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Application of Six Sigma Philosophy for Reducing Process Variability: a DMAIC Model

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Abstract

Now-a-day's many leading manufacturing industry have started to practice Six Sigma and Lean manufacturing concepts to boost up their productivity as well as quality of products. In this paper, the Six Sigma approach has been used to reduce process variability of a food processing industry in Bangladesh. DMAIC (Define, Measure, Analyze, Improve, & Control) model has been used to implement the Six Sigma Philosophy. Five phases of the model have been structured step by step respectively. Different tools of Total Quality Management, Statistical Quality Control and Lean Manufacturing concepts likely Quality Function Deployment (QFD), Failure Mode & Effect Analysis (FMEA), Exponentially Weighted Moving Average (EWMA) chart, Multi Criteria Decision Making Technique (Analytical Hierarchy Process), Regression analysis and finally Process Capability Indices have been used in different phases of the DMAIC model. After having practical demonstration in a food manufacturing firm it can be claimed that the paper will make a fruitful impact on advance decision making techniques for reducing different types of industrial wastage.

Keywords: *Six Sigma, DMAIC model, Variation reduction, Lean management.*

1. Introduction

Six Sigma is a systematic data-driven improvement method using cross-functional teams to reduce variation, improve quality, enhance bottom-line balance sheet performance, and improve customer satisfaction [11]. Every process has a mean and a standard deviation. By comparing the process statistics to the specification limits, we estimate a sigma level. A 'sigma level performance' quantifies the relationship between customer specifications and the natural distribution of the process results [6]. As improvements reduce process variation, more standard deviations will fit between the process mean and the specification limit. When Six Sigma performance occurs, 6 process standard deviations will fit between the process mean and any specification limit, and the product measure will fall within specification limits for 99.9997% of samples, resulting in only 3.4 failures per million opportunities, which means this number of occurrences outside the specification limit. In a comparison with traditional 3 sigma level failure number is 66807 per million opportunities. But in Bangladesh the application of Six sigma is inconsiderable yet now. If we see on the production sectors of any kind of industry in this area there shown a huge amount of loses due to higher degree of defects. For this particular work it is focused on a renowned food processing Industry in Bangladesh. If it would be possible to apply six sigma quality control systems, then it could greatly diminish the defects that are generally happened on the production floor. For this reason authors have been interested to work on Lean Six sigma and applied it through DMAIC model in any food processing company in Bangladesh. Pran Agro Limited is one of the renowned food product manufacturers in Bangladesh. Particularly in their ice-pop department the authors noticed four major types of defects which normally occur. Those are leakage, leaving bottles without coding traces, excess/short materials fill up and cap loose sealing.

2. Literature Review

Lean manufacturing and Six Sigma are two very powerful concepts in manufacturing and industrial sectors. They have been applied in various forms and have proven their worth in making businesses more productive

over time. For the last few decades we have seen that there occupied a noticeable work in the field of research & methodological study on the basis of lean six sigma concepts. Some works are based on six sigma philosophies, some are based on lean manufacturing & some are based on combination of this two, called lean six sigma. Hung & Sung [5] in their paper applied six sigma concepts to manufacturing processes in the food industry to reduce quality cost. In their research work they have shown a remarkable change after application of six sigma concerns to their field. Furthermore Kwak and Anbari [9] defined the benefits, obstacles and future of six sigma approaches. In passing years, the manufacturing industry has successfully applied the six sigma methodologies to numerous projects. However, due to insufficient data or a misunderstanding of the six sigma methodology, some of the project failed. Besides this, Khalil et.al [7] in their paper captured some of the key concepts in Lean Six Sigma initiatives and how industries were utilizing it to lower production costs while maintaining high quality and speed. In addition of that Ditahardiyani et.al [3] put forward the six sigma methodology and its implementation in a primer packaging process of Cranberry drink. DMAIC approaches have used to analyze and to improve the primer packaging process, which have high variability and defects output. Apart from this, Hekmatpanah et.al [4] in their works they surveyed the six sigma process and its impacts on the organizational productivity. He emphasized on the key concepts, problem solving processes as well as the survey of important fields such as; DMAIC, six sigma, productivity applied program and other advantages of six sigma. There are lots of papers or works on Lean six sigma methodology in the history of literature. The very latest trend in these fields is to combine the techniques and tools from these two methodologies into a new format called “Lean Six Sigma” to improve productivity, quality, and speed. In this paper lean six sigma methodologies have been implemented through DMAIC model in a food processing industry in Bangladesh to reduce process variation. The difference of this work from the others is in terms of tools used in conducting this work and its perspectives. At the primary section of this paper six sigma & lean concepts have introduced with some relevant literature reviews. Then in the later portion all the calculations and analysis for DMAIC model have been discussed. After which some recommendations for the manufacturer and for future works have provided. At last an informative conclusion is drawn which is followed by some references.

