MODELLING AND SIMULATION STUDY TO DETERMINE THE SUITABLE NUMBER OF DIRECT LABOURS AND BALANCE THE ASSEMBLY LINE

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Abstract:
The case study company is the producer of an automotive exhaust pipe that currently faced challenges in high expenses and decreased customers demand. The purpose of this study was to improve production process by reducing the number of required direct labour and balancing the assembly line resulting in the improvement of direct labour cost and operator utilization. The final assembly line focused in the study was the assembly line which had overproduction. Therefore, it was selected for this study. This study focused on two major products, accounted for 90.78% of overall production capacity, which were HR1 and HR2. Simulation was applied to mimics the current process which had 7 operators by using Arena software package. There are 3 scenarios in the study after verification and validation the simulation model of the current process. Each simulation model has 5, 4, and 3 number of operators, respectively in order to compare the results. The current process and the 3 proposed scenarios aim to compare 3 Key Performance Indicators (KPIs), comprising 1) number of finished parts, 2) operator utilization and 3) direct labour cost. The scenario 2 using 4 operators inclined to give the best results among them. It met the average actual demand while satisfying the operator utilization and direct labour cost. The result of this scenario satisfied all 3 KPIs mentioned above: number of finished parts produced best fit the actual demand, reduced the direct labour costs by 42.86 percent, and increased the operator utilization by 19.39 percent.

Keywords: simulation, line balancing, arena, direct labour

1. INTRODUCTION

The case study company, a manufacturer of the automotive exhaust pipe, adopted Just-in-Time system by delivering products to customers every 15 minutes. Due to economic downturn in Thailand, the company has burden with many expenses and the decreasing of customers demand. This company would like to reduce the unnecessary costs in order to sustain the profit. Hence, labour force layoff is a key point need to be determined. The process of producing HR1 and HR2 are selected because of a high proportion of demand represented in Figure 1. Drawing for product HR1 and HR2 are in Figure 2 and 3, respectively. Total demand for HR1 and HR2 are 270 pieces per day accounted for 90.78 percent of all products in one of the assembly line in this factory.

Figure 1: Demand breakdown by products of the case study company

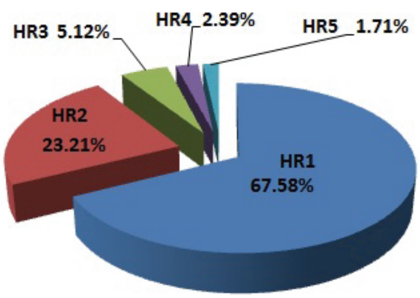


Figure 2: Drawing of product HR1

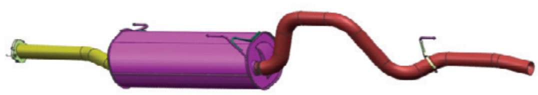
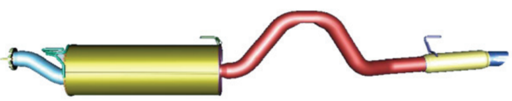


Figure 3: Drawing of product HR2



For the current process, the line produces finished exhaust pipes at 386.36 pieces per day which exceeds the average demand of 270 pieces per day. Furthermore, from the observation, operators at the line regularly was kept idle while the machine operating. Therefore, this study attempts to increase the operator utilization by reducing the number of operators while retaining the number of output which is 270 pieces per day. The objective is measured by 3 Key Performance Indicators (KPIs), the first one is to satisfy the actual demand which is 270 pieces per day, the second one is to decrease direct labour cost by 20% and finally to enhance the operator utilization by 15%. All of those were resulted from a decrease in the number of direct labours.

