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REDUCING PROCESS VARIABILITY BY USING DMAIC MODEL: A CASE STUDY IN BANGLADESH

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, P Control chart, Fish-bone diagram, Analytical Hierarchy Process, Pareto analysis have been used in different phases of the DMAIC model. The process variability have been tried to reduce by identify the root cause of defects and reducing it. The ultimate goal of this study is to make the process lean and increase the level of sigma.*

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

1. Introduction

Six Sigma management is the philosophy of reducing variation in all critical process to achieve continuous and breakthrough improvements. Lean manufacturing seeks to provide optimal quality by eliminating waste. Lean Six Sigma is the combination of both. Lean manufacturing and Six Sigma are powerful philosophies baked by several tools for improving quality, productivity, profitability and market competitiveness for any corporation in a holistic manner (Cudney *et al*., 2006). In the competitive environment, the fundamental goals of the company are to survive in the market and for the long term. Productivity should be evaluated as one of the most important indicators of the business performance. Product quality is now measured by the level of error in the millions. To achieve these strict quality levels, the whole system starting from the design step should be constructed such that it can produce right at first time. Six Sigma provides an integrated improvement approach that increases quality by reducing variation, defects. Six sigma focuses on quality rather than speed, where speed up can be resolved by Lean management. Six sigma has been implemented by Motorola in the early in 1980s and Lean manufacturing has emerged towards the end of the 1990s. It has become so popular methods and become prevalent in all business areas over time. There are lot of works on six sigma and Lean management and combination of both. In the modern

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competitive market product performance is being measured in terms of defect level per million opportunities. In six sigma quality control the numbers of defective products per billion opportunities are only 2, when mean does not shift. It is very few amounts as compared with traditional three sigma quality control system. But in Bangladesh the application of Six sigma is inconsiderable yet now. There are huge amount of loses due to higher degree of defects in the food processing industry in Bangladesh. If it would be possible to apply six sigma quality control systems, then both the company's benefits and customer's satisfaction would increase. For this reason authors have been motivated to work on Lean Six sigma and applied it through DMAIC model in any food processing company in Bangladesh. Pran Agro Limited (PAL) is one of the renowned food product manufacturers in Bangladesh. Particularly in their ice-pop department the authors noticed five major types of defects which normally occur. Those are leakage, presence of black particle, leaving bottles without coding, excess/short materials fill up and cap loose. Alarming to see that the process mean's spread of the products was far away from the mean in both sides. To reduce this spread of the process, the process needs to be improved. That is why the authors emphasized on that department only.

2. Literature review

For the last one decade's history in the literature, a number of academic terms has found about these methodologies. O'Neil and Duvall (2003) in their works they have focused on post occupancy evaluation (POE) research method and discussed about the application of six sigma quality frameworks. They have used POE to create and manage the optimal space for the office workers. The team began to process of tracking these data using Minitab, which contain six sigma quality tools- such as control chart. Does and Koning (2006) explained the uses of lean six sigma concepts in a hospital to provide the healthcare facilities to the patients at a lowest possible cost and time. They had tried to reduce the waiting time of the patients which is perhaps one of the most important quality indicators from the perspective of their patients in healthcare. Meanwhile Kwak and Anbari (2006) have identified the benefits, obstacles and future of six sigma approaches. In recent 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. Moreover Chang and Wang (2007) explained six sigma methodologies as a method that can lead to a continuous decrease in process variance. In their work they applied six sigma methodologies and proposed a continuous improvement model on different phases of collaborative planning, together with forecasting and replenishment (CPFR). Ditahardiyani *et.al* (2008) has presented 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. In addition of that Hekmatpanah *et.al* (2008) in their works they surveyed the six sigma process and its impacts on the organizational productivity. They 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. Again Chakravorty (2009) provided a model to effectively guide the implementation of six sigma philosophies for reducing variation or waste from the operation. At the same time Yang and Hsieh (2009) suggested that six sigma philosophies is a tactical tool in achieving operational excellence. Barac *et al.* (2010) have applied Lean six sigma methodologies in supply chain management in manufacturing products. They have tried to eliminate non-value added process and waste in terms of time, cost or inventory. Waste reduction and the removal of unnecessary process can save companies millions of dollars a year. Getting the right product at the right price, at the right time to the end customer is not only key to the success of companies in competitive markets, but also the key to their survival. Six sigma focuses on quality more than speed. Lean management removes the weakness of six sigma by speeding the processes. The Lean six sigma methodology developed by using these two techniques together. The goal of application is making process Lean and increasing the Level of sigma. Implementation studies can be carried out in service and public sectors where Lean six sigma practices are rather inconsiderable (Atmaca and Girenes, 2011). Johannsen *et al.* (2011) in their work they aimed to systematically identify key problems of the six sigma application in service and to assign them to the DMAIC phases to determine the exact moment of their beginning. DMAIC (define measure, analyze, improve and control) method in six sigma is often described as an approach for problem solving. DMAIC is applicable to empirical problems ranging from well-structured to semi-structured, but not to ill-structured problems or pluralistic messes of subjective problems. The advantage of such methods is that they are very versatile. Mast and Lokkerbol (2012) has highlighted the characteristics of the DMAIC approach and its limitation, specifically from problem solving perspectives.