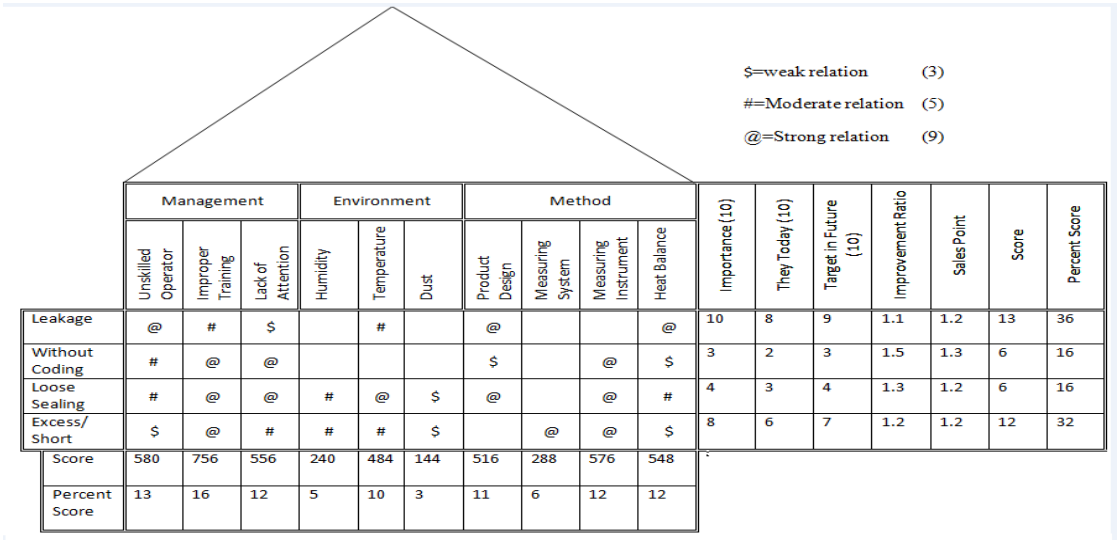
3. Research Methodology

Here in this research work, the authors employed DMAIC model for successful implementation of six sigma philosophy. DMAIC, an acronym for Define, Measure, Analyze, Improve, and Control, is a structured problem-solving procedure widely used in quality and process improvement. In the different Phase of DMAIC model different types of Six sigma tools and lean tools such as Quality Function Deployment (QFD), Exponentially Weighted Moving Average (EWMA), Process Centring Index, Regression analysis, Analytical Hierarchy Process (AHP) and Failure Mode & Effect Analysis (FMEA) were employed. For doing this paper work data were taken from a leading food-product manufacturing company in Bangladesh named Pran Agro Ltd. Among various departments of this industry Ice-pop department and their products had been chosen for collecting data. A total of 26 working days data were collected from the quality assurance department. After doing that the authors targeted four types of defects named leakage, leaving bottles without coding, loose sealing, and Short/Excess material filled up.

4. Implementation of DMAIC Model

4.1 Define Phase

The Define phase of a six Sigma DMAIC model is used to identify the product quality characteristics which are critical to customer [2]. For this particular work the authors use a Quality Function Deployment (QFD) structure to indicate the relationship between the defects and the factors that affect these defects.



