between five stations, which results in high WIP as shown in Figure 6.There are five workstations which are divided into two main processes as follows.

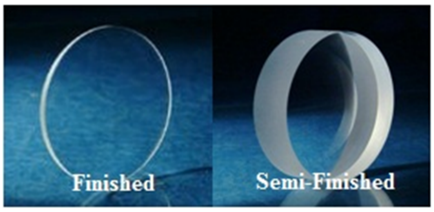

Figure 2. Type of plastic lens CR39.

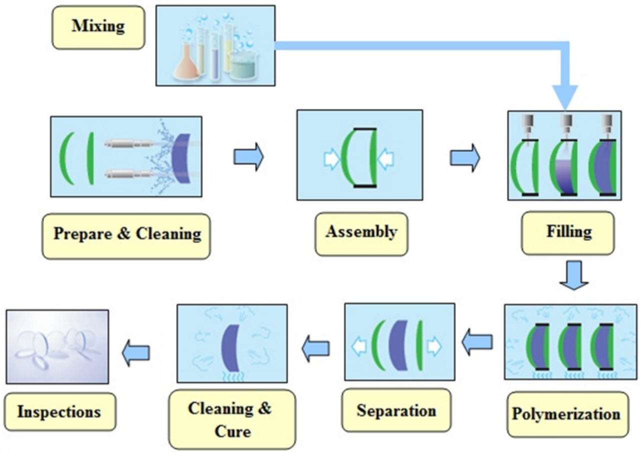

Figure 3. Plastic lens CR39 operation process chart.

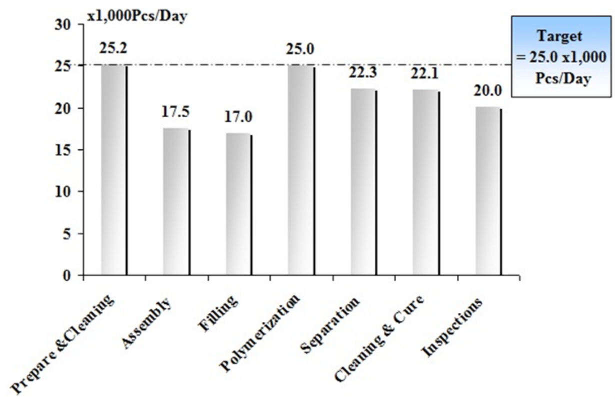

Figure 4. Production capacity of each Station in CR39 production line.

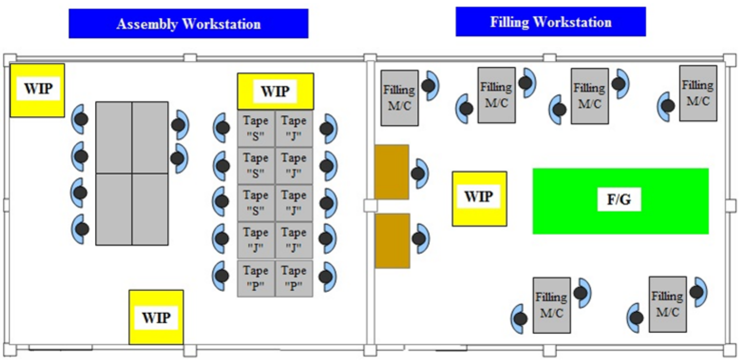

Figure 5. Process layout of assembly and filling station of current line.

Table 1. Resources allocation.

Workstation	No. of Staff	No. of Machines
Mould Inspection	4	-
Mould Assembly	10	10
Gasket Assembly	2	-
Spring Assembly	2	-
Filling Monomer	10	10
Summary	28	20

(1) Mould Assembly with Machine: This process starts at the mould inspection station. Moulds are then sent to the mould assembly station and the filling station respectively.

(2) Mould Assembly with Gasket: This process starts at the mould inspection station and then the mould is assembled with a gasket. A spring is added to the mould at the spring assembly station. Moulds are then sent to the same filling station as in mould assembly with a machine line. The resources allocation is shown in Table 1. From a method and time study, the standard time can be calculated as shown in Figure 6.

