Implementation of DMAIC six sigma principle in thermoforming for improving rate of production

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ABSTRACT

Fast processing of plastics for producing disposables is dependent on production rate of a manufacturing process and therefore thermoforming is generally preferred. The technological developments in thermoforming technique have led enhanced control of the process which makes easier to carry out research studies on a thermoforming machine. For achieving a high production rate and high rated quality product, the cyclic control of thermoforming machine must be concrete in order to meet desired standards which further introduce a challenge for researchers. The current endeavor focuses on reducing number of defective pieces which are produced due to miscellaneous reasons in a thermoforming set up. The quality related problems for manufacturing disposable plastic glasses are understood in terms of production quality variables and latter are sorted out by using DMAIC principle of six sigma by performing a series of experiments on the thermoforming set-up.

KEYWORDS: Six sigma, Thermoforming, characteristics Critical To Quality), DMAIC, Schimdt and Launsby formula

1. INTRODUCTION

The current scenario of service and manufacturing sector gives thrust to produce services and products quicker, finer and cheaper owing to large competition among the organizations. This is making organizations to look for better prospects for producing low cost and high quality products to retain their place in the market. To fulfill such demands, improvements in the manufacturing processes with stability is required. Six Sigma is a well-known standard for maintaining productivity and quality. It is a well - disciplined and structured approach which lays focus on providing perfect product or services to the customer constantly. In terms of statistics, Six Sigma means 3.4 defects per million opportunities (DPMO). It is a method that emphasizes Define, Measure, Analyze, Improve and Control (DMAIC) approach to problem solving [1-6]. The purpose of Six Sigma is to put together all operations throughout the manufacturing steps to make them deliver desired outcomes [7-10]. It has been applied in a variety of fields covering information technology, distribution operations, health care, supply chain management, inventory management, education, construction, warehouse, etc [11-17]. Owing to application of six sigma in such large variety of industries, the current work was planned to examine the effect of six sigma technique on production rate and simultaneously product quality in a small scale thermoforming industry. For present work, DMAIC principle of six sigma was employed for enhancing product quality in a thermoforming plastic industry. The purpose of present work is to identify

2. MATERIALS AND METHODS

Thermoforming is a manufacturing process where a plastic sheet is heated to a pliable forming temperature, formed to a specific shape in a mold, and trimmed to create a usable product. Thermoplastics can be thermoformed according to the principles of positive, negative or free forming, with or without the use of air pressure or vacuum. Free-formed thermoplastics need to be kept in their desired shapes until they have reached a temperature lower than 70 °C. A study of Thermoforming unit of ABC Thermoforming industry producing various types of plastic disposable glasses was carried out. Table 1 proposes the specifications of the process.

Table 1 Process Specifications

Material Used	Poly Propylene (PP) (80%) + Crystal Granules (20%)
Operating Temperature	250^{o}C
Production Rate/hr	22000-25000 glasses/hr
Manufacturing time	8hrs (with a break of 1 hr)
Other Materials Used	HIPP (High impact PP), GPP (General PP)

3. APPLICATION OF SIX SIGMA DMAIC METHODOLOGY

3.1 Define phase

In this stage, with assistance of process, inputs, supplies and output various stages in the thermoforming set-up process were established. Following are the results of the Define stage:

1. Customer – Workers who collects and packs the glasses (Internal Customer)
2. Team – Machinists and Operators, Production Control Staff
3. Process Boundaries – All Process Steps from putting the raw materials till the final glasses are obtained

3.2 Measure phase

In the second stage, the characteristics of a product or process to be evaluated are chosen and the performance levels for those characteristics are ascertained, and then a “CTQ (characteristics critical to quality) Flow chart is made to recognize the correlation between the inputs and outputs as shown in Figure 1.

