Defect Reduction in Ready Rice Packaging by Applying Six Sigma

Angsumalin Senjuntichai, Nuttapong Wonganawat, and Boonwa Thampitakkul

***Abstract*—The objective of this study is to reduce the defects of Ready Rice product by applying Six Sigma starting from Define phase to identify major problems which are the out of shape, wrinkle of seal and unreadable date code of plastic cup. Then, in Measure phase, the defective percentage of 5.14% of Ready Rice is measured. Various quality tools are applied in Analyze phase to determine the root causes. It is also statistically proved that pressure and temperature of retort machine and temperature, time and vacuum of sealing machine are significant to defective rate. Experimental designs are employed in Improve phase to determine the suggested machine setting with respect to minimum overall defective rate. The p chart is deployed to monitor the process in Control phase. After improvement, the total defective percentage is reduced by 56.42% from 5.14% to 2.24%.**

***Index Terms*—Defect reduction, experimental design, p-control chart, six sigma.**

I. Introduction

Six Sigma is a process improvement approach that seek to determine and eliminate causes of defects, reduce cycle time and cost of operation and improve productivity. It is based on five steps of a simple problem solving which are Define, Measure, Analyze, Implement and Control (DMAIC). A variety of statistical and quality control tools are selected and employed in each step. Six Sigma is one of the popular approach to improve the process performance in various industries such as computer and electronic [1], [2], and high precision manufacturing [3]. Example of previous works that applied Six Sigma methodology to the food manufacturing include Ditahardiyani *et al.* [4], Lazzaro *et al.* [5], Knowles *et al.* [6], Dora and Gellynck [7] and Hung and Sung [8]. These studies used the DMAIC framework. However, the tools that they used in each step are different based on situations. For example, three-layer diagram and pareto chart were used by Hung and Sung [8] to identify important problems and product lines. Cause and effect diagram was applied by Knowles *et al.* [6] and Dora and Gellynck [7] in Measure and Analyze phases, respectively. The goal of Six Sigma is not only to reduce the defective rate by reducing the process variation but also to produce the higher quality products according to the customer requirements [9]. Competition in food industry is undergoing pressure for businesses to seek for the competitive advantage strategy. The best way to grow in the market and to gain more profits is to improve the productivity by reducing production cost and speeding up product to market. The studying company has found that the packaging defect of Ready Rice (ready-to-eat) product such as the unreadable date code, the wrinkle of seal and the out of shape of plastic cup illustrated in Fig. 1(a)-(c) [10] approximately costed the company 430,000 THB per year. Therefore, Six Sigma is taken into consideration as the useful technique for defect reduction of Ready Rice packaging.

II. Methodology

This research has applied Six Sigma approach to improve process efficiency by reducing a number of packaging defects. There are five steps based on Six Sigma approach which are Define, Measure, analyze, Implement and Control (DMAIC) widely used in many industries. The DMAIC procedure can help the company team as a roadmap for problem solving and process improvement starting from defining the company problem and then finding the appropriate way to set the best practice and standard to ensure that the problem will not be re-occurred in the future [11].

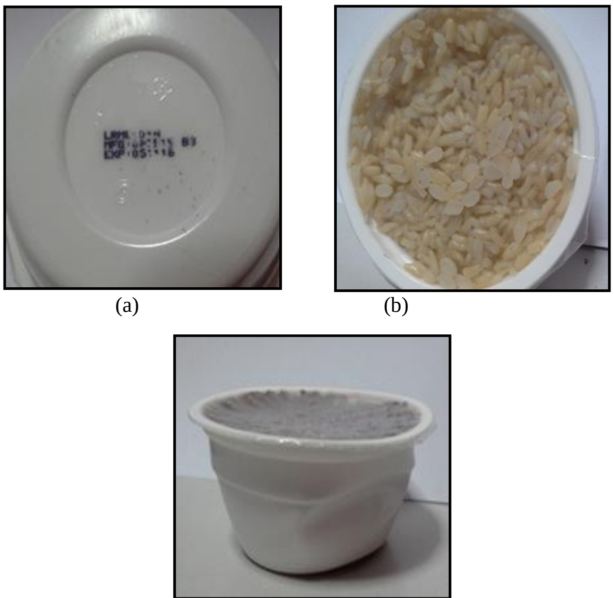

Fig. 1. (a) Unreadable (b) Wrinkle of seal (c) Out of shape.