There are lots of papers or works on Lean six sigma methodology in the history of literature. 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. Here Lean tools have been suggested to reduce the defective items and reworks and Six sigma tools like control chart, fish-bone diagram, Pareto analysis etc have been used to analyze and determine what have to be controlled. The structure of this paper has been organized in following manners. In the first 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. Finally a limpid & informative conclusion is drawn which is followed by some references.

3. Research methodology

The methodological frameworks which have been used for the subsequent empirical analysis is presented here. After conducting a literature review, the core of the research work was to collect relevant data. Prior to visit any company a detailed questionnaire was developed with the aim of finding out how many defects and reworks were being occurred regularly and what caution they normally follow to reduce them. The data has been taken in two ways. At first field questionnaire was conducted from the operators or workers and then statistical records were collected from the quality control department. The study also included direct observation which has given in-depth knowledge. After the data collection, calculations and analysis have been done according to the DMAIC approach. In the different Phase of DMAIC model different types of Six sigma tools and lean tools such as QFD, control chart, Fish-bone diagram, Pareto analysis and Analytical hierarchy process were employed. After defining the problem and observing situation in control chart, the defects which is about 80% responsible for the variation of the process has been identified. Then the root causes of these defects were identified in the analysis phase by using cause effect diagram, after which some guidelines were placed to improve the condition with implementing some Lean and TQM tools.

4. Results & results analysis

For doing this paper work data were taken from a leading food-product manufacturing company in Bangladesh named Pran Agro Ltd. Some of their major departments are Jam-Jelly, Spice, Choco-bean, Ice-pop, Plastic, Mango juice etc. Among them ice-pop department had been chosen and their products for collecting data. In this department all product are being produced in the same procedure with different shape, color, and flavor. There were three flavored and those are Mango, orange and litchi. Collected Data were dominantly focused on to the quality characteristics of the product such as what types of defects normally occur, how frequently they occur, what is the reason behind these, what procedure they follow etc? A total of 26 working days data were collected from the quality assurance department. In doing so the authors targeted five types of defects named leakage, presence of black particles, leaving bottles without coding, loose sealing, and Short/Excess material filled up. Since the objective of this paper work was to minimize the process variations the authors employed the DMAIC model. Here in the following sections all phases are described accordingly.

4.1 Define phase

The Define phase of a six Sigma DMAIC model is used to identify the product quality characteristics which is critical to customer (called CTQs). In this work the authors create a Quality Function Deployment (QFD) structure to identify the relationship between the defects and the factors that affect these defects, which is somehow quite different than traditional models.

	Unskilled operator	Raw material	Heat balance	M/C setup	Dust	Noise	Lack of attention	Measuring accuracy	Importance(10)	Today(10)	Target in future(10)	Improvement ratio	Sales point	Scores	Percent score (100)
Leakage	3	1	9	3	1		1		10	8	9	1.1	1.2	13	28
Black particle		3		3	9		3		8	6	7	1.2	1.1	11	24
Without coding	3			9		1	3		4	2	3	1.5	1.3	8	17
Loose sealing	1					3	3	9	3	3	4	1.3	1.2	5	11
Short/Excess	1					1	9	3	6	4	5	1.2	1.2	9	20
Score(Sum∑1664)	166	100	252	309	244	70	364	159							
Percent score(100)	10	6	15	19	15	4	22	10							

Figure 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. QFD clearly shows the relationship as a tabular form and that's why the authors were akin to choose it. In the diagram it is seen that lack of worker's attention has the highest score. Here importance means is the numbering the defects among 10. Here in figure 1 the used symbols 1, 3 and 9 represents weak relation, moderate relation and strong relation respectively.