4. Methodology

4.1 Work study method

The analysis of the production improvement use several performances measured to compare the results which are productivity and efficiency. From the data in Figure 6, the job time for mould assembly is equal to 22 seconds. The number of workstation can be calculated from equation (1)

$$N = \frac{\sum_{i=1}^{j} t_i}{C_d} \quad (1)$$

where t_i is time for task i, j is the number of tasks, C_d is cycle time, and

$$N = \frac{(4.35+22+10.9+3.13+11.6)}{22} = \frac{51.98}{22} = 2.36 \approx 3 \text{ workstation}.$$

In this case, the number of workstation should be reduced from 5 to 3 is to increase the production line efficiency according to the concept of *expert line balancing system* (ELBS).

In this stage, standard time is calculated using work study. Line balancing is then conducted by reducing the number of workstation to three stations by combining the mould assembly and filling monomer into one station. Gasket assembly, spring assembly, and filling monomer are also grouped together as a single station. By doing so, the distance of movement is decreased. One piece flow production can be implemented and the batch size of mould inspection station is reduced by half as shown in Figure 7.

After the workstations are combined, some unnecessary activities can be removed and, hence, the standard times of some assembly steps are decreased. The standard time of improved line is presented in Figure 8.

According to the improvement, the workstations of mold assembly operation and filling monomer operation are combined into new workstation. The total number of machines required by the new workstation is eighteen. Ten of them are for the mold assembly operation and eight of them are for the filling monomer operation. Also, the workstations of gasket assembly operation, spring operation, and filling monomer operation are combined into the new workstation. Here, the total number of machines required is two. They are for the monomer filling operation. From the improved standard time, resources allocation can now be modified as shown in Table 2. From the line balancing and improved working method, production layout can be improved as shown in Figure 9.

The efficiency for the production line calculated from Equation 2:

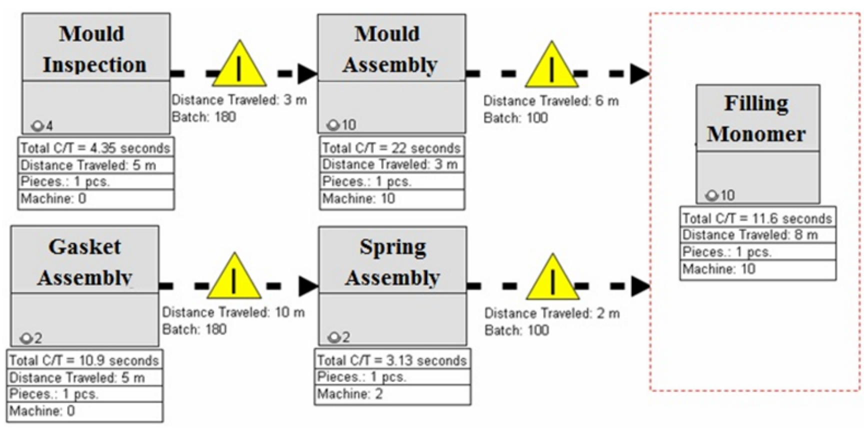

Figure 6. Value stream mapping of current line and standard time of workstations of the current line.

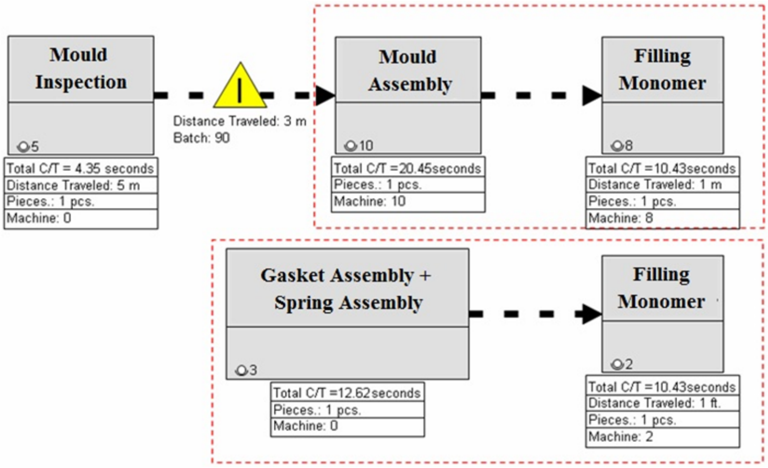

Figure 7. Value stream mapping of improved line.

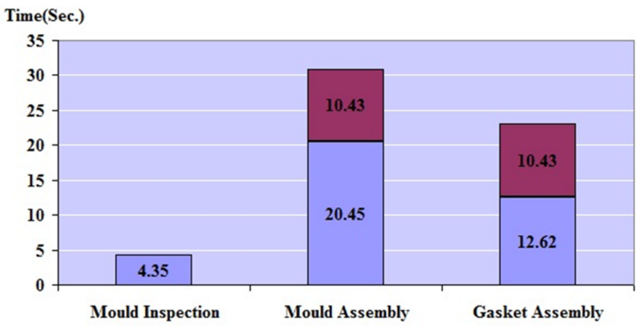

Figure 8. Standard time of workstations of improved line.