A. Define Phase

This phase is started with the production process of 500 ml Ready Rice product by identifying the key problems impacted to the production process performance. From data collection recorded during July 2014 to March 2015, the total number of

Manuscript received December 15, 2017; revise August 12, 2018. This work was supported in part by the studying company.

A. Senjuntichai and B. Thampitakkul are with Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, 10330 Thailand (e-mail: angsumalin.s@chula.ac.th, boonwaie@yahoo.com).

N. Wonganawat was with Regional Centre for Manufacturing Systems Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, 10330, Thailand (e-mail: nwonganawat@gmail.com).

doi: 10.18178/ijimt.2018.9.4.810

defective items was 49,372 from 960,545 production volume, resulting in the total defective percentage of 5.14%. There are three major types of defect which are the out of shape, the wrinkle of seal and the unreadable date code yielding the defective percentage of 1.62, 1.43 and 1.66% respectively. These three defects account for 80% of all defects as shown in Fig. 2. Therefore, the main objective of process improvement is to reduce the number and cost of defective items due to these three defect types.

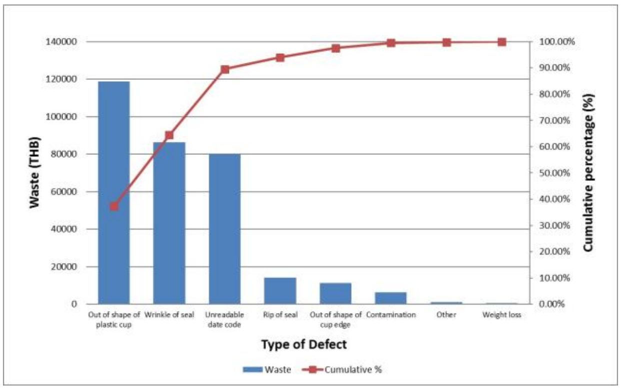

Fig. 2. Waste of each defect type.

B. Measure Phase

This phase focuses on understanding the current performance of the process and collecting any necessary data needed for the analysis. In this phase, the research team was formed from cross functional department to identify the root causes of each defect type. The Cause & Effect diagrams were constructed to identify the potential causes of each defect type. Lists of the identified cause such as no standard setting of retort pressure, of retort temperature, of sealing temperature, of sealing time, etc. for the wrinkle of seal as example among three defect types are illustrated in Table I.

Consequently, Failure Mode and Effect Analysis (FMEA) was applied to evaluate the cause priority of each defect type. The RPN (Risk Priority Number) score is the combined score represented the importance of potential causes based on severity level of defect, probability of occurrence and probability of detection. Table I also shows the average RPN scores graded by the research team for each potential cause of the wrinkle of seal and sorted from the highest to the lowest scores, it is evident that there are ten potential causes approximately accounted for 80% of total RPN scores. Among ten causes, there are only four controllable causes for the wrinkle of seal described in Table II selected for the further analysis in the next step. Other causes such as scratched by retort's divider plate, incorrect inspection, scratched by staff or unstable sealing machine's pressure force are addressed by the research team with suggestion/action that can be immediately deployed. Actions and suggestions are usually preventive maintenance or training program. Other causes that cannot be addressed in this study is due to the food standard and company policy for no machine adjustment. The same tools such as the cause and effect diagram and the FMEA were performed for the out of shape and the unreadable date code as well. Their selected factors are presented in Table II.