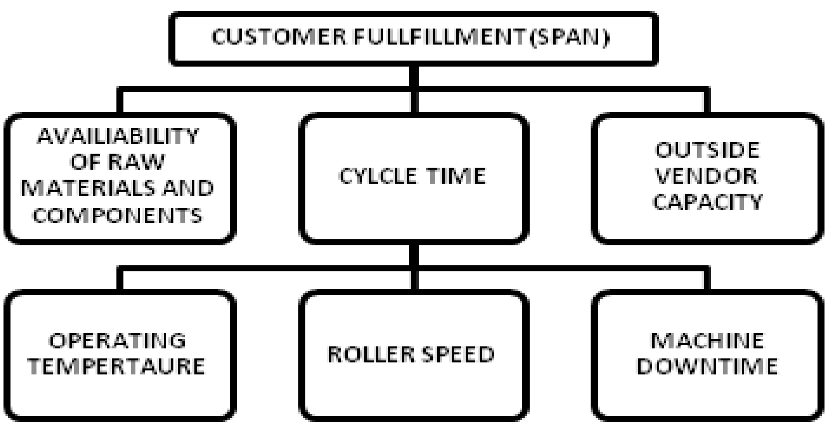

Figure 1 Manufacturing Cycle

However, factors like scheduled holidays and product mix are also taken into account for the current study. Another tool in the form of fishbone diagram is represented in Figure 2 which covers the entire aspects which lead to the presence of defects in thermoformed glasses.

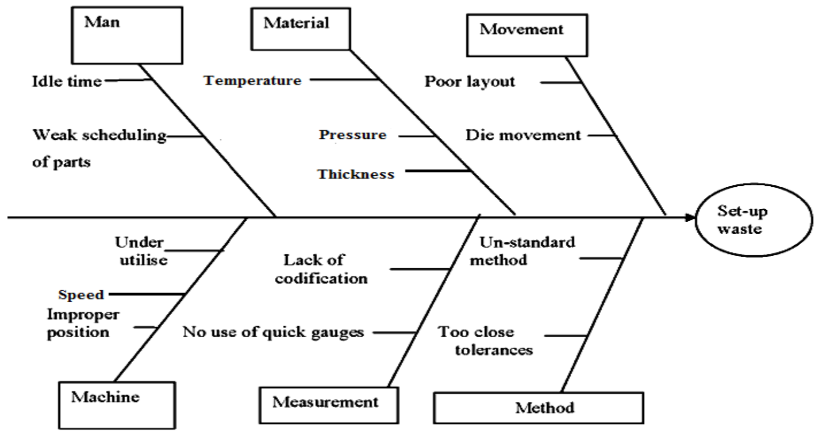

Figure 2 Fishbone diagram of defects

3.2.1 Current Sigma Level

For this purpose the data was taken from industry for three months and then the analysis was performed and improvement with the help of the expertise later. Here is the chart in Figure 3 showing the data collected in these three months.

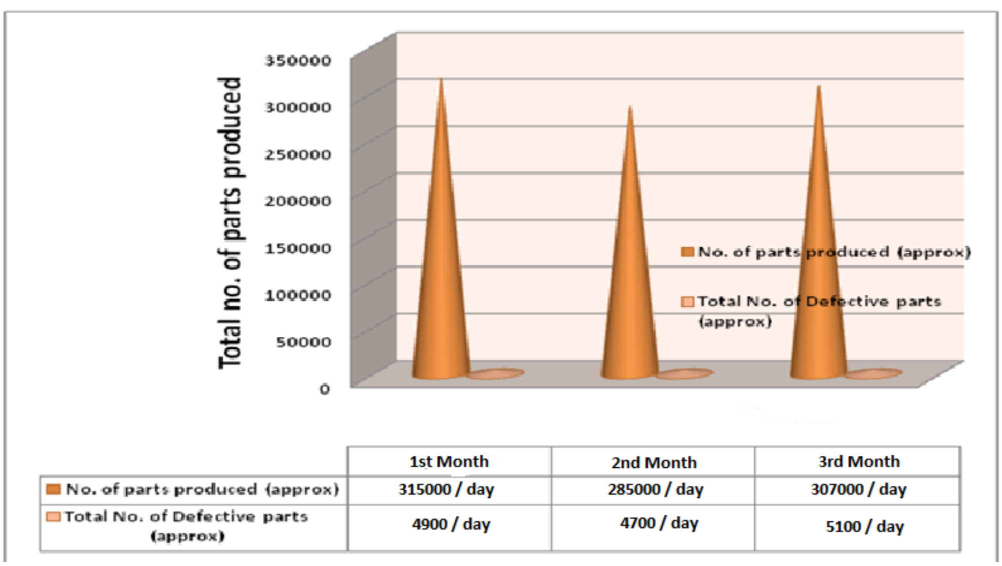

Figure 3 Production vs defects

3.2.2 Calculations

Defects/unit (DPU) = 0.0162

Defects per million opportunities (DPMO)