4.2 Measure phase

In the measure phase of DMAIC model, the primary purpose is to measure how frequently each & every defects occur & to decide whether the production process is going out of control or not. Since the prior signal about the possible out of control situation may be obtained through the control chart. So this chart can be acted as a diagnostics of the possible out of control state of the process. The process which is in control situation is considered as a stable process and the process which is out of control situation is considered as an unstable process. When the out of control situation is observed in the control chart then it is up to the operators, engineers or management of the process to find out which reason behind this out of control situation and trying to solve that. Here to measure the amount of data which are out of control limits, P type control chart is used. Since the data is attribute type (table 1) which means conforming or non-conforming type that's why P chart is mostly auspicious. There also some other types of attribute charts likes c, np, u chart but c chart follows Poisson distribution and in np chart population's fraction non-conforming data need to know. That is why the authors can claim that P chart (Figure 2) is mostly suitable here.

Table 1. Number of non-conforming pieces from 26 days with sample size n=810 pieces

Sample no (day)	No of abnormalities	Fraction non conforming	Sample no (day)	No of abnormalities	Fraction non conforming
1	5	0.0061	14	9	0.0111
2	4	0.0049	15	6	0.0074
3	6	0.0074	16	5	0.0061
4	9	0.0111	17	7	0.0086
5	3	0.0037	18	12	0.0148
6	6	0.0074	19	5	0.0061
7	4	0.0049	20	3	0.0037
8	11	0.0135	21	4	0.0049
9	6	0.0074	22	6	0.0074
10	3	0.0037	23	3	0.0037
11	5	0.0061	24	5	0.0061
12	6	0.0074	25	7	0.0086
13	4	0.0049	26	4	0.0049

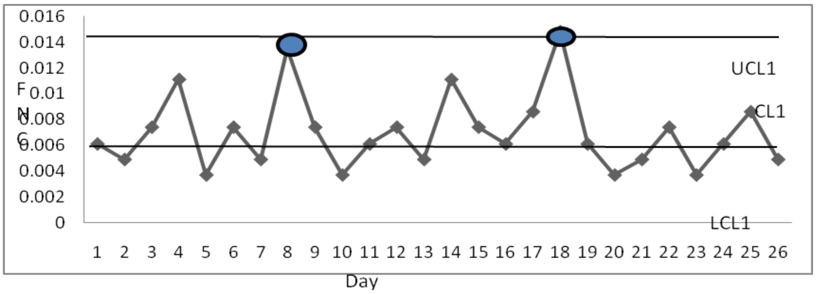

Figure 2. P (fraction nonconforming) chart

For constructing this P chart the authors assume p is the fraction non-conforming. Then (1 - p) is fraction conforming. Mean fraction non-conforming for the data of table 4.1 is 0.00699. Since population fraction non-conforming is not known, the p value can be used to calculate the upper and lower control limits.

$$UCL_1 = p + 3\sqrt{\frac{p(1-p)}{n}} = 0.0157\,;$$

$CL_1 = p$ = 0.00699 and

$$LCL_1 = p - 3\sqrt{\frac{p(1-p)}{n}} = -0.00179 = 0$$

The LCL is a negative value, which is infeasible, because fraction non-conforming cannot be negative; this is why it is taken as zero. The control limits were drawn in figure 2, and subsequently 26 fraction non-conforming values were plotted. It is evident in the figure that the sample no. 8 and 18 are out or nearer to the upper control limit. So there might have some specific reason behind this and investigation needed to identify.