TABLE I: RPN SCORE OF EACH CAUSE

No.	Cause/Factor of the wrinkle of seal	Average RPN score	% Cumulative Average RPN
1	No standard setting of sealing temperature	39.6	12.24
2	No standard setting of retort temperature	34.2	22.82
3	No standard setting of retort pressure	32.4	32.84
4	Improper sealing head position	29.4	41.93
5	Inconsistent sealing pressing force	28.8	50.83
6	Scratched by retort divider plate	26	58.87
7	Error of inspectors	25.2	66.67
8	No standard setting of sealing time	21.6	73.35
9	No standard setting of retort time	17.2	78.66
10	Scratched by staffs	11.8	82.31
11	Careless handing process	10.6	85.59
12	No standard of plastic film feeding	8.6	88.25
13	Scratched during transportation	7.2	90.48
14	Untrained inspectors	6.6	92.52
15	Blunt cutter	6.2	94.43
16	Poor plastic film quality	4.2	95.73
17	Unclean of plastic cup edge	3.6	96.85
18	Too thin of plastic film	2.8	97.71
19	Dirty of cutter	2.8	98.58
20	Insufficient number of inspectors	2.6	99.38
21	Type of plastic film	2	100

TABLE II: SELECTED POTENTIAL CAUSES

Priority	Causes of the out of shape	Causes of the wrinkle of seal	Causes of the unreadable date code
1	No standard setting of retort pressure	No standard setting of retort pressure	No standard setting of retort pressure
2	No standard setting of retort temperature	No standard setting of retort temperature	No standard setting of retort temperature
3		No standard setting of sealing temperature	Varying amount of air remaining in cup (Sealing vacuum)
4		No standard setting of sealing time	Unsuitable ink intensity (by sealing machine)

C. Analyze Phase

The objective of this phase is to identify the significance of each potential causes/factors on each defective proportion of three defects. The response of the hypothesis test is the defective proportion. The sample sizes are determined based on the hypothesis test of two population proportions at significant level of 5% (α= 0.05) and 80% power of test (β= 0.2). The current defective proportions (p_1) of each defect type are previously mentioned while the expected defective proportions (p_2) are projected to be half of the current proportion. Therefore, the sample sizes needed for the hypothesis test for two population proportions are 2871, 3257 and 2801 units for each defect type. Due to the production volume of 3,888 units/day, the sample size for each experiment was then designed to be 3,888 units which is greater than the calculated sizes. Conversely, with sample size of 3,888 units, type II error of test (β) for each defect type is less than 0.2. Two-sided hypothesis tests for two population proportions at low (p_L) and high (p_H) levels of each factor are performed to check whether the corresponding factor are statistically significant to the defective proportion. These hypothesis tests called one-factor-at-a-time (OFAT) tests are preferred under certain conditions in which number of experimental runs is limited and the focus is on system improvement rather than on efficiency in estimating model parameters since the interaction among factors cannot be considered [12].

TABLE III: THE HYPOTHESIS TESTS

Defect Type	Factor	$\hat{p}_L$	$\hat{p}_H$	p-value
Out-of-shape	The retort pressure	0.012	0.026	0.000
	The retort temperature	0.014	0.010	0.118
Wrinkle of seal	The retort pressure	0.010	0.011	0.505
	The retort temperature	0.010	0.033	0.000
	The sealing temperature	0.013	0.034	0.000
	The sealing time	0.013	0.021	0.007
Unreadable date code	The retort pressure	0.015	0.029	0.000
	The retort temperature	0.018	0.014	0.241
	The vacuum of sealing m/c	0.012	0.025	0.000
	The ink intensity of inkjet	0.012	0.008	0.107

As shown in Table II, all causes are from two separated machines, retort and sealing machines. Since these two machines are operated independently, it is expectantly that factors from these two machines are independent to each other. Then, the interaction between factors across machine might be omitted. With OFAT analysis, only the interaction between factors from the same machine is not considered. As presented in Table III, the factors with p-value less than 0.05 significance level indicate that the pressure of retort is the only one significant factor that effects to the defective proportion of the out of shape. While there are three significant factors which are the temperature of retort machine, the temperature of sealing machine and the sealing time that effect the defective proportion of the wrinkle of seal. Finally, the pressure of the retort machine and the remaining air in cup are the significant factors of the unreadable date code. Table III shows the p-value of the hypothesis tests for the significant factors of all three defect types.

D. Improve Phase

This phase is to determine the appropriate setting value for each factor subject to minimum number of all defects. The three-level full factorial design of experiments was chosen for each defect type with two reasons (1) it is easy to understand and implement by research team especially for their own further experiments in the future (2) similarly to CCD and Box-Behnken design, it enables further detection of non-linearity (if necessary) in the relations between inputs and the response. According to number of experimental run, Box-Behnken design requires fewer run than CCD and three-level factorial design, but the latter two designs produce better model. CCD is also superior than three-level factorial design as it requires a fewer data point but it is not a good choice for this study because it requires an extreme factor setting than usual.