$$= \frac{\text{Defective parts}}{\text{Total parts produced}} \times 1{,}000{,}000$$

$$= \frac{14700}{907000} \times 1{,}000{,}000$$

$$= 16207.27$$

So, DPMO is 16207

3.2.3 Schimdt and Launsby formula

This formula is a basic formula for calculating the sigma level. It just needs the variable i.e. Defects per million opportunities i.e. DPMO.

Sigma = 0.8406 + Sqrt (29.37-2.221×ln (DPMO))

= 3.64095

3.3 Analyze Phase

At this stage determination of the process sigma level is done and variation is regarded as an enemy. This sigma value shows that the process has an average no. of defects. Certainly aim will be to improve the level and reduce the wastage and time for the processes. Based on the study in thermoforming plant 4 variables as 'key' variables that effect the production rate were obtained. These are optimum temperature, sheet thickness, operating pressure and roller Speed. In this stage of the analysis the following technique was used to determine which inputs should be the focus of improvement efforts. A discussion with the project team also helped to identify the effect each parameter has on the product quality. Now to get the mathematical results following factors were kept constant. Now one by one each factor is allowed to vary keeping other factors as constant at their operating values. This process is applied for all the factors. Results are shown the following Table 2.

Table 2 Average defects and their effect

Variables	Average no. of defects on variation (per 1000)	%age effect of each variable
Temperature	22.4	29
Roller speed	16.7	21.7
Pressure	18.2	23.7
Thickness	19.8	25.6

This shows that temperature has the maximum and roller speed has the minimum effect on the defect level. So on the basis of this stress will be given more on temperature values followed by thickness, pressure and roller speed. This marks the end of analysis stage. Now the improvements will be carried out in the next stage.

3.4 Improve Phase

Now in this stage DESIGN OF EXPERIMENTS (DOE) technique was carried out for the improvement. Earlier calculations for the average no. of defects due to each variable were made. But now in this stage determination for the value of variables (one by one keeping other factors constant) that has least no. of defects is done. Initially the values used are given in Table 3.

Table 3 Initial operating parameters values for improve phase

Operating Temperature	250°C
Thickness of the sheet used	3.6 mm
Pressure	10.4 Kgf
Roller Speed	2400 rpm

Now all the factors at their initial values are kept, then each factor, one by one is varied and the value at which the defect level is minimum is selected. The experimental results are given in Figures 4-7.