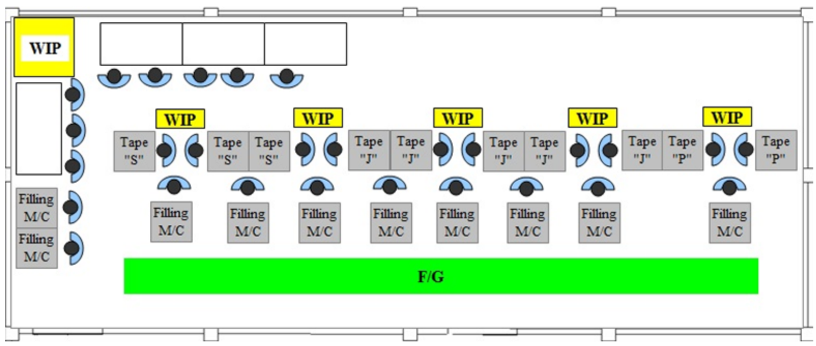

Figure 9. Process layout of assembly and filling station of improved line.

Table 2. Number of operators and machines of the improved line.

Workstation	No. of Staff	No. of Machines
Mould Inspection	5	-
Mould Assembly + Filling Monomer	18	18
Gasket Assembly + Spring + Filling Monomer	3	2
Summary	28	20

Table 3. Results of the improvement from the work study.

KPI	(1) Before Improvement	(2) After Improvement	$\frac{[(2)-(1)]}{(1)}*100 =$ % of Difference
No. of Staff	28	28	-
Productivity (pieces/day)	18,344	19,601	7%
Productivity (pieces/hr/man)	82	88	7%
Utilization Average (%)	80%	85%	6%
Total Efficiency (%)	47.25%	78%	55%

$$E=\frac{\sum_{i=1}^{j} t_i}{NC_a} \quad (2)$$

where t_i is time for task i, j is number of tasks, C_a is actual cycle time, N is the number of workstation, and

$$E=\frac{(4.35+22+10.9+3.13+11.6)}{(5*22)}=0.4725.$$

The result shows that the efficiency for the current production line is 47.25%. Table 3 shows the operation performance results both before and after the improvement.

From the above results, the production capacity increased by 1,257 pieces per day. However this capacity is still below the target value of 25,000 pieces per day. Therefore, an additional improvement is needed in order to reach the target. It is worth noting that the above analysis is studied with average values only. The result might be different if data with variances are considered here. Thus it is necessary to conduct a computer simulation in order to verify the correctness of the experiment and to analyze the amount of WIP. Moreover, different line balancing scenarios can be simulated in order to obtain the optimal solution for the production line by considering system throughput, work in process and production cost per unit.

4.2 Simulation model by ARENA

Figure 10 shows the simulation flow diagram of the studied production line.

