International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Managing and Analyzing Manufacturing Defects – A Case of Refrigerator Liner Manufacturing

Chowdhury, B.[Ȧ*], Deb, S.K.[Ȧ], Das, P.C.[Ḃ]

[Ȧ] Department of Mechanical Engineering, Assam Engineering College, Guwahati, Assam, India.
[Ḃ] Department of Business Administration, Gauhati University, Guwahati Assam, India

Accepted 03 January 2014, Available online 01 February 2014, **Special Issue-2, (February 2014)**

Abstract

Defects obtained during the various phases of manufacturing a product, play a critical role from developing to shaping it to the final one. It may so happen that the list of defects surfacing may be extremely large. In such a case, it is difficult for the organization to address each of these defects as this involve extra resources (man, material, money, machine and time) which in turn, soars up the quality investments. Again, no address to these issues will lead to a poor product eventually leading to the product's failure. So, it is necessary that these defects are well defined, managed and analyzed effectively such that critical defects are filtered out. This helps making the entire defect prevention procedure cost and effort effective. Keeping these points in view, it is important to perform the analysis through multiple approaches and prioritize the defects into critical ones. In this paper an attempt has been made to analyze a list of production defects using multiple defect analyzing approaches and sieve out the exact sources of variations. For this purpose, the defects obtained during the manufacturing of thermoformed refrigerator liners have been taken. Quality improvement approaches like Six Sigma have been used together with statistical tools like FMEA, Test of Hypotheses to perform the analysis.

Keywords: *Production defects, Six Sigma, FMEA, Pareto analysis, Cause –effect analysis.*

1. Introduction

Defects are significant entities that play the major role in improving productivity of a manufacturing organization and thereby reduce the cost of poor quality (COPQ). COPQ depends upon four cost factors - appraisal costs, prevention costs, internal failure costs, and external failure costs (Evans and Lindsay, 2002). But at the end, it is seen that whatever ways COPQ costs are categorized, these all form a part of preventive and predictive quality control models. These quality control models or techniques are essential to detect and categorize defects (Weheba *et al*, 2004).

Defects detected during the design, fabrication, assembly and manufacturing of a product in a product line need to be analyzed effectively and critical to quality defects must be sieved out. This is extremely essential so as to well manage, handle, correct and prevent defects from reoccurring as well as making the entire defect prevention procedure cost and effort effective (ElMekkawy *et al*, 2006). To sieve out the major defects, it is seen from various upcoming literatures that it is extremely important to go for multiple approaches for prioritizing the defects into quality ones. The most commonly used defect analyzing approaches vary from the most common ones such as the Total Quality Management (TQM), Six Sigma, Kaizen, 5 S, Just In Time (JIT), Statistical Process Control (SPC) to non-traditional ones as Failure Mode Effect Analysis (FMEA), Test of Hypotheses and many others (Finlow-Bates *et al*, 2000), (Card, 1998). Whatever type of quality control techniques are deployed, the prime objective of a quality engineer is to look out for and identify the root causes of the problems (Mays *et al*, 1990). Thus effective analysis is essential, otherwise, it is difficult for one to reach at the exact cause of the problem and rectify it. Furthermore, the most vital is that if these are not prioritized and analyzed, they may have adverse effect on the product quality and quality investments.

Many researchers are found to combine the principles of quality improvement approach like Six Sigma with statistical tools so as to effectively analyse manufacturing defects.

Six Sigma concept originally developed and launched by Motorola saw its successful implementation that helped analyzing defects from its root causes to its eradication. Its successful implementation has been benchmarked by General Electric Company, one of the leading process innovators (Handerson *et al*, 2000), (Leopoldo *et al*, 2009).