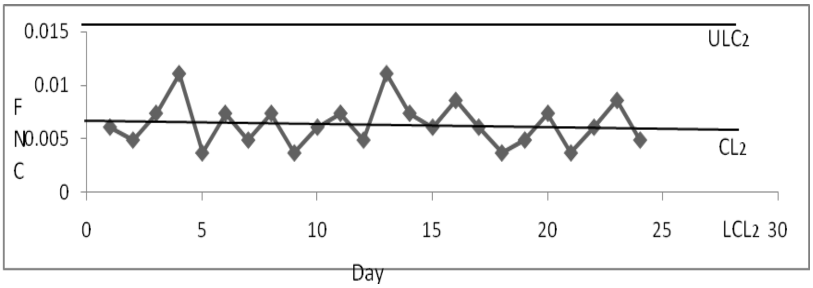

Figure 3. P chart after neglecting two points

After consulting with QC department it was found that bad weather like storm was caused for excessive black particles on those two days. So it can be neglected. After neglecting those two data mean fraction non-conforming for the data of table 1 is 0.0064 and the modified control limit becomes

$$UCL_2 = p + 3\sqrt{\frac{p(1-p)}{n}} = 0.0148\,;$$

$CL_2 = p$ = 0.0064 and

$$LCL_2 = p - 3\sqrt{\frac{p(1-p)}{n}} = -0.0084 = 0$$

Then the revised control limits were plotted in another P chart shown in figure 3. This shows all data are randomly distributed within the control limits. Data number 4 & 13 is nearest points to the upper control limits. Further investigation was needed to identify the root cause for these points.

4.3 Analysis phase

The analyze phase involves identifying input and output variables that affect each Critical to Customers (CTQs) using process map or flowchart, creating a cause-effect-diagram to understand the relationship between the CTQs. In this phase normally finding out of critical work or major problems which are responsible to the large part of the problem is identified. Three tools named cause-effect diagram, Pareto chart, Multi criteria decision making (MCDM) techniques have used to analyze the defects.