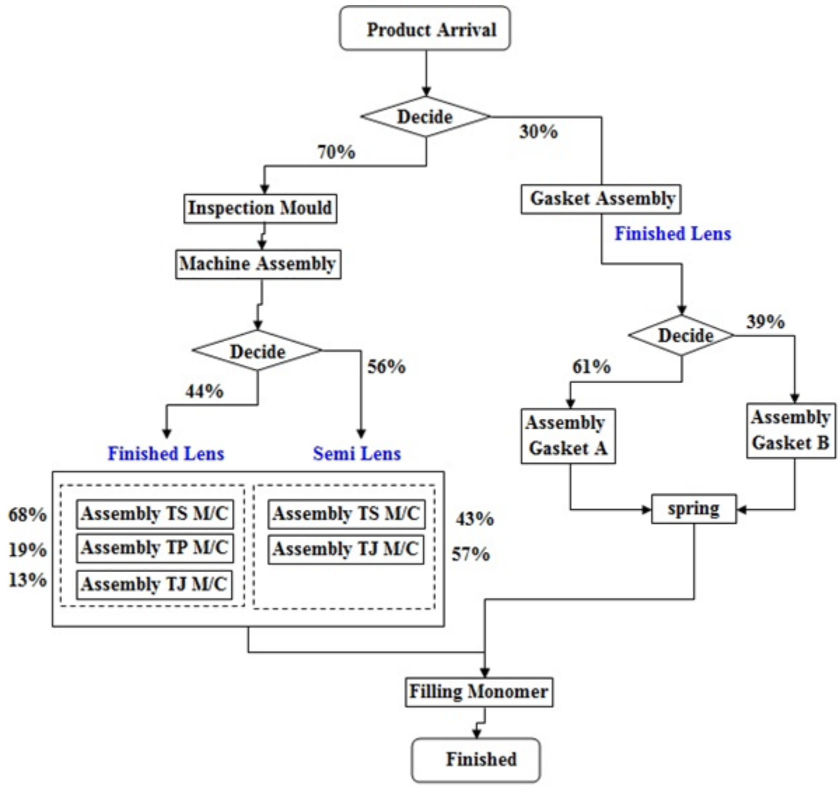

Figure 10. Simulation flow diagram.

Table 4. Distribution processing time of each workstation (time in seconds).

Workstation	Activities	Lot size	Processing time	P-value
Cleaning	Product Arrival	240	Constant (2)	
Assembly	Pick and Place mould on the tape inspection table	180	Constant (61.23)	
	Inspect Mould	1	1.1 + LOGN(2.26, 1.25)	>0.15
	Place mould in the holding cabinet	180	Constant (66.05)	
	Assembly staff picks mould from the holding cabinet	180	Constant (89.34)	
	Assembly mould Tape	2	16 + GAMM(1.61, 2.34)	>0.15
	Bring mould Assembly to filling department	100	Constant (108.83)	
	Pick and Place mould on the gasket inspection table	180	Constant (77.40)	
	Inspect and assemble mould gasket A	2	8.04+3.96*BETA(1.18, 1.39)	>0.15
	Inspect and assemble mould gasket B	2	7 + WEIB(1.46, 1.12)	>0.15
	Bring mould gasket to spring installation department	100	Constant (126.56)	
	Install spring	1	1.59+LOGN(0.756, 0.481)	>0.15
Filling	Bring mould gasket to waiting area for filling	100	Constant (28.86)	
	Pick and Place mould assembly on the filling machine	100	Constant (73.26)	
	Filling Gasket A	1	8+3.96*BETA(1.09, 1.67)	>0.15
	Filling Gasket B	1	6+WEIB(1.48, 1.31)	>0.15
	Filling Tape SF	1	NORM(11.8, 0.892)	>0.15
	Filling Tape F	1	6+GAMM(0.458, 2.3)	>0.15

An input analyzer was used in order to measure the statistical dispersion of data. The Kolmogorov-Smirnov Test with a sample size N=30 was conducted under a 95% confidence interval (significant level = 0.05). The null hypotheses will be accepted if P-Value >0.05. The input distribution processing time of each workstation is represented in Table 4. From the Kolmogorov-Smirnov Test, the results in Table 4 show that the p-value >0.15. Therefore, we fail to reject the null hypothesis (H_0). The data is the representation of the real processing time. The simulation model based on the input data can be constructed as illustrated in Figure 11. The simulation model was used to find the productivity, work in

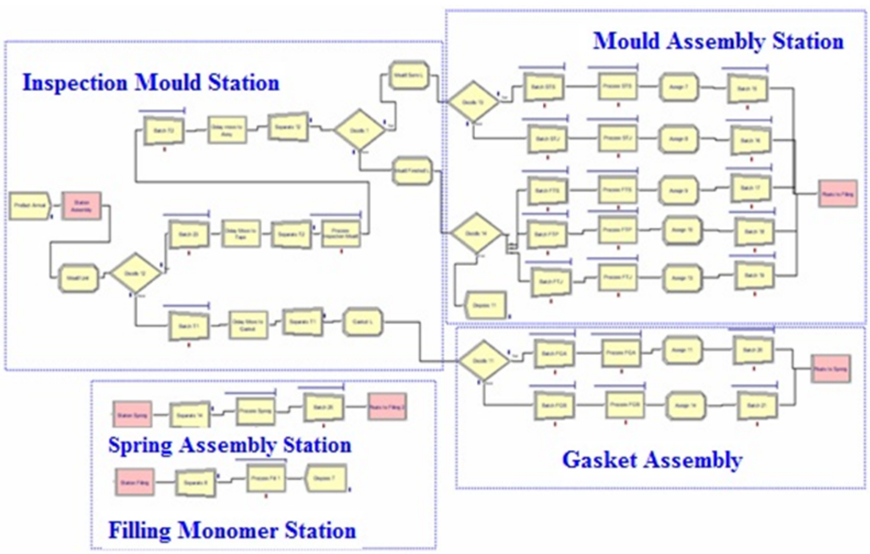

Figure 11. Simulation model of the assembly and filling stations of the current line.

process, number of operators and machines, and utilization percentage both before and after the improvement had been made.