Six Sigma is adopted for the study because of its powerful adaptability to a situation and commitment towards delivering a dynamic solution (Omar and Mahmoud, 2012), (Braunscheidel *et al* 2011). All processes have variations which subsequently infuse

*Corresponding author: **Chowdhury, B**

defects into products. Six Sigma gathers the information about process variation and dictates upon this variation to identify the critical to quality (CTQ) issues that affect the product significantly (Pyzdek, 2003), (Taghizadegan, 2006). It uses a simple performance improvement model or tool known as **Define-Measure-Analyze-Improve-Control,** or **DMAIC**, used for analyzing and correcting existing products or processes, and **DMADV**, used for creating new products or processes. The methodology provides an atmosphere on the lookout for many CTQ problems through team efforts. CTQ could be a critical process/product result characteristic to quality, or a critical reason to quality characteristic. The former is termed as CTQy, and the latter CTQx (Park, 2003).

The statistical tools like failure mode and effect analysis (FMEA) and Test of Hypotheses help to understand and determine the exact sources of variability. FMEA approach of defect analysis was originally used by US military to assess the wide impact of its system and equipment malfunctions and was later on implemented by manufacturing companies. This is because of FMEA's ability to assess the CTQ defects at the initial stages of manufacturing a product which later help to raise the productivity (Teoh and Keith, 2005). It is a process of risk quantification where the potential modes and causes of failure are evaluated (Mitra, 2000), (Montgomery, 2009). This helps in estimating the volume of risks and requirements that may be associated with a process execution (Crites and Kittinger, 2009). The analysis is a team activity involving cross functional individuals from different departments - the production engineer, operator, project team and quality engineer. The quality engineer performs the FMEA with inputs from the operator and production engineer on each mode of failure (Breyfogle, 2003).

Further, Hypothesis testing helps to regard a defect as a potential one on the basis of its statistical inference (Cipriano, 1995), (Anderson *et al*, 2000). The list of defects obtained from FMEA is claimed through null hypotheses performed on a defined number of samples. The potential defects so obtained from Test of Hypothesis analysis can be relied upon due to its dynamic behavior.

Thus, to deliver a product of the highest caliber, without any defects, there must exist a highly competent problem finding, or rather, defect finding approach. Generally, it is seen that combinations of the above mentioned techniques are mostly used as an effective approach to quality defect detection.

So, in this paper an endeavor has been made to analyze a list of production defects and filter out the critical defects using a series of robust defect analysis techniques. As such, a company manufacturing refrigerators is chosen and the unit which produces the refrigerator liner is selected for the study. The rejection data of refrigerator liners are taken and analyzed using the Six Sigma DMAIC approach. The defects so obtained are prioritized into critical to quality (CTQ) factors that may affect the final product manifold. The CTQx and CTQy parameters are identified. Further analysis is performed with FMEA and Hypotheses testing. Once the potential defects are segregated out by the quality engineer and root causes analyzed, it becomes easier for the production engineer to concentrate, correct and monitor the same.

The paper also discusses in steps how the analysis has been done using different approaches required to identify the CTQs. Data on rejections, their effective management, key process input and output variables are also presented. Insights into the measurement system used for rejections, nature of defects and reasons of their occurrences are also provided to some extent.

2. Methodology

The Six Sigma DMAIC principle is used to identify the CTQ defects. The CTQx are the various reasons for rejection of thermoformed liner and CTQy describes a defective thermoformed liner. So, CTQy is a function of CTQx. The main aim of the paper is to identify the CTQx which directly affect the CTQy from a list of reasons for rejections. The current sigma level is not calculated as it is not the priority of the current research. The study is focused on adopting two phases of Six Sigma. The Define phase and Measure Phase of Six Sigma have been used to define, manage and measure defects. To analyze and identify the potential defects, statistical tools such as FMEA, Test of Hypothesis are applied.

2.1 Defect Definition

This part of the research pertains to the D or Define Phase of Six Sigma - to align the defects against their causes. Defects here mean the huge data of rejected refrigerator liners obtained from ABC refrigerator manufacturing plant. The measurement system that has been adopted for defining the rejections has been validated and discussed by the authors in a research paper (Chowdhury *et al*, 2012).
The liners are produced by the thermoforming process, a small unit in a Refrigerator manufacturing plant. The liners are rejected against a defined checklist (shown in Table 1) that forms the acceptance or rejection criteria for a thermoformed liner. If the liner fails to meet any of the criteria or specifications of the checklist, it is rejected. For any non-conformance to the checklist, there will be wrinkles formed at the groove, corners or undercut area, thinning of the sheet at the corners, formation of lump, bumps and dents, scratches on the sheet. Non-conformance generally occurs due to incomplete or over forming of the sheet, due to incorrect setting of heater temperature, forming temperature etc.