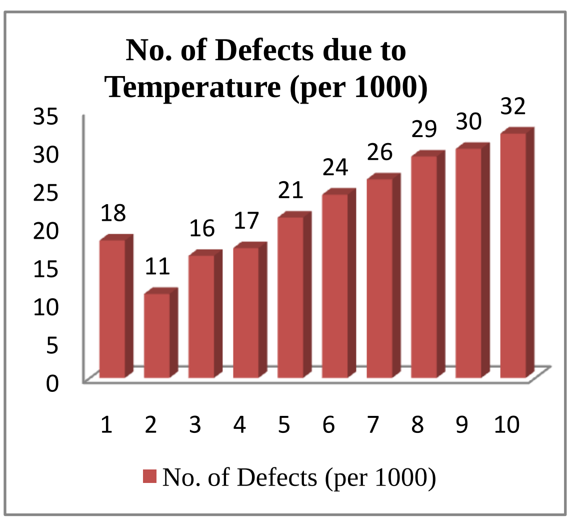

Figure 4

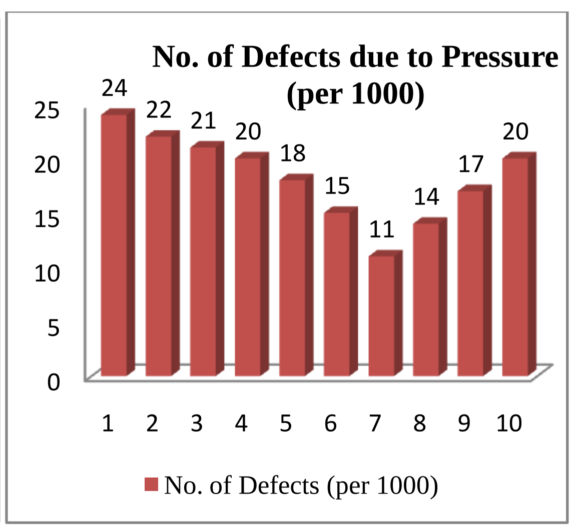

Figure 5

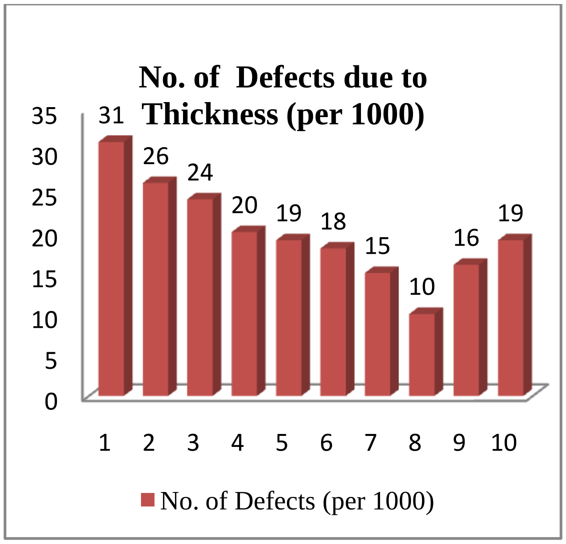

Figure 6

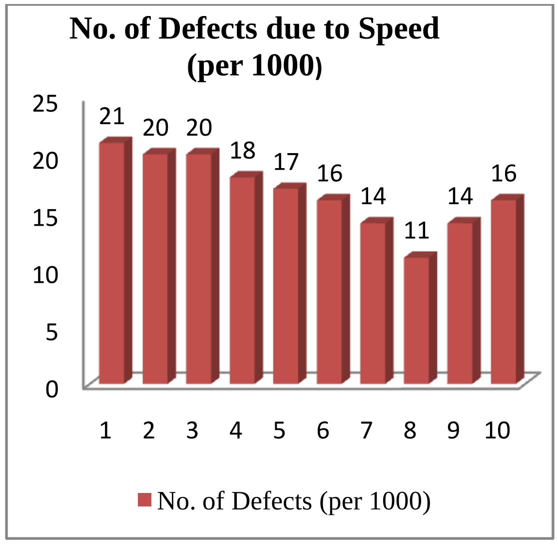

Figure 7

Now after all these experiments the Operating Conditions were changed. The following were used values which had minimum no. of defects. The changed values are given in Table 4.

Table 4 Changed values for implementing improvements

Operating Temperature	244^{o}C
Thickness of the sheet used	3.8mm
Pressure	10.6 Kgf
Roller Speed	1400 rpm

After applying all these values the number of defects was checked as summarized in Table 5. As the Defect level has reduced considerably so three readings were taken per ten thousand.

Table 5 Summary of number of defects after implementation of revised operating parameters

S.No	Total no. of defects	Total parts produced
1.	12	10,000
2.	10	10,000
3.	10	10,000
Average.	10.667	

3.4.1 Calculations

Defects/unit (DPU) = $\frac{10.667}{10000}$ = 0.0010667

Defects per million opportunities (DPMO)

$$= \frac{\text{Defective parts}}{\text{Total parts produced}} \times 1{,}000{,}000 = \frac{10.667}{10000} \times 1{,}000{,}000 = 1066.67$$

So, DPMO is 1067

3.4.2 Schimdt and Launsby formula

Sigma = 0.8406 + Sqrt (29.37-2.221×ln(DPMO))

Capability= Sigma/3

So, Sigma = 4.566704

Finally the success was achieved in reducing the defect level to such an extent. We could have achieved even more but that required changes in the whole processes, using high quality machines, automatic machines for clamping and packaging purpose. All these steps will decrease the manual effort and decrease the time taken thus improving the efficiency of the process.

