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Productivity improvement based line balancing: a case study of pasteurized milk manufacturer

Chueprasert, M. and *Ongkunaruk, P.

Department of Agro-Industrial Technology, Faculty of Agro-Industry, Kasetsart University 50 Ngam Wong Wan Rd., Lad Yao, Chatuchak, Bangkok, Thailand

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Abstract

Due to the low rate of milk consumption in Thai people compared to the world, the Royal Thai government campaigned school milk in 1992 to encourage primary students to drink milk. Hence, the milk plants in Thailand have served milk to schools and other channels for decades. This research studied the production processes of a pasteurized milk manufacturer, which is a small and medium sized milk plant in the central region of Thailand. Our objective was to improve the productivity and efficiency in a line process of a case study. First, we analysed the production process based on work-study principles. The results showed that the current production efficiency was lower than 70%. It implied that there were waiting times, which are considered wasteful and result in high production costs. Next, the bottleneck operation was identified at the packing process, which depended on machine capacity. Then, combinations of work-study, line balancing and continuous improvement concepts were implemented to improve the efficiency. The normal and standard time in the production processes were determined. Then, we proposed three improvement models. The first method was to reduce unnecessary resources; the second was to increase the efficiency; and the third implemented ECRS concepts. Compared to the current line efficiency of 65.51%, the line efficiency of the three methods was increased to 68.97%, 88.33% and 71.56%, respectively. The number of workers reduced in the three methods were six, four and six, respectively. In addition, we compared the total cost reduction from labour and energy cost saving. The result showed that the total cost reduced per year was 570,283 baht, 437,400 baht and 561,600 baht, respectively. In summary, the productivity of workers and machines can be increased by the proposed methods. Then, the company could provide an incentive for workers to improve productivity.

Introduction

In Thailand, the dairy industry has been promoted by the government according to the National Economic and Social Development Plan No. 4 (1977–1981) and the National Economic and Social Development Plan current No. 11 (2012–2016). The Royal Thai government aimed to enhance Thai people's health by having them consume milk and to support the cow milk farmer to serve the domestic demand (Food Intelligence Center, 2014). However, the statistics showed that the average milk consumption of Thai people is much lower than that of the world consumption. Hence, the Royal Thai government established a school milk project in 1992 to encourage kindergarten and primary students to drink milk due to malnutrition in children. In addition, the milk project supported the domestic milk supply chain, which could not compete with imported dairy products (School Milk Programs, 1992). In fact, 40% of domestic raw milk production is dedicated to the school milk via either UHT or pasteurized milk. Therefore, the milk farmers have sufficient domestic demand to support raw milk production.

From 2009 to 2013, the consumption of milk products increased, on average, 3.4% annually, while the yield of raw milk increased by 7.66% annually. Raw milk prices determined by the milk board remained high enough to encourage the cow milk farmers to sustain their career. Recently, farmers have had the ability to efficiently manage farms, especially on animal feed and cow breed standards. As a result, raw milk production has increased, and quality is high. In 2014, the production of raw milk in Thailand increased due to the natural expansion of cows. At present, the number of medium and large-sized farms has increased, while that of small-sized farms has decreased. The demand for raw milk was divided into school milk and commercial market milk. Although, the demand for school milk is quite stable, the demand for commercial market milk is likely to increase (Office of Agricultural Economics, 2013).