	Management			Environment			Method				Importance (10)	They Today (10)	Target in Future (10)	Improvement Ratio	Sales Point	Score	Percent Score
	Unskilled Operator	Improper Training	Lack of Attention	Humidity	Temperature	Dust	Product Design	Measuring System	Measuring Instrument	Heat Balance							
Leakage	@	#	$		#		@			@	10	8	9	1.1	1.2	13	36
Without Coding	#	@	@				$		@	$	3	2	3	1.5	1.3	6	16
Loose Sealing	#	@	@	#	@	$	@		@	#	4	3	4	1.3	1.2	6	16
Excess/ Short	$	@	#	#	#	$		@	@	$	8	6	7	1.2	1.2	12	32
Score	580	756	556	240	484	144	516	288	576	548							
Percent Score	13	16	12	5	10	3	11	6	12	12							

Fig 1: QFD model showing the relationship between defects and possible causes

The alternative tools for define phase were SIPOC (supplier, Input, Process, Output, Customer) analysis, Voice of customer analysis etc. In spite of having these ones QFD is chosen because QFD clearly shows the relationship as a tabular form. In the diagram it is seen that unskilled operator & improper training has the highest score. Here importance means is the numbering the defects among 10.

4.2 Measure Phase

In this phase, the measure contains the identification of appearance problems up to each some performance situation [1]. For this research work authors chose to drive this step by the exponentially weighted moving average (EWMA) control chart. Process control charts are chronological graphs of process data that are used to help understand, control, and improve processes – such as infection control or adverse event processes – and that, although based in statistical theory, are easy for practitioners to use and interpret [1]. The EWMA is a statistic for monitoring the process that averages the data in a way that gives less and less weight to data as they are further removed in time. Using the 'QI Macros 2013' extension of 'Microsoft Office Excel 2007' EWMA chart was drawn (shown in fig 2) on experimental data founded in that concerned company floor.

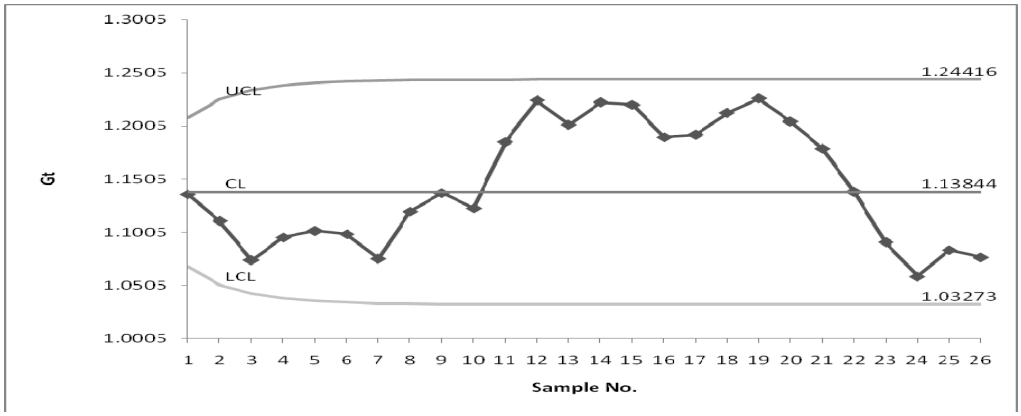


Fig 2: EWMA Curve (using QI Macros)

4.3 Analysis Phase

The analyze phase involves identifying input and output variables that affect each Critical to Customers (CTQs). Three tools named Process Performance Indices, Multi criteria decision making (MCDM) techniques &

Regression analysis have been used to analyze the defects for this research work. At this stage other usable tools are Pareto analysis, Cause-effect diagram, Flow diagram, ANOVA & Brainstorming.

4.3.1 Process Performance Indices

Here in Table 1 summarized on different process performance measuring tools based on statistical quality control concepts.

Table 1: Summary on different Problem relevant Process Performance measures

Problems	Process Potential Index (C_p)	Process Performance Index (C_{pk})	Process Centring Index (K)	Remarks
Leakage	0.5396	0.3736	0.3077	Process is not capable. i,e. $C_p < 1$
Without Coding	0.5311	0.4903	0.0769	Process is not capable. i,e. $C_p < 1$
Loose Sealing	0.5396	0.3736	0.3077	Process is not capable. i,e. $C_p < 1$
Excess/Short Material	0.336	0.2584	0.2308	Process is not capable. i,e. $C_p < 1$

4.3.2 Regression Analysis

The study also uses the simple linear regression relationship between the dependent variable Leakage problem and the independent variables like without coding problem, loose sealing problem & excess/short materials as shown is table 2. These relationships help the manufacturer to find out the Leakage problem very easily.