2.2 Defect Measurement

2.2.1 Defect data collection

On the basis of above check sheet, the rejection data have been collected for the quarter January-March 2011. This data is used for the purpose of this research. A sample rejection data collected is shown in Table 2.

As such the following matrix is defined showing the Critical to Quality (CTQy) parameter of the research
Critical to Quality (CTQy): Rejected Thermoformed Liners.

Table 1 Defect definition checklist

Liner quality check points								**Draft**
Date : / /								**Approve**
Check points for important spec and external							**Appearance**	
Position	**Time**	**A**	**B**	**C**	**D**	**E**	**Remarks**	
	Items of Managing and Check							
A	Flange width 15.5 - 17.5 mm							
B	Flange width 15.5 - 17.5 mm							
C	Mid- front forming is OK							
D	Forming of Rails (ribs) for Ref. And Veg. box is OK							
	There is no other substance, flash spot, stripes, black spot							
	Forming of the Total Flange Part is Ok							
	No Thinning of the Flange part							
	There is no other substance or scratch of total Flange part							
	During Trimming no imprint or suppression							
E	No thinning of the Rear Side							
F	No thinning of the Rear Corner Side							
G	No thinning of roof (side, bottom)							
	No thinning of the whole shelf							
	No Wrinkle/Folding of the Shelf							
	Total no. of punching in T/R is Ok							
	No Blisters on the side parts							
	No Folding of the Mid Front							
	No Folding of the rear corner side							

Table 2 Defect data for a month

Date	**Model**	**Total production**	**Total OK**	**Rejection**	**Powder**	**Thinning**	**Trimming**	**Material**	**Wrinkle**	**Forming**	**Others**
01-Mar-11	RT-23	556	522	34	4	13	9	0	4	0	4
	RT-23	766	720	46	0	9	26	0	4	0	7
02-Mar-11	RT-23	449	438	11	3	5	3	0	0	0	0
	RA-18	408	402	6	2	2	2	0	0	0	0
	RA-18	880	874	6	1	2	3	0	0	0	0
03-Mar-11	RA-18	930	928	2	1	0	1	0	0	0	0
	RA-18	1052	1037	15	2	4	5	0	3	1	0
04-Mar-11	RA-18	764	761	3	2	1	2	0	0	6	0
	RT-26	145	128	17	3	9	2	0	3	13	0
	RT-26	1013	948	65	0	41	2	60	0	1	0
05-Mar-11	RT-26	1620	1540	80	7	3	67	2	3	0	0
06-Mar-11	0	0	0	0	0	0	0	0	0	0	0
07-Mar-11	RA-20	2042	2022	20	4	9	3	7	4	0	0
08-Mar-11	RA-18	1093	1087	6	1	3	2	0	0	0	0
	RA-18	927	927	0	0	0	0	0	0	0	0
09-Mar-11	RA-18	1071	984	87	0	42	2	42	33	0	0
	RA-18	1079	1025	54	0	54	0	48	0	10	0
10-Mar-11	RA-18	1008	925	83	0	40	0	87	31	32	5
	RT-23	1205	1085	120	7	53	0	109	4	31	0
11-Mar-11	RT-23	939	875	64	9	23	17	35	2	9	0
	RT-23	1084	1060	24	2	15	0	21	0	11	0