Due to a processing time variation of each individual task in the production line, the simulation is the effective approach to mimics the behaviour of real system by using computer to evaluate the model numerically (Bank et al,1996; Law and Kelton, 2000). Arena software simulation package provides user-friendly interfaces. Therefore, it is selected to apply in this study. Many researchers applied Arena for their simulation models such as Mendes (2005), Potter et al. (2007) and Kamrani et al. (2014). ARENA consists of three components. The primary component of ARENA is a graphically based software package that utilizes the SIMAN simulation programming code. The graphic basis of ARENA allows models to be quickly developed and easily animated. The second component of ARENA is the Input Analyzer used to fit input data. The last component of ARENA is the Output Analyzer, used to statistically analyze and compare output measures of performance. For more information of Arena software package are described in Drevna and Kasales (1994), Kelton et al (2002), Chung (2004), Rockwell Software (2005), Kelton et al. (2007), and Altiok and Melamed (2008), Pisuchpen (2010).

2. METHODOLOGY

2.1. Study the production process of HR1 and HR2

There are 8 tasks for the assembly line. The allocation of tasks with the responsible operators for current operators is illustrated in Table 1. The flow diagram of the current process is presented in Figure 4.

Table 1: Allocation of tasks and responsible operators for the current process

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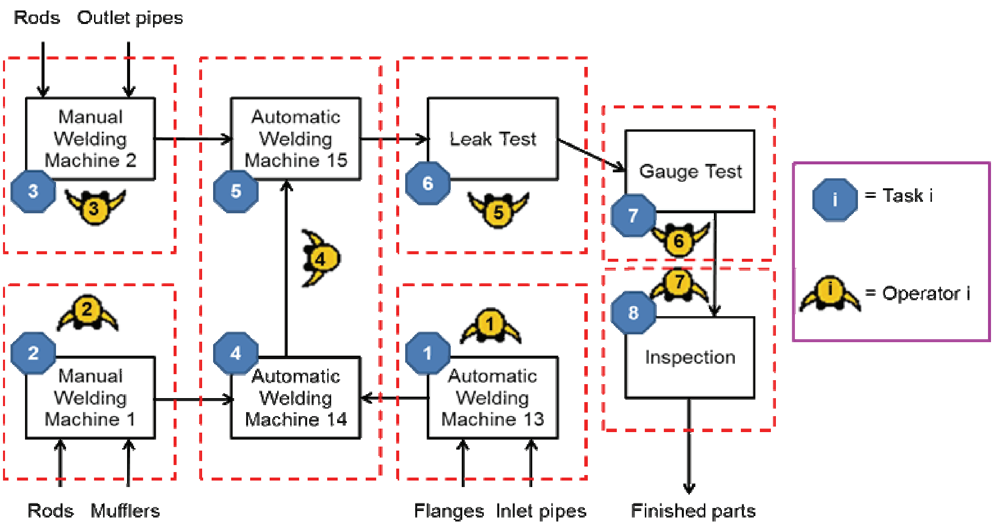
Task i (refer Figure 4)	Tasks	Stations	Operator i (refer Figure 4)
1	Weld flange with inlet pipe	Automation weld 13	1
2	Weld 2 Rods with muffler	Manual weld 1	2
3	Weld 1 Rod with outlet pipe	Manual weld 2	3
4	Weld inlet pipe with muffler	Automation weld 14	4
5	Weld outlet pipe with muffler	Automation weld 15	4
6	Perform the leak test	Leak test	5
7	Perform the gauge test	Gauge test	6
8	Paint welding joint, attach barcode and inspect the finished part	Inspection	7

Figure 4: Flow diagram with operator layout of the current process



2.2. Collect the processing time

The processing time for each activity to produce HR1 and HR2 is not different since they have the same diameter of for both inlet and outlet pipe. Therefore, the welding time for HR1 and HR2 are equivalent. The direct time study of the current process of producing HR1 and HR2 are considered. 30 observations of the processing times for each activity were collected.

2.3. Determining the distribution of processing time for each activities

For input distribution fitting, Input Analyzer tool in Arena software package was utilized. The null hypothesis and alternatives hypothesis are as follows.

H_0: Fitted distribution adequately represents the data

H_1: Fitted distribution does not adequately represent the data

The Kolmogorov-Smirnov goodness of fit hypothesis tests was conducted. If corresponding p-value is greater than a significance level, there will not have enough evidence to reject the null hypothesis indicating that the fitted distribution adequately represents the data at the significance level. On the other hand, if corresponding p-value is less than the significance level, the null hypothesis will be rejected indicating that the distribution is not a very good fit at the significance level.