In the simulation model, the raw materials are created into the system using separate module. The raw materials are created into the system every two minutes 240 pieces with a total of 50,000 pieces per day to produce 25,000 finished products per day. The finished products consist of two raw materials. The assign module is used to distinguish the type of raw materials. The decide module is used to separate 70% of raw materials for inspection mould and 30% of raw materials for gasket assembly. The raw materials will be batched into 180 pieces using batch module before sending them to different departments. At the destination departments, the batches will be separated using separate module and followed by process module.

For example, after inspection mould workstation, the batch module will be used to batch the products with batch size shown in Figure 9. At the following station, mould assembly station, the products will be separated by separate module. The decide module separates lenses into finished-lenses and semi-lenses. The subclasses for finished-lenses are finished lens assembly TS machine(FTS), finished lens assembly TP machine(FTP), and finished lens assembly TJ machine(FTJ). The subclasses for semi-lenses are semi lens assembly TS machine(STS) and semi lens assembly TJ machine(STJ). The percentages for each type of lenses are shown in Figure 10. The batch module is used to permanently batch the products before assembling in process module. After mould assembly station, the products are temporary batched again for 100 pieces before sending them to filling monomer.

As the job in gasket assembly, decide module will be used to separate lenses to be finished lens assembly gasket type A (FGA) and finished lens assembly gasket type B (FGB). In this department, the two of same production type will be batched together permanently using batch module before assembling in process module. Batches of 180 pieces will be delivered to the spring department. After that batches of 100 pieces will be transferred to the fill monomer. In fill monomer operation, the batches will be separated in pieces and processed with filling machine using process module. The finished products leave the system by the dispose module.

Figure 12 represents the model concept of expert line balancing system (ELBS). The number of workstation is reduced from 5 to 3. The gasket assembly operation, spring operation, and filling monomer operation are combined with no batch size during workstations with initiating the one-piece flow continuous process as seem by using three process modules in the model.

The simulation model is run as a terminating system starting from 8:00-17:00 (8 hrs) without a warm up period. An initial run is used to obtain the half-width for the confidence interval to consider the number of replication. The appropriate number of replication can be calculated from Equation 3 when R_0 is an initial number of replication, h_0 is the half-width from the initial run, and h is the required half-width.

$$R \cong R_o \frac{h_o^2}{h^2} \tag{3}$$

The initial run with ten replications results in an h_0 of 17,365 ±75 pieces/day. The half-width (h) of 50 required R = 23 replication from Equation 3. The research sets the number of replication of 30 to reduce the error variance. The validation of the simulation model is completed by comparing the throughput of the actual system with the simulation system. The hypothesis testing for comparing mean is conducted at $\alpha = 0.05$ using MINITAB14.

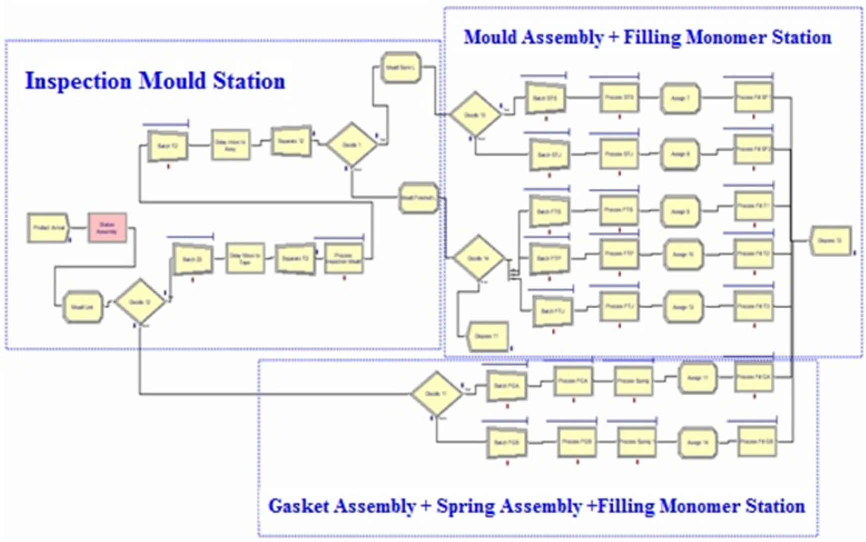

Figure 12. Simulation model of assembly and filling station of improved line.