12-Mar-11	RT-31	1240	760	480	0	250	0	0	150	80	0
13-Mar-11	0	0	0	0	0	0	0	0	0	0	0
14-Mar-11	RT-31	1203	1123	80	1	72	26	1	15	30	0
15-Mar-11	RT-31	717	577	140	0	35	1	0	20	20	0
16-Mar-11	RT-23	1519	1438	81	6	3	65	0	4	0	0
	RA-18	530	466	64	0	40	0	64	20	7	0
17-Mar-11	RA-18	1016	919	97	0	95	0	95	10	30	0
	RA-18	1277	1200	77	0	27	0	77	0	12	0
18-Mar-11	RA-18	737	707	30	0	30	0	30	0	11	0
	RT-23	463	433	30	4	3	0	0	2	10	0
19-Mar-11	RT-23	853	838	15	0	10	6	0	0	0	0
	RT-26	198	170	28	0	12	5	0	10	0	0
20-Mar-11	RT-26	398	372	26	0	6	0	26	0	7	0
	RA-20	770	770	0	0	4	0	0	5	9	0
	RA-20	1182	1150	32	0	17	0	5	0	0	10
21-Mar-11	RA-20	309	303	6	2	0	0	0	0	0	4
	RT-31	331	200	131	0	96	0	0	0	35	0
22-Mar-11	RT-34	1391	1129	262	0	36	0	0	116	45	65
23-Mar-11	RT-26	363	338	25		30	5		23	15	0
	RT-26	824	739	85	0	7	0	68	10	20	0
24-Mar-11	RT-26	1181	1150	31	3	11	0	23	4	0	0
	RT-26	955	933	22	1	17	5	0	0	0	9
	RA-20	223	220	3	1	5	0	0	0	0	0
25-Mar-11	RA-20	1286	1278	8	2	2	3	1	0	0	0
	RA-20	1317	1314	3	1	3	0	2	0	0	0
26-Mar-11	RA-20	1093	1090	3	0	3	0	3	0	0	0
	RT-23	942	930	12	3	0	0	0	0	0	9
27-Mar-11	0	0	0	0	0	0	0	0	0	0	0
28-Mar-11	RT-31	1067	980	87	6	22	42	10	7	5	5
29-Mar-11	RT-23	1100	945	155	0	30	25	130	35	39	0
	RA-18	1020	980	40	0	40	5	0	10	11	0
30-Mar-11	RA-18	1225	1100	125	2	32	1	120	17	12	0
	RA-18	1018	1000	18	0	25	0	10	20	34	0
31-Mar-11	RA-18	1214	1210	4		0	1	0	1	1	0
	RA-18	1060	1056	4	0	2	0	0	2	1	0
TOTAL		49053	46106	2947	80	1293	336	1076	572	548	118

Data Type: Defective
Defect Definition: As per the Check Sheet in Table 1
Unit: One Liner (each unit)

2.2.2 Managing the Collected Data

The three months' data that have been collected are analyzed against various causes and accordingly their effects are identified. The fishbone diagram in the figure below (Fig 1) shows the various causes which lead to high rate of liner rejection.

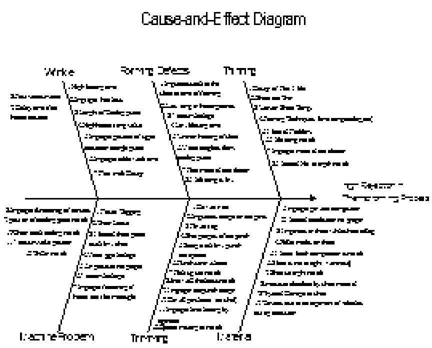

Fig.1 Cause –Effect analysis

2.2.3 Establishing the KPIVs and KPOVs

From the above of cause – effect relationship and rejection data, the cause-effect matrix is established. The cause-effect matrix in Table 3 displays the number of liners rejected due to each cause. The causes thus form the input variables to the thermoforming process, or to be precise the Key Process Input Variables or KPIVs. The KPIVs are responsible for the effects on the rejected liner thus produced. These effects thus form the output variables or Key Process Output Variables or KPOVs.