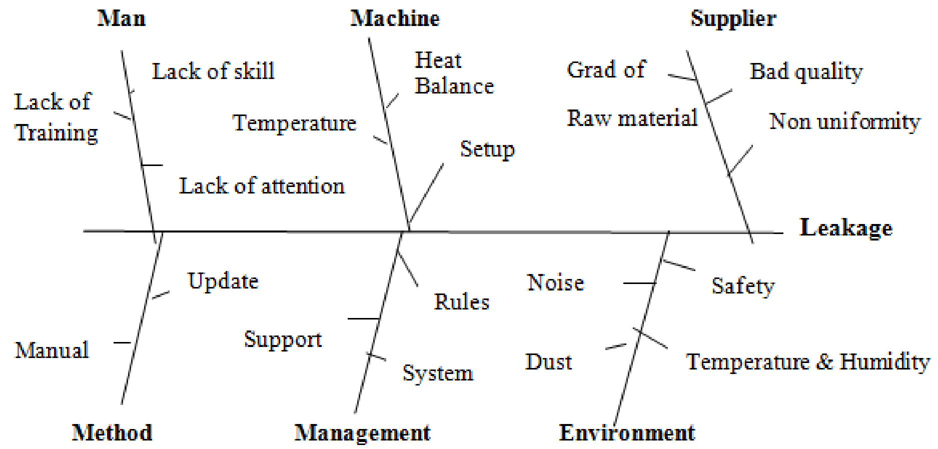

Figure 4. Cause-effect diagrams for leakage

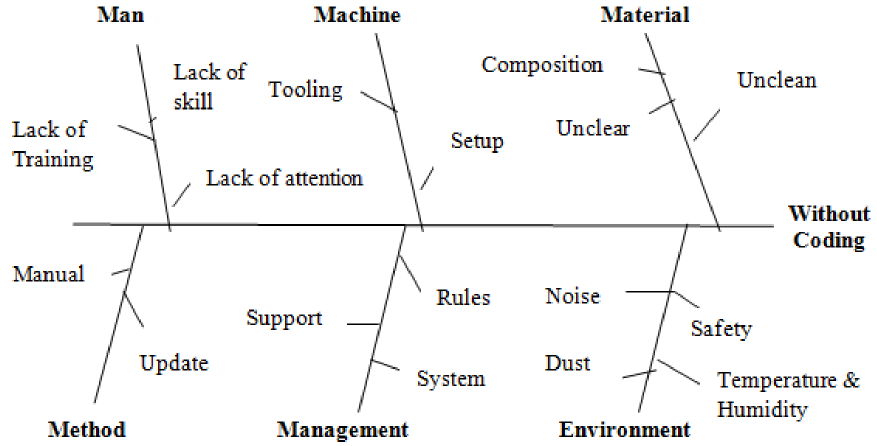

Figure 5. Cause-effect diagram for without coding

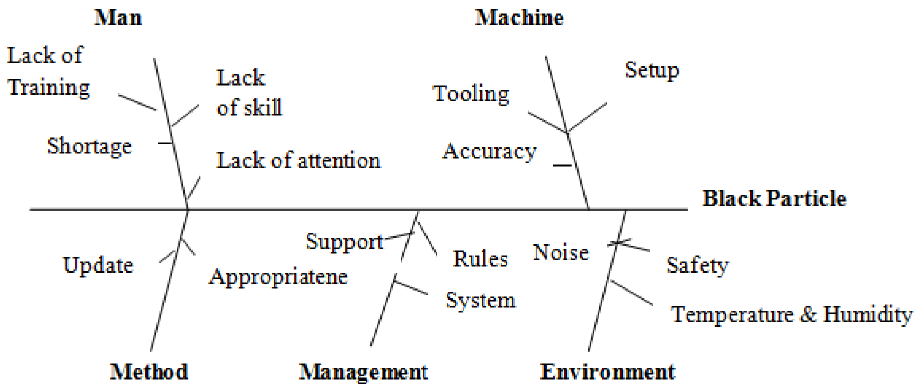

Figure 6. Cause-effect diagrams for black particle

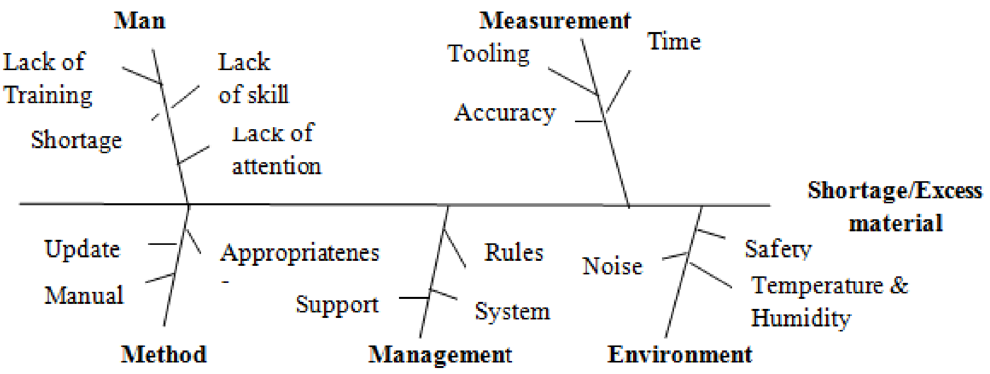

Figure 7. Cause-effect diagram for shortage/excess material

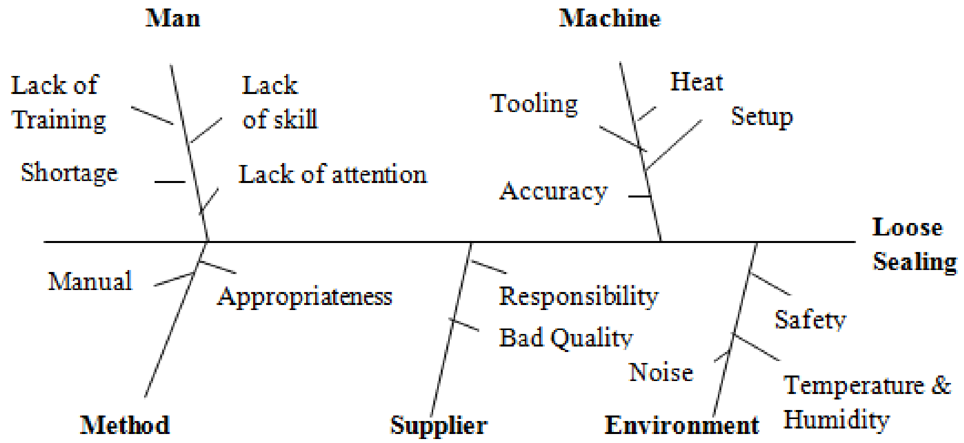

Figure 8. Cause-effect diagram for loose sealing

There are many other alternatives like Failure Mode & Effect Analysis (FMEA), process capability index, Run chart etc. Nevertheless the authors here used C-E diagram, Analytic Hierarchy Process (AHP) as a branch of MCDM and Pareto chart. Relevant concise information is depicts in the following section. Similarly all cause-effect diagram possible causes have been divided into some major factors by brainstorming data. Then also some specific factors related to those major factors have been identified. Furthermore the authors also drawn a Pareto chart to identify the vital few & trivial many. The background reasons were to emphasize on the potential culprits to minimize process variations. All the defect categories are summarized in table 2 and drawn in figure 9. From the figure leakage & presence of black particles are the vital few which contribute around 83% of total defective items & others three are the trivial many which are not in alarming stage at all.