The best distribution of processing time for each activity is presented in Table 2. The distribution of labour switching time from one machine to the others nearby was TRIA(3.5,5.5,8.5). The corresponding p-values for all hypothesis tests were greater than 0.05 significance level. Therefore, there was not enough evidence to reject the null hypothesis. It implied that the fitted distribution adequately represents the data at 0.05 significance level. Hence, these data were suitable to be the input distribution for the simulation model. Flanges and rods were assumed to have infinite capacity. For inlet pipe, outlet pipe and muffler, the operator had to withdraw them from store by using a handcart. The details for withdrawing inlet pipe, muffler and outlet pipe are presented in Table 3.

Table 2: Distribution of processing time for each activity

Task i	Tasks	Activities	Processing time
1	Weld flange with inlet pipe	Place flange and inlet pipe on welding station and press the start button	NORM(25.5,1.73)
		Automatic welding machine no.13 start operating	CONSTANT 15
		Remove part from automatic welding machine no.13	TRIA(8,8.7,12)
2	Weld 2 rods with muffler	Weld 2 rods with muffler	NORM(123,4.54)
3	Weld 1 rod with outlet pipe	Weld 1 rod with outlet pipe	96+18*BETA(0.957,1.24)
4	Weld inlet pipe with muffler	Place inlet pipe and muffler on welding station and press the start button	NORM(26.9,2.17)
		Automatic welding machine no.14 start operating	CONSTANT 20
		Remove part from automatic welding machine no.14	NORM(12.9,1.55)
5	Weld outlet pipe with muffler	Place outlet pipe and muffler on welding station and press the start button	UNIF(26,36)
		Automatic welding machine no.15 start operating	CONSTANT 18
		Remove part from automatic welding machine no.15	TRIA(10,13.5,17)
6	Leak test	Place part on leak test machine and press the start button	13+6*BETA(0.576,0.674)
		Perform the leak test	CONSTANT 20
		Remove part from leak test machine	NORM(11.1,1.34)
7	Gauge test	Place part on gauge and perform gauge test	NORM(68.4,4.04)
8	Inspection	Paint welding joint, attach barcode and inspect finished part	53 + EXPO(2.8)
		Place parts on rack	NORM(11.3, 1.62)

Table 3: Details of raw material withdrawing by quantity per load and time

Raw materials	Quantity per load (pieces /cart)	Withdrawal Time (minutes)
Inlet pipe	100	8
Muffler	20	5
Outlet pipe	40	8

After welding the raw material together, the work-in-process parts are placed on the rack which has limited capacity for each part as described in Table 4. The limited space for placing these parts aids the Just-in-time system; if the space was fully occupied, an operator of that station will stop processing the parts and wait until the operator in the next station pick the part on the rack.

Table 4: Capacity of the rack for each part

Part	Capacity of the rack (pieces/rack)
Flange combined with inlet pipe	5
Rods combined with muffler	6
Rod combined with outlet pipe	5
Final combined: Flange, inlet pipe, rods, muffer were combined together	1

2.4. Modelling the current process by using Arena software package

The simulation model for the current process was built based on input distribution and run as a terminating system without warm-up period. The demand of HR1 and HR2 was 90.78% of all products in this assembly line. Besides each product in this department had equivalent processing time, the production time for these 2 products was 90.78% of the total production time. There were 2 shifts with a production time of 8.1667 hours per shift, totalling 14.8275 hours. The replication length was 1 day with 10 replications, which were adequate to get tight confidence intervals for the different performance measures.

2.5. Verification and validation

Verification and validation are 2 of the most important steps in any simulation project. For verification process, simulation model was checked to ensure that the model was built correctly and worked as intended. For validation process, the simulation output is compared with the output from the actual system in order to determine that a model is an accurate representation of the actual system (Murray-Smith, 1995; Bank et al, 1996; Law and Kelton, 2000).