3.5 Control Phase

The final step in this DMAIC implementation was to ensure that the vital inputs (i.e. temperature, thickness, pressure and roller speed) would stay within the limits defined in the DOE. It was determined that the best way to accomplish this as quickly as possible was to launch two separate DMAIC projects. The first project was focused on reducing defects due to temperature and pressure, while the second project was focused on reducing defects due to thickness, roller speed and machine downtimes. Both of these projects used Statistical Process Control techniques that tracked the values of the inputs listed above over time. Whenever, the inputs were determined to be out of bounds, immediate attention would be given to correct the situation and bring the process back under control.

4. CONCLUSIONS

1. The implementation of six sigma methodology is found successful in reducing the number of defective pieces and thus improving the level of sigma in small scale thermoforming industry.

2. Success was achieved in reducing the defect level and thereby improving the sigma value in. The final sigma value of 4.566704 is achieved. However if industries want to retain or improve this sigma value, necessary control measures have to be taken and proper checks have to be imposed. Quality culture must be developed amongst employees and proper training must be given to them. A good decision for project generation not only provides profits but also increases customer satisfaction.

3. This study aimed to investigate the effect of applying six sigma tools in a thermoforming industry trying to decrease the scrap rate. This study has two advantages. First is to choose the best tools that fit that type of industry. Second is to encourage similar companions to apply the same methodology.

5. REFERENCES

[1] Yang, K., & El-Haik, B. S. (2003). Design for six sigma (pp. 184-186). New York: McGraw-Hill.

[2] Chowdhury, S. (2002). Design for six sigma. Financial Times Prentice Hall.

[3] Mader, D.P., 2002. Design for six sigma. Quality progress, 35(7), p.82.

[4] Antony, J. and Coronado, R.B., 2002. Design for six sigma. Manufacturing Engineer, 81(1), pp.24-26.

[5] Brue, G. and Launs, R.G., 2003. Design for six sigma. McGraw-Hill.

[6] Koch, P.N., Yang, R.J. and Gu, L., 2004. Design for six sigma through robust optimization. Structural and Multidisciplinary Optimization, 26(3-4), pp.235-248.

[7] Pande, P.S., Neuman, R.P. and Cavanagh, R.R., 2000. The six sigma way. McGraw-Hill.

[8] Kwak, Y.H. and Anbari, F.T., 2006. Benefits, obstacles, and future of six sigma approach. Technovation, 26(5), pp.708-715.

[9] Harry, M.J., 1998. Six Sigma: a breakthrough strategy for profitability. Quality progress, 31(5), p.60.

[10] Linderman, K., Schroeder, R.G., Zaheer, S. and Choo, A.S., 2003. Six Sigma: a goal-theoretic perspective. Journal of Operations management, 21(2), pp.193-203.

[11] Sehwail, L. and DeYong, C., 2003. Six Sigma in health care. Leadership in Health Services, 16(4), pp.1-5.

[12] Corn, J.B., 2009. Six sigma in health care. Radiologic technology, 81(1), pp.92-95.

[13] Gaspersz, V. and Fontana, A., 2007. Lean six sigma for manufacturing and service industries. Jakarta: PT Gramedia Pustaka Utama.

[14] Mehrotra, D., 2001. Six sigma in education. Retrieved March, 13, p.2009.

[15] LeMahieu, P.G., LeMahieu, P.G., Nordstrum, L.E., Nordstrum, L.E., Cudney, E.A. and Cudney, E.A., 2017. Six Sigma in education. Quality Assurance in Education, 25(1), pp.91-108.

[16] Stewart, R.A. and Spencer, C.A., 2006. Six-sigma as a strategy for process improvement on construction projects: a case study. Construction Management and Economics, 24(4), pp.339-348.

[17] Puri, A.K. and Singh, S., Six sigma in project management.