Two-Sample T-Test and CI : Output Actual, Output Model
Two - sample T for Output Actual vs Output Model

	N	Mean	StDev	SE Mean
Output Actual	30	17567	539	98
Output Model	30	17399.5	92	17

Difference = mu (Output Actual) - mu (Output Model)
Estimate for difference : 167.3
95% CI for difference : (-36.8 , 371.3)
T-Test of difference = 0 (vs not =) : T- Value = 1.67 P-Value = 0.105 DF = 30

Figure 13. Results for the hypothesis testing.

In Figure 13, the p-value of 0.105 implies that we fail to reject the null hypothesis at $\alpha = 0.05$. The data from the current production and from the simulation model are normally distributed. The throughput from both systems is not significantly different. Therefore, the simulation model can be used to represent the current production system.

Production Line Improvement Alternatives

Alternative 1: Work study and line balancing

In this alternative, a work study and line balancing concept were employed as described above. The simulation model is presented in Figure 12.

Alternative 2: Production batch size

In this alternative, the batch sizes between stations are adjusted using current layout. The optimal batch size was calculated using the process analyzer in ARENA13. Batch size is considered as a control variable. Responses are seven types of work in process which are finished lens assembly gasket type A (FGA), finished lens assembly gasket type B (FGB), finished lens assembly TJ machine(FTJ), finished lens assembly TP machine(FTP), finished lens assembly TS machine(FTS), semi lens assembly TJ machine(STJ), and semi lens assembly TS machine(STS) as well as the output system. The simulation model of the assembly and filling stations of the current line was run and analyzed for five scenarios as shown in Table 7.

Alternative 3: Resources allocation

Alternative 3 employs the concept of expert line balancing system (ELBS) which is the simulation model as shown in Figure 12. The resource allocation of each process was established so that the production capacity reaches 25,000 pieces per day. A process analyzer was also used. Resources are control variables. System output and utilization are responses. Alternative 3-1 is performed what-if analysis for batch size. Alternative 3-2, is performed what-if analysis for resource allocation. Alternative 3-3 is the analysis of the combination of both parameters from what-if analysis.The simulation model of the assembly and filling stations of the improved line was run and analyzed for 22 scenarios.

5. Results

5.1 Production improvement through line balancing: Alternative 1

The results of improvement alternative 1 are shown in Tables 4 and 5. The average resource utilization and productivity increased by 7% and 9% respectively. Moreover, WIP also decreased by 12%.

Table 5. Amount of WIP.

Entity Name	(1) Current Model	(2) Alternative 1	$\frac{[(2)-(1)]}{(1)}*100 =$ % of Difference
Mould	3,405	3,363	1.2%
FGA	84	33	60.7%
FGB	84	20	76.2%
FTJ	53	1	98.1%
FTP	57	1	98.2%
FTS	63	1	98.4%
STJ	84	2	97.6%
STS	61	1	98.4%

Table 6. Improvement results of alternative 1.

KPI	(1) Current Model	(2) Alternative 1	$\frac{[(2)-(1)]}{(1)}*100 =$ % of Difference
No. of Staff	28	28	-
Productivity (pieces/day)	17,400	19,003	9%
Labor Productivity (pieces/man/hr)	78	85	9%
Utilization Average (%)	72%	78%	8%
WIP (pieces)	3,899	3,422	-12%

Table 7. Optimal batch size according to alternative 2.

Response	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Batch 1 = 100 pieces	Batch 1 = 50 pieces	Batch 1 = 30 pieces	Batch 1 = 10 pieces	Batch 1 = 10 pieces
	Batch 2 = 180 pieces	Batch 2 = 90 pieces	Batch 2 = 60 pieces	Batch 2 = 60 pieces	Batch 2 = 30 pieces
Mould	3,406	3,246	3,160	3167	3137
FGA	85	51	38	25	25
FGB	85	51	38	25	25
FTJ	54	30	19	9	9
FTP	58	32	22	11	11
FTS	64	37	25	14	14
STS	62	36	25	14	14
STJ	85	54	42	30	30
Total WIP	3,899	3,537	3,369	3,295	3,265
Output System	17,400	17,679	17,795	17,890	17,894
WIP Decrease(%)	-	9%	14%	15%	16%
Output Increase (%)	-	1.60%	2.27%	2.82%	2.84%

5.2 Production improvement through optimal batch size: Alternative 2

The results are shown in Table 7. Batch 1 is the batch transshipped from the mould assembly station to the filling monomer station and from the gasket assembly station to the filling monomer station. Batch 2 is the batch transshipped from the inspection mould station to the mould assembly station and from the gasket assembly station to the spring assembly station.