*Corresponding author.
Email: *pornthipa.o@ku.ac.th*

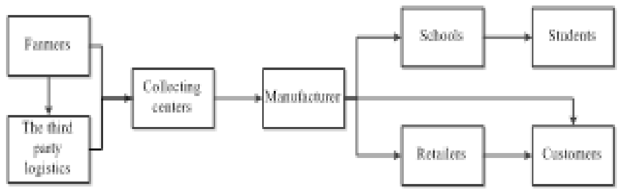

Figure 1. The supply chain of pasteurized milk of a case study

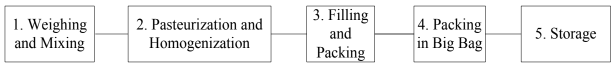

Figure 2. The pasteurized milk production process

Our study focuses on a case study company of medium-sized pasteurized milk plants located in central Thailand. Its supply chain stakeholders are farmers, local third party logistics providers who collect and deliver raw milk from several farms to a collecting point, collecting centres (which have a contract according to the milk board agreement), a processing plant, retailers, schools and consumers who directly buy from a plant, as shown in Figure 1. Our objectives are to explore the current supply chain and increase the productivity of the production process. The current production process is shown in Figure 2. The process begins with weighing raw material and mixing it in a tank. Then, the mixed milk is pasteurized and homogenized in a tank at a certain capacity. Next, the filler machine fills pasteurized milk and packs it in a plastic bag. Then, the worker will count 50 packs and pack those in a big plastic bag for convenient handling and delivery. Finally, the product will be kept in temperature-controlled rooms at under 8 degrees Celsius until it is delivered to customers.

The productivity improvement focused on in this company is line balancing (LB). In food processing plants, the production cycle time is based on worker pace, machine speed and conveyor speed. In the assembly line, there are several stations that are composed of particular tasks. The original line balancing problem was developed to be cost efficient for mass production of standardised products (Boysen *et al.*, 2007). The concept was to design or group tasks in workstations so that the work force (the number of station) is minimised, or the output rate is maximised, which is equal to minimised cycle time. Line balancing methods attempt to allocate equal amounts of time for each worker so that the production flows smoothly without long waiting times (Bhattacharjee and Sahu, 1987). Several researchers proposed algorithms to look for optimal solutions of LB (Padron *et al.*, 2009; Becker and Scholl, 2004). The traditional methods of assembly line balancing assumed that production task time is constant, which is not realistic (Das *et al.*, 2010). In labour intensive production processes, the task time is uncertain since it depends on the skill of each employee, work environment, fatigue, etc. Shin and Min (1991) and Das *et al*. (2010) studied line balancing when the task time is varied. Then, to reduce the waiting time of other stations other than the bottleneck, the station can implement the ECRS concept, which stands for Eliminate, Combine, Rearrange and Simplify (Al-Saleh, 2011; Ongkunaruk and Wongsatit, 2014; Sane *et al.*, 2014) In a labour intensive industry like the agro-industry, line balancing could save labour costs and increase productivity, as studied by Ongkunaruk and Wongsatit (2014). They analysed the time study of the pre-cooking process at a frozen chicken company and proposed to improve the productivity by integrating ECRS and line balancing concepts. After identifying the bottleneck operation, the number of workers in each station was adjusted so that the waiting time was reduced. In addition, they combined two stations and simplified chicken transportation by using carts instead of walking. After implementing the proposed methods, the line efficiency was increased to 94.20%, and labour and labour costs were reduced.

Materials and Methods

First, we drew the pasteurized milk process of the case study, as shown in Figure 2. Next, we recorded each station to collect task time. Then, the takt time, normal time, standard time and production efficiency were calculated (Freivals and Niebel, 2014; Ongkunaruk and Wongsatit, 2014) as follows:
Given:

C = Capacity per time
D = Customer requirement time
T= Takt time
TA = Adjusted takt time
M = Machine breakdown allowance
NT = Normal time
μ_T = Average cycle time
R = Rating factor
ST = Standard time
A = Allowances
E = Production Line efficiency
TT = Total cycle time
n = The number of stations
B = Bottle cycle time

$$T = C/D \quad (1)$$

$$TA = t^*(1-M) \quad (2)$$

$$NT = \mu T^*R \quad (3)$$

Rating factor is based on the researcher's determination of the pace of an employee.