Table 2 The relationship between Leakage & different independent variables

Dependent variables (Y)	Independent variables (X)	Linear equation
Leakage Problem	Without Coding	Y= 7.294X – 5.47
Leakage Problem	Loose sealing	Y= 27.462X-16.6302
Leakage Problem	Excess/short materials	Y= 243.313X-91.184

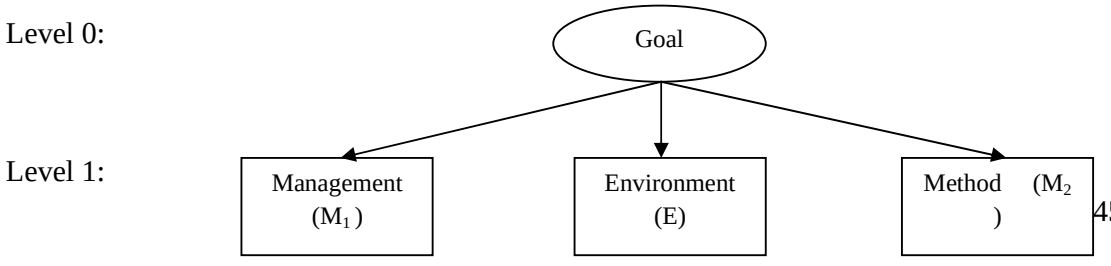
Table 3 The overall relationship with Leakage & others

Dependent variables (Y)	Independent variables (X)		
Leakage (Y)	Without Coding (X_1)	Loose Sealing (X_2)	Excess/Short material (X_3)
Overall Relationship	$Y = 0.902 + 0.801X_1 + 0.796X_2 + 0.181X_3$		

Table 2 and 3 illustrates the regression analysis along with the relationships among different quality parameters. Here by using the derived overall relationship as shown in table 3, the relevant personnel could easily find out the actual scenario for future surmise

4.3.3 Analytical Hierarchy Process

The AHP is a measurement method for determining the relative importance or preference of a set of activities in a multiple criteria decision-making (MCDM) problem. It is a systematic approach for selecting alternatives. Based on mathematics and human psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. Analytical Hierarchical Process (AHP) is a decision-making method for prioritizing alternatives when multiple criteria must be considered and allows the decision maker to structure complex problems in the form of a hierarchy, or a set of integrated levels.



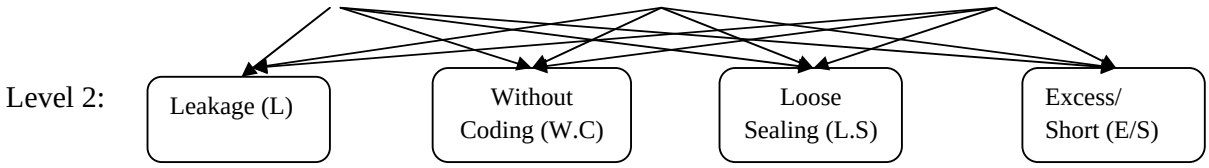


Fig 3: Proposed AHP Model

Table 4: Level of preference weights for AHP model

Level of preference	Definition	Explanation
1	Equally preferred	Two activity contribute equally to the objective
2	Moderately	Experience and judgment slightly favour one activity over another
3	Strong Importance	Experience and judgment strongly or essentially favour one activity over another
4	Extreme Importance	The evidence favouring one activity over another is of the highest degree possible of affirmation
Reciprocals	Reciprocals for inverse comparison	

Table 5: Average Random Index (RI) based on matrix size (adapted by Saaty)

N	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 6: Final Evaluation under AHP approach

Attribute	Attribute & their weight			Composite Weight	Final Ranking
	Management (0.56)	Environment (0.12)	Method (0.32)		
Leakage	0.55	0.146	0.16	0.377	2
Without Coding	0.08	0.12	0.07	0.012	4
Loose Sealing	0.13	0.27	0.16	0.156	3
Excess/Short	0.24	0.48	0.61	0.387	1

Here the important information is being given in tables 4, 5 & 6. For successful implementation of AHP techniques, the authors employed the level of preference as in table 5. Then by using the random indices from table 5, the authors concluded the results in table 6. From table 6, it is clear that Excess/Short materials problem for each cant is the main culprit which is followed by leakage problem, loose sealing problem & finally without coding problem sequentially.