Therefore, for the out of shape defect with one significant factor, one-way ANOVA with three level was applied with 3 experimental runs. While a 3x3x3 factorial design was used for total experimental runs of 27 of three significant factors of the wrinkle of seal defect. Finally, 9 experimental runs of the 3x3 factorial design was conducted for two significant factors of the unreadable date code defect. The setting for three levels of each factor is set at the minimum, current (as middle) and maximum levels that each factor can be set. The middle setting is supposed to be the mid-point between minimum and maximum setting. But in this case, the current setting is preferred by the research team to avoid excessive loss which can be occurred from the unusual production process. Table IV presents the level setting of each factor. Since the experiments are separately designed and performed according to each defect type, the different impact of significant factors corresponding to one defect on other defects might occur, the proportion of total defective items due to all defect types recorded from sample size of 3,888 units is then considered as the response of the experiment. Since the response is the total defective proportion, to satisfy the ANOVA assumption of common variance, the Freeman and Turkey (F&T) transformation is required [13] based on (1).

$$P\,(F\&T) = \frac{\arcsin\sqrt{\frac{n\hat{p}}{n+1}} + \arcsin\sqrt{\frac{n\hat{p}+1}{n+1}}}{2} \qquad (1)$$

where $\hat{p}$ = sample defective proportion
n = number of samples in the experiment
P(F&T) = the transformed defective proportion

Table V presents the p-value from ANOVA tables based on the design experiments of each defect. With the significance level of 5%, p-values less than 0.05 of (1) the retort pressure and (2) retort temperature as the main effects and the interaction between (1) the sealing temperature and sealing time and (2) the retort pressure and sealing vacuum are evident that they are statistically significance to the total defective proportion.

TABLE IV: LEVEL SETTINGS OF EACH FACTORS

Defect Type	Factor	Level Setting			
		Min	Current	Max	Units
Out-of-shap e	The retort pressure	1600	1700	1800	mbar
Wrinkle of seal	The retort temperature	116	117	125	℃
	The sealing Temperature	150	174	195	℃
	The sealing time	2	2.7	4	sec
Unreadable date code	The retort Pressur	1600	1700	1800	mbar
	The sealing Vacuum	10	23	40	bar

The main effect plots and interaction plots, are respectively illustrated in Fig. 3-6. The main effect plot of Fig. 3 shows that the lowest total defective proportion is occurred at the middle setting of 1,700 mbar of the retort temperature which is consistently agreed with the production procedure. If the retort pressure is too high or too low, the plastic cup might be deformed. Meanwhile, with the main effect plot of Fig. 4, the lowest total defective proportion is at 116℃ of the retort temperature which is reliably with the production procedure as well. If the retort temperature is too high, the seal might get wrinkle. Normally, this retort temperature was set at low temperature of 117℃, with this analysis, it can be set a bit lower for one more degree Celsius. There was a normal practice to set the sealing temperature and the sealing time in the reverse way. If the sealing temperature is set at high level, the sealing time must be set at low level, otherwise the wrinkle can be occurred at plastic seal or the seal is not attached well.

The interaction plot presented in Fig. 5 demonstrates the interaction between the sealing temperature and the sealing time which are occurred as predicted except at one situation when the sealing temperature is set at 195℃ with the longest sealing time of 4 second. Therefore, the sealing temperature and the sealing time are suggested to be at 150℃ and 4 second, respectively, according to the objective of this study in minimizing the defective proportion. Lastly, the interaction plot of Fig. 6 displays the lowest defective proportion at 1,700 mbar of the retort pressure and 10 mbar of the sealing vacuum. The retort pressure at 1,700 mbar is preferable since it is consistent with the previous analysis but the minimum value of the sealing vacuum of 10 mbar is a bit different from normal expectation. According to the experimental results and the statistical analysis, the suggested settings are 1,700 mbar of the retort pressure, 116℃ of the retort temperature, 150℃ of the sealing temperature, 4 second of the sealing time and 10 mbar of sealing vacuum.