Table 3 Cause and Effect matrix

Cause and effect Matrix							
Sl. No.	**Customer KPOVs**	Thinning	Forming Defect	Wrinkle	Trimming	Material	Total
		9	9	9	8	7	
	KPIVs						
1	Heating time	9	8	9	9	5	341
2	blowing time	8	9	9	7	6	332
3	Individual heater setting	9	9	9	6	4	319
4	Heating zone Temp.setting	9	9	8	7	4	318
5	Mold Temp.	8	9	8	4	6	299
6	Design of mold/part	9	8	6	7	5	298
7	Vacuum Pressure/Time	7	8	8	6	5	290
8	Table Work Time	7	8	9	5	3	277
9	Thermocouple temp. setting	8	8	7	4	3	260
10	Sheet thickness	9	4	7	7	1	243
11	Improper Heat loss	8	9	8	1	1	240
12	improper Insulation of midfront pad in a chamber	7	8	7	1	1	213
13	cooling bar length and height	7	7	6	3	1	211
14	Air Cooling	6	7	5	2	1	185
15	power tripping	4	7	3	6	1	181
16	chain loose	3	7	8	0	1	169
17	Improper position of upper reduction triangle guide	5	4	8	1	1	168
18	Scratches/marks	0	3	0	9	9	162
19	Chain track cooling	1	8	6	0	1	142
20	trimming die/ punch design	0	0	0	9	9	135
21	impurities on mold/trimming die	0	0	0	9	9	135
22	Water leakage	2	8	2	0	1	115
23	Scrap b/w punch and ejector	0	0	0	9	1	79

The KPIVs are heating time and temperature, sheet thickness, insulation to name a few which strongly impact the factors such as thinning, forming process, wrinkle, trimming and many others. These factors are the KPOVs which need to be improved to reduce the production rate of rejected liners. But solving all the KPOVs is a time consuming and effort taking activity on the part of the manufacturing unit. So, the KPIVs are further analyzed so as to filter out the quality causes which greatly impact the rejection of liners.

2.2.4Pareto Analysis

The cause-effect matrix data for rejection is taken as a basis for further analysis using Pareto Chart. The chart so obtained is shown below in Fig 2.

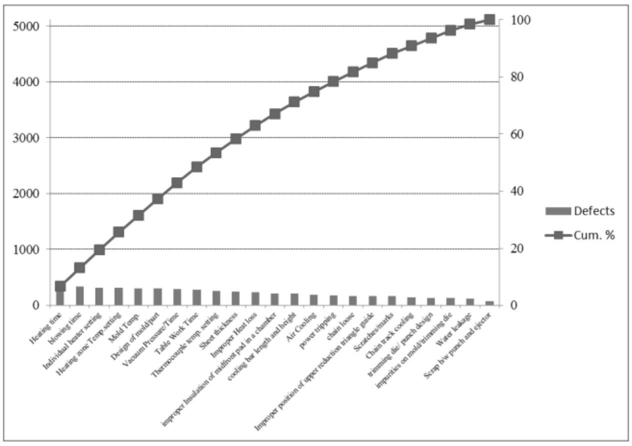

Fig.2 Pareto Chart Analysis for causes

From the Pareto analysis for causes, the causes which contribute to 80% of the problems are focused. These form the potential causes which need to be addressed. Confining the focus on the potential causes through the analysis of Pareto Chart and Cause effect matrix, the critical to quality factors also called potential X's which contributed to liner rejections are:

1) Heating Time
2) Heater Panel Temperature Setting
3) Individual Heater Setting
4) Blowing Time
5) Mold Temperature
6) Vacuum Pressure/Working Time
7) Improper Insulation of Chamber area
8) Sheet Size
9) Thermocouple Temp. setting
10) Cooling bar length and position
11) Chain Track Cooling/ Chain Loose
12) Incorrect Trimming Die Design

These prioritized factors form the potential critical to quality that is CTQx factors on which the CTQy factor depend. However, the list still seems to be an extensive one.

Thus in the Measure Phase of Six Sigma methodology, the rejection data have been collected, managed, measured and an extensive list of critical causes are identified.

2.3 Analysis Using FMEA

The factors, obtained from the Pareto analysis above, being extensive are further analyzed. In this step, the top 80% contributing factors which form the potential causes (potential X's) of liner rejection are analyzed for different failure modes and their effects (FMEA).