4.4 Improvement Phase

The improve phase deals with the activity related to the improvement of the project. Many types of tools can be used for this phase. The goal of this phase is to improve the process to bring it to the performance goal. While this phase involves experiments, often several experiments - it allows discovery and testing of an improved process. For this research work, the tool used is Failure Mode & Effect Analysis (FMEA).

No	Function	Failure	Effects	Sensitivity Rating, S	Causes	
1	Damage on the Products	Leakage	Manage 3-5 more cans to damage with the marked one	4	Product design, Improper training, Heat balance, Temperature & Unskilled operator	
2		Without Coding	Coding isn't done well on few times, so at that time operation should be retaken	2	Measuring instruments	
3		Loose Sealing	Sealing on the cap of the bottle isn't done properly & some of them are damaged after few days	3	Controlling of environmental factors & attention of workers	
4		Excess/ Short	Goodwill are damaged gradually; Company can face loss	5	Attitude of worker; Training of worker; Measuring instruments	
Occurrence Rating, O	**Detection, D**	**Critical Characteristics**	**Current Condition**	**RPN (Risk Priority Number) = S×D×O**	**Recommended Action**	**Action Taken**
4	3	Y	Product is not well designed, Improper training is provided to the worker	5×3×3= 45	Product should be well designed; Proper training should be provided to the worker.	Both are taken
3	1	N	Measuring instruments are insufficient	2×1×1=4	Modern instruments should be provided	New budget for latest instrument is already taken.
2	2	N	Controlling system of environmental factors isn't very good & lacking in the attention of customers	3×1×2=6	Analytical meters should be replaced by digital meters at various environment related factors.	Analytical meters are replaced by digital meters.
1	5	Y	Lack of attention of workers; Measuring instruments are not well calibrated	4×1×5= 20	Workers should be brainstormed & measuring instruments should be calibrated in the shortest possible time.	Different brainstorming procedures of the workers are undertaken.

Fig 4: Schematic View of targeted Failure Mode & Effect Analysis chart

4.5 Control Phase

The objective of this step is the control the burning issues found from the analysis phase and to maintain or implement proper supervision environment for new improved process. The controlling process could be done based on the experiments of EWMA & FMEA. But, the most important thing for this stage is that to make proper inspection & taking necessary steps. Implementation plan, Process control plan, Standard operating procedures, Communication plan & other up to date tools may be usable to control the process variation.

5. Conclusion & Future Works

The key objective of this study was to reduce process variability by applying Six Sigma philosophy through DMAIC model.The reduction of process variations is a continuous process. To achieve the Six Sigma level for any manufacturing firm is a laborious & time consuming task. Lean and Six Sigma both have been implemented as integrated form in this study to obtain better results and support to each others. The major outcomes of this research work are to reduce cost, reduce time, maximize profits & quality of the products and also increase customer satisfaction. In this study, various Six Sigma and Lean tools such as Failure Mode & Effect Analysis (FMEA), Regression analysis, Quality Function Deployment (QFD), Exponentially Weighted Moving Average chart (EWMA) and also AHP technique of MCDM approach have been used. Other techniques of MCDM approach such as Grey relational analysis (GRA), fuzzy sets may be applied here. Data have been taken over one month only. If more data was taken it would give more precise results. Here only defective items and their causes have been described and have tried to overcome these. Other type of waste such as motion, inventory,

transportation etc. also can be solved by this technique. Value process map can be used for the purpose of identification the activity which does not add value. Non value added activity will need to be identified to apply 5S philosophy or elimination of other type of defects. But here non value added activity have not identified although 5S tools have been suggested to evaluate the work place area. The application of Lean Six sigma in the service sectors in Bangladesh is inconsiderable yet now. So there should some steps to implement this philosophy.

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