As can be seen from Table 7, the optimal batch size is in scenario 5 (Batch 1=10, Batch 2=30) which resulted in a 16% reduction in WIP. Moreover, the system output increased by 2.84%.

5.3 Production improvement through resource allocation: Alternative 3

Alternative 3 can be divided into three schemes as follows. Alternative 3-1: The batch size is modified and production resource allocation remains unchanged from alternative 1. This scheme includes scenario 1, 2, 3, and 4. Alternative 3-2: The batch size remains unchanged and resource allocation is modified from alternative 1. This scheme includes scenario 5, 6, 7, 8, 9, 10, 11, 12, and 20. Alternative 3-3: Both batch size and resource allocations are modified from alternative 1. This scheme includes scenario 13, 14, 15, 16, 17, 18, 19, 21, and 22. Table 9 summarizes the additional number of machines and operators required in each process.

The simulation model was then run with overtime being considered. The new output was used in order to calculate the cost per unit. Filling machines cost is 1,000,000 Baht per machine and the cost for new layout design is 100,000 Baht. Therefore, as in scenario 17, the total set up cost for four machines is 4,100,000 Baht. In this study, annual worth criterion is employed. Operational cost per day (OC) is computed from the cost of machine per day plus labor wage per day (LC) and can be presented as follows.

$$OC = LC + [\text{Machine Cost } (A/P, 10\%, 5) / \text{number of operating days per year}] \quad (4)$$

Table 8. Resource Allocation according to Alternative 3

Scenario	Resource	Batch size Capacity	Utilization Average (%)	Output System (pieces/day)
Scenario 1	28	180	78%	18,976
Scenario 2	28	90	78%	19,003
Scenario 3	28	60	78%	19,022
Scenario 4	28	30	78%	19,032
Scenario 5	29	90	81%	20,462
Scenario 6	30	90	83%	21,885
Scenario 7	31	90	85%	23,335
Scenario 8	33	90	85%	24,205
Scenario 9	32	90	85%	24,190
Scenario 10	33	90	83%	25,137
Scenario 11	31	90	89%	25,088
Scenario 12	32	90	86%	25,135
Scenario 13	31	30	86%	24,306
Scenario 14	31	30	86%	24,300
Scenario 15	32	30	83%	24,294
Scenario 16	31	60	89%	25,106
Scenario 17	31	30	89%	25,138
Scenario 18	32	30	86%	25,139
Scenario 19	31	180	88%	25,031
Scenario 20	34	90	81%	25,172
Scenario 21	34	30	81%	25,191
Scenario 22	35	30	79%	25,189

Table 9. Additional resources required in the system.

Scenario	Resource				
	No. of Staff	Tapping TJ Machine	Tapping TP Machine	Tapping TS Machine	Fill Machine
Scenario 1	0	0	0	0	0
Scenario 2	0	0	0	0	0
Scenario 3	0	0	0	0	0
Scenario 4	0	0	0	0	0
Scenario 5	1	0	0	1	0
Scenario 6	2	0	0	2	0
Scenario 7	3	0	0	3	0
Scenario 8	5	0	0	4	0
Scenario 9	4	0	0	4	0
Scenario 10	5	0	0	4	1
Scenario 11	3	0	0	4	0
Scenario 12	4	0	0	4	0
Scenario 13	3	0	0	3	0
Scenario 14	3	0	0	3	0
Scenario 15	4	0	0	3	0
Scenario 16	3	0	0	4	0
Scenario 17	3	0	0	4	0
Scenario 18	4	0	0	4	0
Scenario 19	3	0	0	4	0
Scenario 20	6	0	0	5	0
Scenario 21	6	0	0	5	0
Scenario 22	7	1	0	5	0

Table 10. Unit manufacturing cost of each alternative.