Table 2. Different types of defects percentage

Defect	Num. of abnormalities	Frequency(percentage)
Leakage	31	48
Black particle	22	35
Without coding	05	8
Cap loose	04	6
Short/Excess	02	3

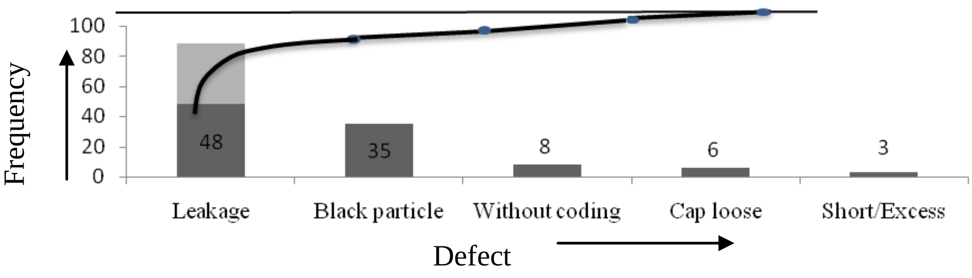

Figure 9. Pareto Chart

4.3.1 Analytic Hierarchy Process

At the final stage of analysis phase the authors employed AHP techniques to reinforce the decision regarding vital few. Here the secondary reason behind using this AHP technique was to prioritize the defect levels & to provide some guidelines to the manufacturer about which defect area should considered first. The Analytic Hierarchy Process (AHP) is systematic approach for selecting alternatives. People deal with complex decisions- rather than prescribing a "correct decision", the AHP helps people to determine one. 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.

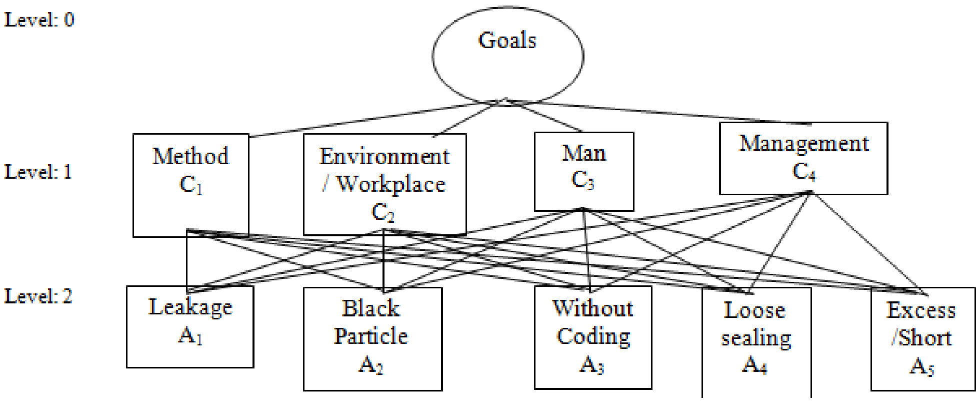

Figure 10. Proposed AHP model

Table 3. 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 favor one activity over another
3	Strong Importance	Experience and judgment strongly or essentially favor one activity over another
4	Extreme Importance	The evidence favoring one activity over another is of the highest degree possible of affirmation
Reciprocals	Reciprocals for inverse comparison	

According the Figure 10 where all the concerned hierarchy is shown, the authors developed some mathematical calculations here to build up the relationship among different alternatives or defective criteria and its cause attributes on level 1 & 2 respectively. The evaluation was carried on level 1 first (shown in table 4), where all the four causes of generating defective items were concerned & their respective priority values were put accordingly considering the priority table 3. For all attributes geometric means along with normalized weights were calculated with some developed formulas. Consistency ratios were also calculated by using table 5 from where random index data were taken for respective number of attributes. These authors satisfied with consistency ratio which is lower than 10% since this was cited from the developer Saaty. After than some evaluations on different defective alternatives (leakage, presence of black particles, without coding, loose sealing and excess/short materials) were carried on to find out which defect parameter is mostly vulnerable for process instability & mean shift. For all alternatives separate table were developed considering each & every attributes or criteria separately. Here also geometric means & normalized means were calculated similarly.