Table 4 Failure Mode Effect Analysis (FMEA)

S. No.	Process Function	Potential Failure Mode	Potential Failure Effect	Current Process Control	Potential causes of Failure	Severity	occurrence	Detectability	RPN
1	1st, 2nd, 3rd Heater zone temperature and heating time	High heating Time/Temperature	Wrinkle at the undercut and grooves **area**	Heating time should be properly set i.e; optimal value	Improper (high) setting of heating time	9	10	7	630
				Individual heater setting and heater zone temperature should be properly set	Setting of heater zone 1,2 & 3 at higher side or individual heater setting is high		10	7	630

The FMEA for the each of the above factors which cause rejection is done in the following way:

(i) Failure due to Heating time

i) Root causes are identified - incorrect setting of heater temperature, prolonged heating etc.

ii) Impact/ Effect of Failure – Wrinkle formation or variation in thickness

iii) Risk quantification –

- Severity of the effect (S) – Severity index is 10 (Fatal) to 1 (no effect). The team selected S = 9.
- Frequency of Occurrence (O) – Ranked from 10 (failure is certain) to 1 (unlikely to fail). O = 10 as 1 sheet failed out of every 2.
- Detectability (D) – Ranked from 10 (Not possible to detect) to 1 (detection is certain). D = 7, as it is somewhat difficult to detect before the failure happens.

iv) RPN (Risk priority number) – Varies from 1 (no risk) to 1000 (Maximum risk). So, RPN = S*O*D = 9*10*7 = 630.

The 'Heating time' factor needs immediate corrective action as it has a high RPN. The RPNs for the other failure modes are calculated in the similar method and is tabulated as shown in Table 4 below.

Based on the high RPN of the factors, those contributing to high rejection rate are identified. Thus, on the basis of the FMEA, the modified list of potential X' or CTQx is obtained as follows:

1. X1: Heating Time/Temperature
2. X2: Forming Techniques
3. X3: Mold Temperature
4. X4: Improper Insulation
5. X5: Sheet Size
6. X6: Cooling Time/Temperature
7. X7: Trimming Tool not proper

2.4 Analysis Using Hypotheses Testing

The above list is further analysed for Hypothesis test to find the exact sources of variability which actually contribute to the rejection rate. As such the defect data is mapped with the potential X form that is to say which defect is because of which potential X. The detailed defect data along with the potential X are listed in Table 5 below.

Table 5 Analysis of X1 using Test of Hypothesis

Detailed Defect Data

Date / Defects	1	2	3	4	5	6
Powder	4	6	3	5	7	0
Thinning	22	9	4	51	3	0
Trimming	35	8	6	6	67	0
Wrinkle	8	0	3	3	3	0
Forming	0	0	1	20	0	0
Others	11	0	0	0	0	0
TOTAL	**80**	**23**	**17**	**85**	**80**	**0**

Potential X's

X1.Heating Time/Temperature
X2.Forming Techniques
X3.Mold Temperature
X4.Improper Insulation
X5.Sheet Size/Material
X6.Cooling Time/Temperature
X7.Trimming Tool not ok

Date / Defects	17	18	19	20	21	22	Potential X's X1	X2	X3	X4	X5	X6	X7
Powder	0	4	0	0	2	0	12	10	0	0	58	0	0
Thinning	122	33	22	27	96	36	443	87	44	13	653	53	0
Trimming	0	0	11	0	0	0	46	24	10	0	0	60	196
Wrinkle	10	2	10	5	0	116	127	111	9	187	77	67	0
Forming	42	21	0	16	35	45	79	83	37	34	283	32	0
Others	0	0	0	10	4	65							
TOTAL	**174**	**60**	**43**	**58**	**137**	**262**	**707**	**315**	**100**	**234**	**1071**	**212**	**196**

Each of the above Potential X is analyzed using the Hypothesis test (1-proportion test).

Analysis of X1: Heating Time/Temperature

To perform Hypothesis testing, the team is instructed by the management of the organization to assume a rejection percentage due to each X as 7%. Hence, the Null Hypothesis (H0) is set at 7% and the Alternate Hypothesis (H1) is set at greater than 7% with level of significance as 0.05 for the test. Table 6 below shows the Hypothesis Testing of X1.