Model	No. of Staff	OTCost (Baht)	NT Cost (Baht)	Labor Cost/ Day(Baht)	Annual Worth/ Day(Baht)	Total Cost/ Unit(Baht)	Output system (pieces)
Current	28	-	8,400	8,400	-	0.4828	17,400
Current + OT	28	6,300	8,400	14,700	-	0.6851	21,457
Policy 1	28	-	8,400	8,400	-	0.4420	19,003
Policy 1+OT	28	6,300	8,400	14,700	-	0.6628	22,179
Policy 2	28	-	8,400	8,400	-	0.4694	17,894
Policy 2+OT	28	6,300	8,400	14,700	-	0.6718	21,880
Policy 3-1	28	6,300	8,400	14,700	-	0.6623	22,197
Policy 3-2	31	-	9,300	9,300	2,170	0.4572	25,088
Policy 3-3	31	-	9,300	9,300	2,170	0.4563	25,138

Table 11. Comparison of the operational performances of the improved models.

KPI	Current	Alternative 1	Alternative 2	Alternative 3-3
No. of Staff	28	28	28	31
Productivity (pieces/day)	17,400	19,003	17,894	25,138
Productivity (pieces/hr/man)	78	85	80	101
Utilization Average (%)	72%	78%	72%	89%
WIP (pieces)	3,899	3,422	3,265	1,036

It can be seen that alternative 3-3, adding workers into the production line is necessary as in Table 9. The output reached the goal of 25,000 pieces per day. The best scenario is scenario 17 which adds 31 workers and gains 89% utilization. This means that the unit manufacturing cost is lowest and the production capacity reaches the target.

5.4 Comparison of operational performances of the improvement alternatives (without overtime)

Table 11 compares the operational performances of the current model and the improved models.

6. Conclusions and Recommendations

All three improvement alternatives provided better production performances. Alternative 1 used line balancing and work study concepts. The batch size was decreased by half. The production capacity increased from 17,400 to 19,003 pieces per day which means the capacity increased by 1,603 pieces per day. Moreover, labor productivity increased from 78 to 85 pieces per man-hour. Resources utilization improved by 8% and WIP decreased by 12%. In alternative 2, small lot size production was implemented. As a result in Scenario 5, WIP decreased by 16% and the production capacity increased from 17,400 to 17,894 pieces per day which means the capacity increased by 494 pieces per day or 2.84%. The production resources of both alternatives remained unchanged. However, this improved production capacity is still below the target capacity. An additional improvement alternative was proposed in order to increase the utilization percentage to 100% or full capacity. In this third alternative, additional operators and machines were added to the bottleneck point of the process. The best scenario 17 with the lowest unit production cost provided a 44% increase of production capacity. This means that the capacity increased to 25,138 pieces per day or increased by 7,738 pieces per day from the current production line, which reached the target capacity. The average utilization percentage is 89% which satisfied the objectives. The economic analysis for alternative 3 shows the payback period of 2.33 years. This is an interesting option to apply to the production line with high possibility to be implemented and reached customer needs and company policy to increase the productivity of the mean production line. The further research can consider other types of costs as factors in production line and can apply to similar case study.

References

Duran T., Selcuk, K., Ertan, G. and Baykoc, O.F. 2008. Simple and U-type assembly line balancing problems with a learning effect. Applied Mathematical Modeling. 32, 2954–2961.

Hadi, G., Kursat,A.,Cevriye, G and Emel, K. 2005. A shortest route formulation of simple U-type assembly. Applied Mathematical Modeling. 29, 373-380.

Keytack, H.O. 1997. Expert Line Balancing System (ELBS). Computers and Industrial Engineering. 33, 303-306.

Khalid, S. and Saleh, A. 2011.Productivity improvement of a motor vehicle inspection station using motion and time study techniques. King Saud University – Engineering Sciences. 23, 33-41.

Mikell, P.G. 2008. Automation,Production System, and Computer – Integrated Manufacturing. Pearson Education Inc., New Jersey, U.S.A.

Raymond, G. 2010. Leveraging new SEMI standard to reduce waste and improve flow for Semiconductor manufacturing. Simulation Modeling Practice and Theory. 26, 658–664.

Resnick, M.L. and Zanotti, A. 1997. Using Ergonomics to target Productivity Improvement. Computers and Industrial Engineering. 33, 185-188.

Savsar, M. and Jawini, A.Al. 1995. Simulation analysis of just-in-time production. International Journal of Production Economics. 42(1), 67-78.

Shuang, L., Wang, X. and Lixin, M. 1997. Optimization of Assembly Line Based on Work Study. Harbin University of Commerce, Harbin, P.R. China.