TABLE V: P-VALUES FROM ANOVA TABLES

The out of shape		The wrinkle of seal		The unreadable of date code	
Factor(s)	P-value	Factor(s)	P-value	Factor(s)	P-value
Retort Pressure	0.000	Retort Temp (A)	0.011	Retort Pressure	0.000
		Sealing Temp (B)	0.026	Sealing Vacumn	0.000
		Sealing Time (C)	0.001	Interaction	0.011
		Interaction AB	0.808		
		Interaction AC	0.680		
		Interaction BC	0.000		

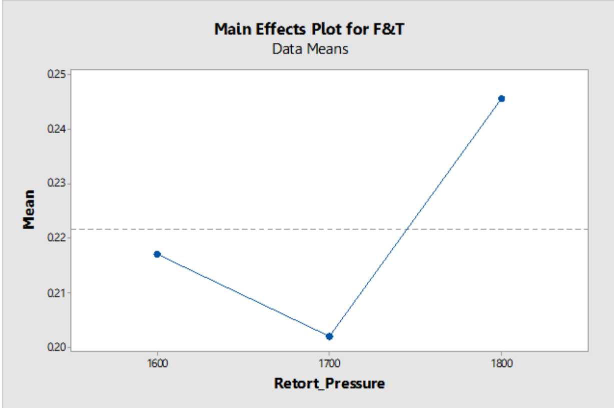

Fig. 3. Main effect plot from out of shape experiment.

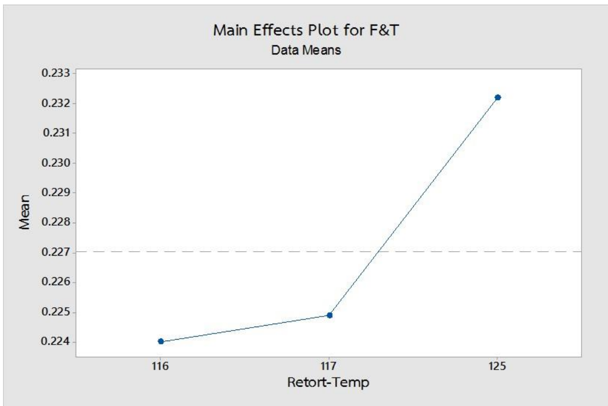

Fig. 4. Main effect plot from wrinkle of seal experiment.

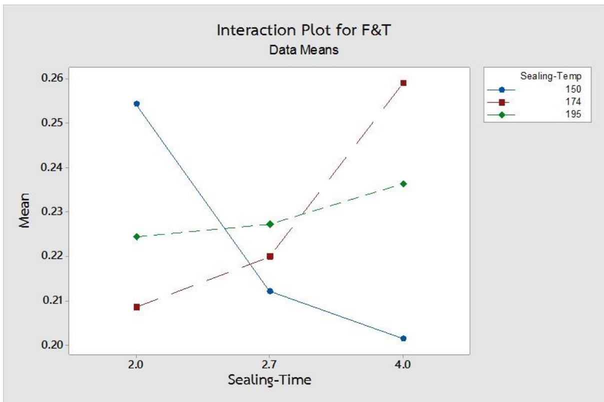

Fig. 5. Interaction plot from wrinkle of seal experiment.

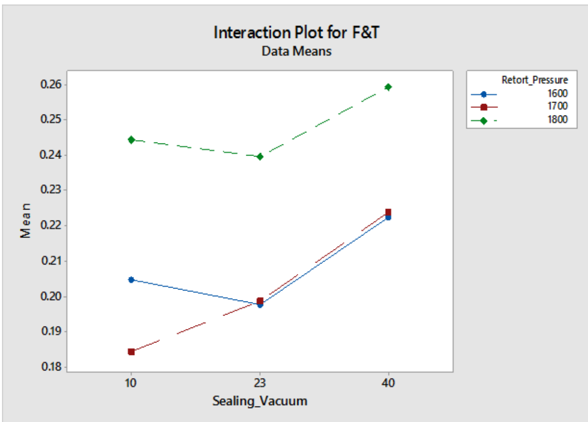

Fig. 6. Interaction plot from unreadable date code experiment.