Table 1. Comparison of normal time, standard time, number of workers/machines and cycle time per worker/machine of the current and proposed methods

Station	Average cycle time (sec/l)	Normal time (sec/l)	Standard time (sec/l)	# of workers/machines				Cycle time per worker/ machine (sec)			
				Current method	Proposed method			Current method	Proposed method		
					1	2	3		1	2	3
1	1.34	1.34	1.48	2	1	1	1	0.74	1.48	1.48	1.48
2	1.01	1.01	1.11	1	1	1	1	1.11	1.11	1.11	1.11
3	8.24	8.24	9.07	6	4	6	6	1.51	2.27	1.51	1.51
4	6.65	6.65	7.31	6	3	5	3	1.22	2.44	1.46	2.02
5	1.01	1.01	1.11	3	1	1	1	0.37	1.11	1.11	1.11

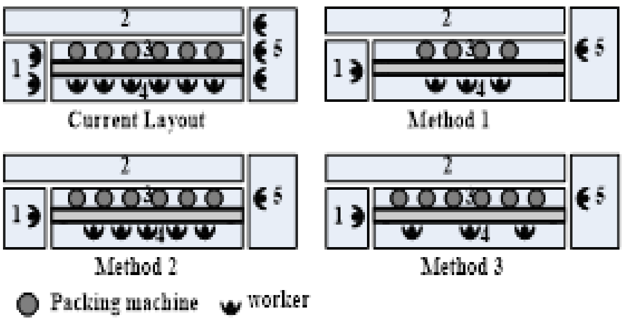

Figure 3. Comparison of layout of current and proposed methods

$$ST = NT^{*}(1+A) \quad (4)$$

The researcher should determine allowances based on the theory that is the summation of personal allowance, basic fatigue allowance, and delay or contingency allowance. (Kanjanapanyakom, 2009).

$$E = 100^{*}(TT)/(n^{*}B) \quad (5)$$

Later, we identified the bottleneck operation that has the maximum cycle time. Next, we proposed three methods based on LB and ECRS methods, and determined the optimal number of workers and machines to balance resources and reduce waiting time such that production line efficiency is increased. Finally, we compared the standard time, number of resources, total cost savings and line efficiency of the current production line with three proposed methods and discussed the result.

Results and Discussion

The study of the current production line

We categorised the process into five stations (i.e., weighing and mixing, pasteurization and homogenization, filling and packing, packing in big bags and storage) as shown in Figure 2. We collected the current cycle time for each workstation for 30 replications from all employees in the stations and calculated average cycle time of all stations.

Identifying the bottleneck operation and calculating takt time

The bottleneck of the pasteurized milk process was filling and packing in station three. We computed the takt time according to Equation (1). The total customer requirement was 8269 litres per day. The production capacity is the production time of eight hours per day including a one-hour break, which plans to produce 86% of all production quantities. Thus,

$$T = (8\ h/day - 1\ h/day)^{*}(0.86^{*}3{,}600\ sec/h)/82{,}691\ l/day$$
$$= 2.62\ sec/l$$

With a machine breakdown allowance of 5%, we can calculate the adjusted takt time as follows:

$$T_A = 2.62^{*}0.95 = 2.49\ sec/l$$

Calculating the standard time of the production line

We collected the cycle time for each station and determined the number of replications of cycle time at a 95% confidence interval. The maximum number of replications was less than 30. Hence, our data collection was sufficient to calculate. We defined the personal allowance to 3%, basic fatigue allowance to 2% and delay or contingency allowance to 5%. Thus, the total allowance is 10%. Then, we calculated the average cycle time, normal time, standard time and cycle time per worker for 1 litre of pasteurized milk as shown in Table 1.

$$E = (100^{*}4.95)/(5^{*}1.51) = 65.51\%$$

From the analysis, the cycle time per worker of

Table 2. Comparison of the current method and the three proposed methods

Performance indicator	Current method	Proposed method		
		1	2	3
# of workers	11	5	7	5
# of reduced workers	-	6	4	6
Bottleneck cycle time (sec/l)	1.51	2.44	1.51	2.02
Total cycle time per worker/machine	4.95	8.40	6.67	7.02
Total production reduction (baht/year)	-	570,283	437,400	561,600
Line efficiency (%)	65.51	68.97	88.33	71.56

the bottleneck station was less than the takt time. This implied that the current capacity was more than the demand for products. Hence, the marketing department should be able to stimulate the sales. However, the line efficiency is quite low since there was waiting time in some stations due to an imbalance in the number of workers. Hence, we proposed three methods to improve production efficiency based on the different objectives as follows.