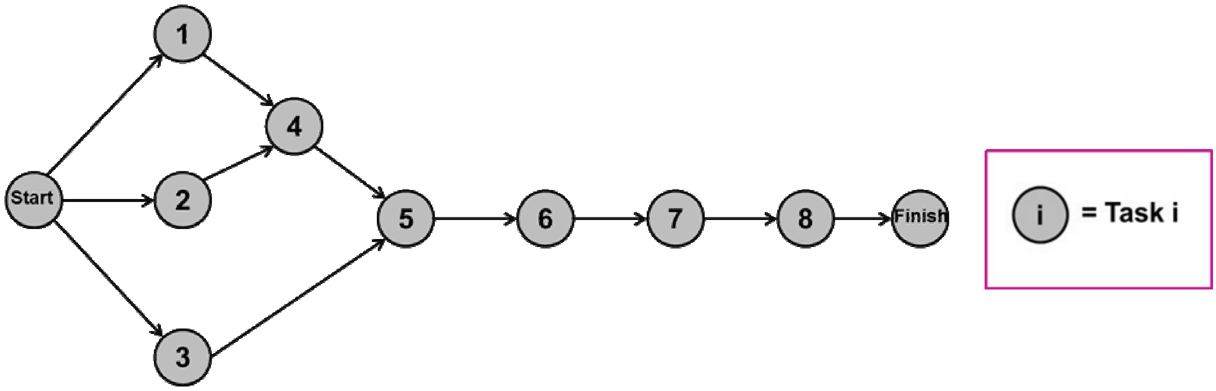
From simulation model of the current process, the average cycle time is 138.06 seconds and the half-width is 0.14 seconds. The 95% confidence interval of average cycle time is (137.92,138.20). Hence, the average cycle time of actual system is 138.16 seconds falls in this confidence interval. It can be concluded that the average cycle time of simulation model is not different from the actual model. Therefore, the simulation model can mimic the real system. Then, we can improve the process by using this simulation model.

2.6. Proposed alternatives for improvement

Since the average number of finished exhaust pipes exceeded the average demand, decreasing the number of finished products was necessary. Hence, reducing the number of required direct labour would affect the number of finished products. 3 scenarios were proposed.

Due to this assembly line has some automatic machine such as automatic welding machine and leak test machine, the operators are responsible for placing the part to the machine and removing the part from machine. The utilization of some operators at the automation machine of the current process is small. Therefore, the number of operators can be decreased and then rearranged the task to balance the assembly line by using line balancing technique. The objective of line balancing technique is to assign tasks to the operators such that the total time required at each operator approximately same and below takt time. For assigning tasks to the operators, the precedence relations of task must be considered. The precedence diagram of all tasks in this assembly process is illustrated in Figure 5. Starr (1996) and Nof et al. (1997) presented basic concept of line balancing technique and gave some examples. There are many studies using line balancing technique such as in Peng and Lang (2011), Sindhuja, Mohandas Gandhi, and Madhumathi (2012), Breginski, Cleto, and Sass Junior (2013), Pulkurte, Masilamani, Sonpatki, and Dhake (2014).

Figure 5: Precedence diagram of assembly process



The allocation of tasks and operator utilization for current process is presented in Table 5.

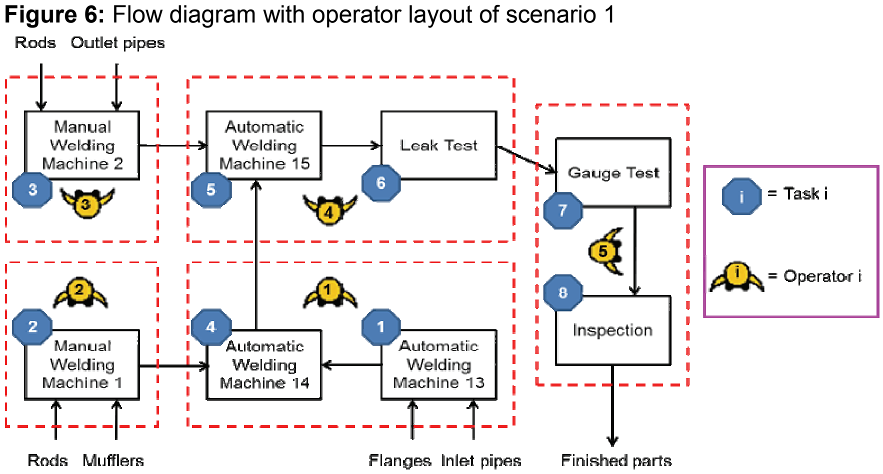
Table 5: Allocation of tasks and operator utilization for current process