Table 4. Evaluation at level 1

Attribute	C_1	C_2	C_3	C_4	Geometric mean	Normalized weight
C_1	1	3	½	4	1.57	0.3298
C_2	1/3	1	1/3	2	0.686	0.144
C_3	2	3	1	3	2.06	0.4313
C_4	¼	½	1/3	1	0.452	0.0949
Sum	3.583	7.5	2.167	10	4.76	

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

At the final stage of analytic hierarchy process a final evaluation table 6 was drawn where in parenthesis normalized weight of each attributes are given according to table 4, the first evaluation table. Here from this table considering different composite weight it is quite evident that presence of Leakage & black particles should be the major concern for removing the process instability & shortening process variations. Conversely excess or short materials in a particular pet bottle are the least vulnerable which totally shows consistent results with Pareto analysis. These results under AHP certainly provide the researchers some ways to prioritize different difficult alternatives.

Table 6. Final Evaluation under AHP approach

Alternative	Attribute & their weight				Composite weight	Rank
	Method (0.3298)	Environment (0.144)	Man (0.431)	Management (0.0949)		
Leakage	0.365	0.26	0.183	0.22	0.258891	1
Black particle	0.275	0.174	0.228	0.18	0.231169	2
Without coding	0.0947	0.167	0.215	0.18	0.165092	4
Cap loose	0.1318	0.226	0.199	0.21	0.182	3
Excess/Short	0.135	0.174	0.173	0.199	0.163	5

4.4 Improve phase

The improve phase deals with the activity related to the improvement of the project. This phase is involved in designing the appropriate experiments to understand the relationships between the CTQs. In the analysis phase it was noticed after employing Pareto analysis and AHP techniques that presence of black particles and leakage are the main problem for shifting the process mean from the desired value & spreading a broader zone. For those reasons, 5S philosophy can be implemented for reducing black particles since work area/ Environment is the main cause for it. Method needs to be updated and operators also need to be trained up to reduce leakage problem. The tubes of ice-pop department from the supplier need to inspect properly because thickness of the tube is one of main factor for leakage. In necessary supplier can be changed.

4.5 Control phase

The final phase of the DMAIC model named control phase which involves avoiding potential problems in CTQ*s* with risk management and mistake proofing, standardizing successful process changes and controlling the critical CTQs, development the process plan and documentation of the process plan. This solution and continuous improvement process must need to maintain over time. For this purpose continuous training schedule for the worker need to setup along with update new standards of documentation (i.e. procedure, work inspection) must be established. In control phase the primary purpose is to control the activity as if it is done according to preplanned.

5. Recommendations and future works

The key objective of this study was to reduce process variability by applying Six Sigma philosophy through DMAIC model. In this study, various Six Sigma and Lean tools such as Pareto analysis, cause-effect diagram, control chart and also AHP technique of MCDM approach, QFD 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. Only p chart have been used to measure the problem, other type likes u, c, np etc also can be applied and use of more than one would more precise results. 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. If there is any relation between the defects to each other or dependency then regression analysis may be used to understand the relationship. 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.

6. Conclusion

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. In this study the authors just emphasized on only the beginning or first iteration of DMAIC model. This iteration need to be continued untill the variation of process reduces up to the desired level of Six sigma approach. Lean and Six Sigma both have been implemented as integrated form in this study to obtain better results and support to each others. Lean Six Sigma can be applied easily in any kind of business areas like service, production, marketing, sales and procurements etc. The major outcomes of this approach are to reduce cost, reduce time, maximize profits, quality of the products and increase customer satisfaction. Although all preventive and corrective actions have defined but until or unless the manufacturers practice these concepts it cannot be claimed that the number of defective items is in decreasing trend. But at least it can be assured that the successful implementation of this management technique must bring huge positive impacts to the organization.

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