E. Control Phase

This phase is to control and monitor the process performance when the machine parameters are set based on the suggested settings from the previous phase. Fig. 7 shows the *p* control chart for the total defective from 30 trials with 3,888 samples for each trial. With all in-control points, the process after improvement is more stable and standard than the process before improvement. The defective percentage of all defects is also significantly dropped by 56.42% from 5.14% to 2.24% while the defective percentage after improvement of the out of shape, the wrinkle of seal and the unreadable date code are decreased to 0.67, 0.79 and 0.33%, respectively. It can be concluded that both results are in the same direction.

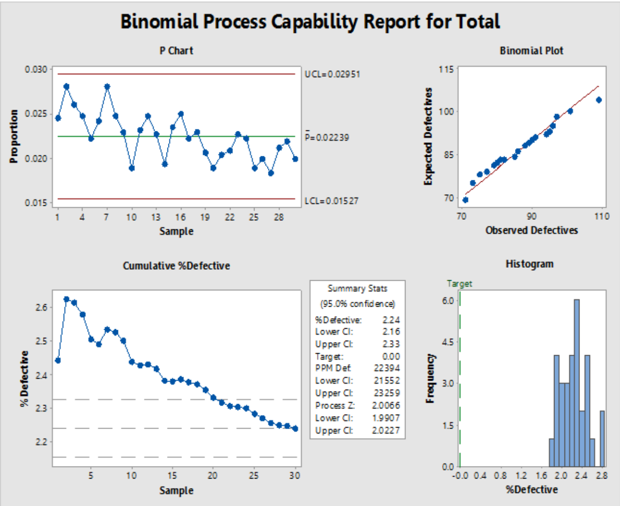

Fig. 7. *p*-chart of total defective after improvement.

III. Conclusion

The main objective of process improvement is to reduce the number and cost of defective items according to three defect types by applying the Six Sigma concept. The methodology consists of five phases of DMAIC staring from Define, Measurement, Analyze, Implement and Control. In the define phase, the defective percentages of each defect type are measured and compared to prioritize the problem. In measure phase, the process performance in form of the defective percentage is determined along within analyze phase, the significant factors of each defect type are statistically identified. There are one, three and two significant factors for the out of shape, the wrinkle of seal and the unreadable date code defects, consequently. The three level factorial designs and the analysis of variance are applied to investigate the main effects and interaction effects of each factor on the total defective proportion. The suggested values of each factor with respect to minimum number of total defective are 1,700 mbar of the retort pressure, 116 ℃ of the retort temperature, 150 ℃ of the sealing temperature, 4 seconds of the sealing time and 10 mbar of the sealing vacuum. The *p* chart is used to monitor the process performance after the improvement. With all in-control points, the process after improvement is more stable and standard than the process before improvement. The total defective percentage is decreased by 56.42% from 5.14% to 2.24% and this signify that the approach used in this research is worked. However, there are room for improvement in two further ways (1) with OFAT experiments performed in analyze phase to screen the factors, some interactions between factors may be not considered in study, hence the experiments can be further designed and performed for all factors together following CCD or Box-Behnken design to investigate other interactions between factors (2) the results of this experiment can be further investigate for non-linearity in the relations between factors and the response for more precise optimal setting.

References

[1] A. Damrongvanich and A. Senjuntichai, "Bit error rate improvement of hard disk drive," *Advanced Material Research*, vol. 740, pp. 670-675, 2013.

[2] A. Senjuntichai and A. Pongtrairat, "Scratch defect reduction of hard disk drive media," in *Proc. 2015 International Conference on Engineering and Applied Sciences*, Hokkaido, Japan, July 20-22, 2015, pp. 173-182.

[3] N. Rojanarowan and A. Senjuntichai, "Development of efficient washing system for reduction of oil contamination on machining parts," *Advanced Materials Research*, vol. 156-157, pp. 1545-1554, 2011.

[4] P. Ditahardiyani, Ratnayani, and M. Angwar, "The quality improvement of primer packaging process using six sigma methodology," *Journal of Teknik Industri*. vol. 10, no. 2, pp. 177-184, 2008.