Operator i of current process (refer Figure 4)	Task i	Tasks	Stations	Operator Utilization of the current process (%)	Operator i of scenario 1 (refer Figure 6)
1	1	Weld flange with inlet pipe	Automation weld 13	25.71	1
2	2	Weld 2 rods with muffler	Manual weld 1	89.05	2
3	3	Weld 1 rod with outlet pipe	Manual weld 2	75.18	3
4	4	Weld inlet pipe with muffler	Automation weld 14	64.93	1
	5	Weld outlet pipe with muffler	Automation weld 15		4
5	6	Perform the leak test	Leak test	19.17	4
6	7	Perform the gauge test	Gauge test	49.10	5
7	8	Paint welding joint, attach barcode and inspect the finished part	Inspection	48.16	5

Scenario 1: Reduce operators to be 5 operators

According to Table 4, operator 2 (responsible for task 2) and 3 (responsible for task 3) have high utilization. Hence, for scenario 1, we did not change the task for these 2 operators but rearrange the rest of tasks for other 3 operators, totalling 5 operators (this number of operators was reduced from 7 operators). The consideration for the rest is to allocate effort of less utilization operators to handle the nearby station. For example, the automation weld number 13 is close to number 14; therefore, Operator number 1 in scenario 1 was assigned to handle both stations. The flow diagram with operator layout of scenario 1 is shown in Figure 6.

Figure 6: Flow diagram with operator layout of scenario 1



The allocation of tasks and operator utilization for scenario 1 is presented in Table 6.

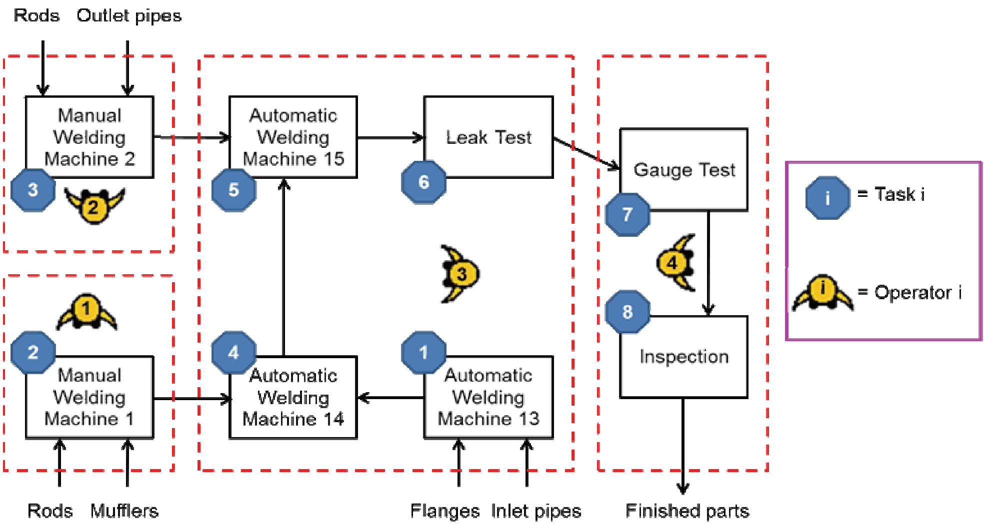
Table 6: Allocation of tasks and operator utilization for scenario 1