Table 6 Hypothesis Testing of X1

Analysis of X1 using Hypothesis (1- proportion test)
Question : Heating Time/Temperature setting affects the quality of Liner or rejection rate of Liner ?
Tool : Hypothesis (1-Proportion Test)
Hypothesis :
H0: P=7% (rejection is equal to 7%) X1 707
H1: P >7% (rejection is greater than 7%) Total 2947
Test and CI for One Proportion
Test of P = 0.07 vs P > 0.07

From the above table, it can be inferred that since p value <0.05, that is, 0.000 therefore the setting of Heating Time / Temperature is an important factor.

Hence, X1 (Heating Time/Temperature) is a Vital X

In a similar way, the other six potential Xs are analyzed using the Hypothesis test. From the test, the list of vital X is established which are actually the sources of variability. From the above analysis the list of vital X or the vital CTQx which contribute to the rejection rate of liner are:

1. Heating Time/Temperature
2. Forming Techniques/Method
3. Improper Insulation
4. Sheet Size/Material
5. Cooling Time/Temperature

3. Conclusions

Rejection data of thermoformed liners was taken and reasons for rejections of thermoformed liners were analyzed and critical to quality ones have been filtered out. The huge data of production defects were collected and measured against a standard checklist. This data is then analyzed using the cause-effect diagram where reasons for rejections were mapped and inter-relationships among these were established.

The causes were further examined which gave way to key process input and output variables and the cause effect matrix is instituted. This matrix showing the key process input and output variables (KPIVs and KPOVs) gave a clear picture of the factors that are responsible for causing the rejections. Pareto analysis helped to prioritize the top 80% of the causes. Thus, the first set of potential causes of failure or the CTQx or potential Xs' were outlined. Heating time and temperature setting, blowing time, mold temperature, vacuum pressure/working time, improper insulation of chamber area, sheet size, thermocouple temp. setting, cooling bar length and position, incorrect trimming and many others have been listed.

But managing all these causes and solving each one would be an immense time and effort consuming activity, which in turn, will shoot up the cost of quality control investments. Hence the research with the aim to find quality defects, had utilized the powers of Six Sigma in defining, measuring and managing the defects. This Six Sigma managed defects were then examined using the tools of statistics – FMEA and Test of Hypotheses.

Using FMEA, each of the CTQx is examined through its Risk Priority Number and the domain of CTQx is further narrowed. The list thus obtained has been extensively analyzed using Hypotheses Testing in which the defect data facts have been mapped with the potential X. This analysis gave the extreme CTQx responsible for variability. Thus heating time/temperature, forming techniques/method, improper insulation, sheet size/material and cooling time/temperature formed the vital CTQx which actually contribute to the rejection of thermoformed liners.

Analysis using other latest quality control tools like Lean, System Dynamics could have been used. Research is going on within the quality team of the organization for intended use of these tools which could make the analysis a more dynamic one leading to some unknown facts.

References

Mays, R.G., Jones, C.L., Holloway, G.J. and Studinski, D.P. (1990), Experiences with defect prevention, *IBM Systems Journal*, Volume: 29, Issue: 1, pp: 4 - 32.

D. N. Card (1998), Learning from our mistakes with defect causal analysis, *IEEE Software*, Jan-Feb 1998.

Evans, J.R. and W.M. Lindsay, (2002), The Management and Control of Quality, *5th edition. Cincinnati*, OH: South-Western College Pub.

Finlow-Bates, T., B. Visser and C. Finlow-Bates (2000), An integrated approach to problem solving: Linking K-T, TQM and RCA to TPM, *TQM Magazine*, 12(4): pp: 284-289.

Weheba, G.S. and Elshennawy, A.K., (2004), A revise model for the cost of quality, *International Journal of Quality and Reliability Management*, 21(3): pp: 291-308.