[5] D. C. Montgomery and G. C. Runger, *Applied Statistics and Probability for Engineers*, 6th ed. Singapore: Wiley, 2014.

[6] G. Knowles, M. Johnson, and S. Warwood, "Medicated sweet variability: A six sigma application at a uk food manufacturer," *TQM Magazine*, vol. 16, no. 4, pp. 284-292, 2004.

[7] M. Dora and X. Gellynck, "Lean six sigma implementation in a food processing sme: A case study," *Quality and Reliability Engineering International*, vol. 31, no. 7, pp. 1151-115, 2015.

[8] H. C. Hung and M. H. Sung, "Applying six sigma to manufacturing processes in the food industry to reduce quality cost," *Scientific Research and Essays*, vol. 6, no. 3, pp. 580-591, 2011.

[9] M. Kumar, J. Antony, and M. K. Tiwari, "Six sigma implementation framework for SMEs — A roadmap to manage and sustain the change," *International Journal of Production Research*, vol. 49, pp. 5449-5467, 2011.

[10] Information. [Online]. Available: http://www.bscmfoods.co.th/en/products

[11] L. Ramanan, M. Kumar, and K. Ramanakumar, "Six sigma – DMAIC framework for enhancing quality in engineering educational institutions," *International Journal of Business and Management Invention*, vol. 3, no. 1, pp. 36-40, 2014.

[12] D. Frey, F. Engelhardt, and E. Greitzer, "A role for "one-factor-at-a-time" experimentation in parameter design," *Research in Engineering Design*, vol. 14, no. 2, pp. 65-74, 2003.

[13] S. Bisgaard and H. T. Fuller, "Analysis of factorial experiments with defects or defectives as the response," *Quality Engineering*, vol. 7, no. 2, pp. 429-443, 1994-1995.

Angsumalin Senjuntichai obtained her first degree in industrial engineering (B.Eng) from Chulalongkorn University, Bangkok, Thailand in 1994. She received Master of Science in industrial engineering (M.S.I.E.) from University of Minnesota, Minnesota, USA in 1999 and Doctoral Degree (D.Eng) in industrial engineering from Asian Institute of Technology, Thailand in 2011.

In 1994, she has joined the department of Industrial Engineering, Chulalongkorn University where she is currently a full-time assistant professor.

Dr. Senjuntichai has been constantly involved in professional activities. She has served as a technical consultant to several government and private sectors for various engineering projects. She has also published papers in international journals and conference proceedings. Her interested fields are applied statistics, financial engineering and energy management in factories and buildings.

Boonwa Thampitakkul was born in Bangkok, Thailand in 1948. He received Bachelor of Engineering in industrial engineering from the University of New South Wales, Sydney, Australia in 1973. He received his Master of Science in industrial and management engineering from the University of Iowa, Iowa City, USA in 1976. Later he was awarded D.E.A., and Docteur de Troisieme Cycle (Science de gestion) from L′Universete d' Aix-Marseille III, Aix-en-Provence, France in 1987.

He was a lecturer at the Department of Industrial Engineering, Chulalongkorn University in Thailand from 1973 to 2008, and has become a special lecturer since his retirement in 2008. He was assigned to work in the position of STQC (Standards, Testing and Quality Control) Program Co-ordinator at STDB (Science and Technology Development Board) in 1986-1988. At present he is an independent director of the board of Directors of Siam Steel International Public Company.

Nuttapong Wonganawat was born in Bangkok, Thailand, in 1991. He graduated the Bachelor Degree in industrial engineering from Mahidol University, Thailand, in 2013. Then, he continued his Master Degree in engineering business management from Dual Master's Degree Programs jointly offered by Chulalongkorn University, Thailand and University of Warwick, UK and graduated in 2016.

In the part of working experience, Nuttapong gained the opportunity as an internship in the engineering function of Johnson & Johnson (Thailand) in 2012, where he successfully completed the project to reduce machine changeover time in manufacturing operation. Currently he is a Six Sigma Specialist in Manufacturing Excellence function, Pandora Production Thailand Company. His key role and responsibility is process improvement applying statistical methods.