Operator i of scenario 1 (refer Figure 6)	Task i	Tasks	Stations	Operator Utilization of scenario 1 (%)	Operator i of scenario 2 (refer Figure 7)
1	1	Weld flange with inlet pipe	Automation weld 13	62.88	3
	4	Weld inlet pipe with muffler	Automation weld 14		3
2	2	Weld 2 rods with muffler	Manual weld 1	89.16	1
3	3	Weld 1 rod with outlet pipe	Manual weld 2	72.53	2
4	5	Weld outlet pipe with muffler	Automation weld 15	55.99	3
	6	Perform the leak test	Leak test		3
5	7	Perform the gauge test	Gauge test	97.39	4
	8	Paint welding joint, attach barcode and inspect the finished part	Inspection		4

Scenario 2: Reduce operators to be 4 operators

According to Table 6, operator 5 (responsible for task 7 and 8) has the highest utilization followed by operator 2 (responsible for task 2) and 3 (responsible for task 3), respectively. Therefore, scenario 2, we did not change the task for these three operators. For the rest of tasks which are task number 1, 4, 5, and 6 are assigned for the rest operator (operator number 3 in scenario 2).The flow diagram with operator layout of scenario 2 is shown in Figure 7.

Figure 7: Flow diagram with operator layout of scenario 2



The allocation of tasks and operator utilization for scenario 2 is presented in Table 7.

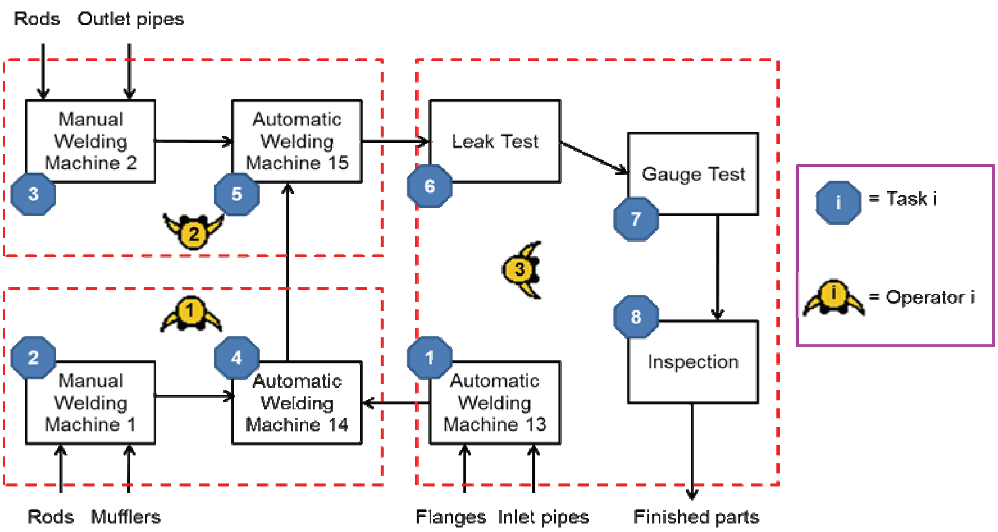
Table 7: Allocation of tasks and operator utilization for scenario 2

Operator i of scenario 2 (refer Figure 7)	Task i	Tasks	Stations	Operator Utilization of scenario 2 (%)	Operator i of scenario 3 (refer Figure 8)
1	2	Weld 2 rods with muffler	Manual weld 1	68.05	1
2	3	Weld 1 rod with outlet pipe	Manual weld 2	57.24	2
3	1	Weld flange with inlet pipe	Automation weld 13	91.49	3
	4	Weld inlet pipe with muffler	Automation weld 14		1
	5	Weld outlet pipe with muffler	Automation weld 15		2
	6	Perform the leak test	Leak test		3
4	7	Perform the gauge test	Gauge test	72.95	3
	8	Paint welding joint, attach barcode and inspect the finished part	Inspection		3

Scenario 3: Reduce operators to be 3 operators

According to Table 7, operator 2 (responsible for task 3) has the lowest utilization followed by operator 1 (responsible for task 2). Adding task to these two operators would result in an increase of their utilization. Therefore, we added task 4 to operator 1 and added task 5 to operator 2 due to their close proximity between the two stations. However, task number 1, 6, 7, and 8 were assigned for the rest operator (operator number 3 of scenario 3). The flow diagram with operator layout of scenario 3 is shown in Figure 8.