Process improvement

Method 1: To reduce unnecessary resource allocation

From previous analyses, the current production capacity was over the demand for products. Hence, we could reduce resource allocation in some stations (i.e., reduce one, three and two workers in stations 1, 4 and 5, respectively, and reduce two machines in station 3), as shown in Table 1 and 2. Then, we calculated the production line efficiency as follows:

$E = (100^*8.4)/(5^*2.44) = 68.97\%$

Next, we calculated the total cost reduction since we could save six workers' wages and electricity bills by turning off two fillers.

Wage reduction = 6 workers*300 baht/day*6 day/w* 52 w/y = 561,600 baht/y
Electricity bill = 2 machines*0.75 kW*7 h/day*2.6506 b/kW-h*6 days/w*52 w/y = 8,683.36 baht/year
Thus, total reduction = 561,600+8,683.36 = 570,283 baht/year

Method 2: To increase the production line efficiency

We observed that the line efficiency of the first proposed method was not much improved. Therefore, we proposed the second method to increase the efficiency without maximum resource reduction. On the other hand, we tried to reduce the waiting time among five stations to increase the efficiency. Then, we reallocated one, five and one workers in stations 1, 4 and 5, respectively, and other stations remained the same as shown in Table 1 and Figure 3. The results showed that the line efficiency was increased to 88.33%. Similarly, we calculated the four worker's wages and cost saving to be 437,400 baht/year. The results are shown in Tables 1 and 2.

Method 3: To further improve based on ECRS methods

We implemented the ECRS concept by combining jobs in station 4. Currently, the worker will count the products from each filler and pack it in a big bag. Then, we proposed that one worker could count the product from two fillers instead. Hence, the number of workers in station 3 is reduced to three. In addition, the workers can operate faster because they do not need to wait for the product from previous stations that have longer cycle times. Next, the allocation in stations 1 and 5 was one and one, respectively. Therefore, total worker reduction was six, and total wage reduction was 561,000 baht/year. However, the line efficiency is reduced from that of method 2 to 71.56%. The results are shown in Tables 1 and 2.

Comparison of current and proposed methods

In this section, we compared the number of workers and machines, bottleneck cycle time, total cycle time per worker/machine and line efficiency of the current method versus the three proposed methods, as shown in Table 2. The result showed that the line efficiency of the three methods was increased to 68.97%, 88.33% and 71.56%, respectively, and the number of workers reduced was six, four and six, respectively. In addition, we compared the total cost reduction from labour and energy cost savings. The result showed that the total costs reduced per year were 570,283 baht, 437,400 baht, and 561,600 baht, respectively. Then, we compared the process layout of current and proposed methods in Figure 3. There were several key performance indicators in the production department; if the manager would like to maximise total cost reduction, they should select the first method. However, if the manager would like to increase only production line efficiency, then method two outperforms. Finally, if they would like to balance both total cost savings and line efficiency, method three outperforms. In summary, our analysis is proposed to the plant manager who is a decision maker of this improvement.

Conclusion

This study aimed to improve the productivity of a case study that produces pasteurized milk. From our analysis, the bottleneck operation was part of the filling and packing processes. However, the current capacity is more than the demand for the product as the comparison between takt time and bottleneck cycle time showed. Hence, we suggested that, if the demand for the product increased in the future, the company could decide whether to replace the current filling machines. On the other hand, if the demand remains stable, the third method is the most suitable to decrease the number of workers and cost, and increase the production line efficiency. Thus, the company could consider giving an incentive to the employees to encourage them to cooperate in the process improvement. We hope that this case study could be an example for the other milk plants to improve their productivity. In the future, we can implement the simulation model to determine the best methods instead of implementing it in the actual production.

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