Chowdhury, B., Deb, S.K. and Das, P.C., (2012), Computer Aided Measurement System Analysis of Attribute Data: A Case of Liner Manufacturing, conference proceedings of *the 4th International & 25th AIMTDR Conference 2012*, Jadavpur University, Vol. II(48), pp: 948-954.

T.Y. ElMekkawy, P.A. Hachkowski, D. Strong, D.D. Mann (2006), Defect analysis for quality and productivity improvements in a manufacturing system, *Canadian Biosystems Engineering, LE GÉNIE DES BIOSYSTÈMES AU CANADA*, Volume 48, pp: 7.9-7.12.

Mitra, A., (2000), Fundamentals of Quality Control and Improvement, *EEE: Pearson Education*, 2nd ed.

Montgomery, D. C., (2009), Statistical Quality Control, A Modern Introduction, *WSE: John Wiley& Sons*, Sixth Edition.

Park, S. H. (2003), Six Sigma for Quality and Productivity Promotion, *Productivity Series 32. Asian Productivity Organization*, e-Book edition.

PYZDEK, T., (2003), The Six sigma Handbook. A Complete Guide for Green Belts, Black Belts, and Managers at All Levels, *McGraw – Hill*, e Book edition.

Taghizadegan, S., (2006), Essentials of Lean Six Sigma, *Elsevier Inc.*, Copyright © 2006.

Omar Rabee'a Mahdi AL-Mfrajia and Mahmoud Khalid Almsafirb (2012), Sustainable Competitive Advantage Using Six Sigma Methodology: Review, *Journal of Modern Marketing Research* 1 (2012) 10-26. ISSN: 2231-9131

Handerson, K.M. and Evans, J.R., (2000), Successful implementation of Six Sigma: Benchmarking General Electric Company, *Benchmarking: An International Journal*, Vol. 7 No. 4, pp. 260-281

Braunscheidel, M. J., Hamister,J. W, Suresh, N. C. and Star, H., (2011), An institutional theory perspective on Six Sigma adoption, *International Journal of Operations & Production Management*, 31(4):423-451.

Crites, J.W. and Kittinger, S.W., (2009), Use of Failure Modes and Effects Analysis (FMEA) Methodology in Evaluation of Process Transfer of Ohmic Liftoff from Low-Pressure-Solvent to High-Pressure-NMP Liftoff , *CS MANTECH Conference*, May 18th-21st, 2009, Tampa, Florida, USA

Teoh, P. C. and Keith Case (2005), An evaluation of failure modes and effects analysis generation method for conceptual design, *Int. J. Computer Integrated Manufacturing*, Vol. 18, No. 4, June 2005, 279 – 293.

Breyfogle, F.W., (2003), Implementing Six Sigma: Smarter Solutions Using Statistical Methods, *John Wiley & Sons, Inc.*, New York, NY, Second Edition.

Leopoldo J. Gutiérrez Gutiérrez, F.J. Lloréns-Montes, Óscar F. Bustinza Sánchez (2009), Six sigma: from a goal-theoretic perspective to shared-vision development, *International Journal of Operations & Production Management*, Vol. 29, Iss: 2, pp.151 - 169.

Cipriano Forza, (1995), The impact of information systems on quality performance: an empirical study, *International Journal of Operations & Production Management*, Vol. 15 Iss: 6, pp.69 – 83.

Pamela Danese, Pietro Romano, (2013), The moderating role of supply network structure on the customer integration-efficiency relationship, *International Journal of Operations & Production Management*, Vol. 33 Iss: 4, pp.372 - 393.

Anderson, D.R., Burnham, K.P. and Thompson, W.L., (2000), Null Hypotheses Testing: Problems, Prevalence and an Alternative, *Journal of Wildlife Management*, 64(4): 912-923.

Norhayati Zakuan and Muhamad Zameri Mat Saman, (2010), The Impact of Six Sigma and TQM on Quality Performance in Manufacturing Industries, conference proceedings of *The 11th Asia Pacific Industrial Engineering and Management Systems Conference and The 14th Asia Pacific Regional Meeting of International Foundation for Production Research,* Melaka, 7 – 10 December 2010.