Figure 8: Flow diagram with operator layout of scenario 3



The allocation of tasks and operator utilization for scenario 3 is presented in Table 8.

Table 8: Allocation of tasks and operator utilization for scenario 3

Operator i of scenario 3 (refer Figure 8)	Task i	Tasks	Stations	Operator Utilization of scenario 8 (%)
1	2	Weld 2 rods with muffler	Manual weld 1	92.69
	4	Weld inlet pipe with muffler	Automation weld 14	
2	3	Weld 1 rod with outlet pipe	Manual weld 2	92.30
	5	Weld outlet pipe with muffler	Automation weld 15	
3	1	Weld flange with inlet pipe	Automation weld 13	97.57
	6	Perform the leak test	Leak test	
	7	Perform the gauge test	Gauge test	
	8	Paint welding joint and attach barcode and inspect the finished part	Inspection	

The summary of allocated tasks for the current process, scenario 1, 2 and 3 are shown in Table 9.

Table 9: Allocation of tasks for the current process and the 3 scenarios

Task i	Tasks	Stations	Operator i			
			Current Process	Scenario 1	Scenario 2	Scenario 3
1	Weld flange with inlet pipe	Automation weld 13	1	1	3	3
2	Weld 2 rods with muffler	Manual weld 1	2	2	1	1
3	Weld 1 rod with outlet pipe	Manual weld 2	3	3	2	2
4	Weld inlet pipe with muffler	Automation weld 14	4	1	3	1
5	Weld outlet pipe with muffler	Automation weld 15	4	4	3	2
6	Perform the leak test	Leak test	5	4	3	3
7	Perform the gauge test	Gauge test	6	5	4	3
8	Paint welding joint and attach barcode and inspect the finished part	Inspection	7	5	4	3

3. RESULTS

After reducing the number of operators, operator utilization was increased and direct labour cost was decreased. The direct labour cost per person is 28,000 baht per month (700 Euro at 1 Euro: 40 Baht) The comparison of KPIs of the current process and 3 scenarios are illustrated in Table 10.

Table 10: Comparison of the current process with 3 scenarios

KPIs	Current Process	Scenarios		
		1	2	3
Number of Operators	7	5	4	3
Output (pieces/day)	383	383	287	249
Average operator utilization (%)	53.04	75.59	72.43	94.19
Direct labour cost per month (baht/month)/ (Euro/month)	196,000/ 4,900	140,000/ 4,500	112,000/ 2,800	84,000/ 2,100

The comparison of 3 scenarios with the target for all KPIs is presented in Table 11.

Table 11: Comparison of three scenarios with target.

KPIs	Targets	Scenarios		
		1	2	3
Output (pieces/day)	270	383	287	249
% Decreased direct labour cost	20.00%	28.57%	42.86%	57.14%
% Increased Operator utilization	15.00%	22.55%	19.39%	41.15%

From Tables 10 and 11, the results showed that scenarios 1 and 2 can produce sufficient number of parts per day, decrease the direct labour cost by more than 20%, and increase operator utilization by more than 15%. However, scenario 3 can decrease the direct labour cost and increase operator utilization by the largest margins, but the number of finished parts does not meet the target. Hence, scenario 2 is the most suitable option among the 3 scenarios. It has over average actual demand by 5.92 percent, reduces the direct labour costs by 42.86 percent, and increase the operator utilization by 19.39 percent.

4. CONCLUSION

This study aims to improve production process by reducing the number of required direct labours and balancing the assembly lines to sustain the actual demand. The obvious benefits from process improvement will potentially result in the reduction of direct labour cost and the increase in operator utilization.

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