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Abstract:	

A holistic approach of quality: A case of UK chocolate manufacturing

Abstract:

Purpose: This research is elucidating quality control theories to reduce variation in chocolate manufacturing process in the UK food company that will help maintain the processes stable and predictable. The main objectives of this research are to reduce defects of the output; to identify the root causes of variation; to establish and implement solutions to this variation problem; and establish a control system to monitor and report any variation in the process.

Methodology: We use experimental case study of a chocolate company to achieve our objective. In this paper, we predominantly use established theory DMAIC (define-measure-analyse-improve-control), customised to the case of the chocolate factory to reduce variations in production processes.

Findings: Our results confirm that customised-traditional theoretical quality models will support manufacturing companies to maintain customer satisfaction while enhancing quality and reliability.

Practical implication: Implementation of customised approach reduced the rate of defect from 8 percent to 3.7 percent. The implications of reduced variation are improved product quality; reprocessing elimination; and a more stable process that support sustainability and reliability in producing chocolates to meet customer needs.

Limitations: We used an experimental based case study approach to test with one company. Testing in multiple case companies may help to generalise results.

Originality: Our research study experimentally tested quality approach with a real case company and hence findings of this study can be applied to other cases working in similar settings.

Key Words: Process variation, defect reduction, quality control, chocolate manufacturing

1. Background of this research

The increasing competitive pressure and customer demands have led companies to focus on new strategies for improving production processes, range of products and product quality in order to satisfy the needs of their customers. As product lines increase, variation in processes also increases. Variation exist in every process and impacts on manufacturers in many different ways ranging from product quality, processing times and product consistency which ultimately affect customer satisfaction (Deming, 1982; Tsikriktsis and Heineke, 2004). Product liability and recall are the main drivers for business losses in the UK and the defective products account for 43% of the value of all claims according to a report from insurer Allianz Global Corporate & Specialty (AGCS). Therefore, it is imperative to reduce variation in the process and produce 'right first time' to avoid losses. There are many approaches for dealing with process variation that have been in existence for years which have found application in various industries. These approaches evolved from Shewhart, Deming and Juran to TQM, DMAIC (define-measure-analyse-improve-control) approach and Six Sigma. However, these are not very specific to any particular company as every company has its own process approach specialised for their product lines. Hence, a specially structured and customised approach is essential for every single product line. Our study focuses mainly on chocolate production, as it is one of the highly consumed food product in every country around the globe and in chocolate confectionery, the quality of the product is paramount for ensuring an enjoyable experience for the consumer (Sundara et al., 2013). As asserted by Sundara et al (2013), the control of the physical processing is crucial for achieving the satisfying snap of a good chocolate and the smoothness in the palate. Therefore, a controlled and tailored process is desirable for the chocolate manufacturers if they are to deliver a quality product that delights their customers.

This paper explores how the case company with relatively high variation in its production process applied a structured and customised DMAIC approach to reduce defective products. This approach can help to reduce defects in the process and thereby improve productivity and on time delivery of products to customers. The main objective of this study is to reduce rate of defects in process output and hence reduce wastes (increase sustainability) and increase the product quality to achieve high level of customer satisfaction. The desired result is a highly controlled process that produces fewer defects,

costs less to operate and allows for an easy identification of out-of-specification products. Improvements in the manufacturing process can help the company save money and resources and benefit the customer through improved quality.

The structure of this article is as follows. Section 2 provides a background literature to support our study. Section 3 provides a clear introduction to the case study and a brief description regarding the case study research methodology. Section 4 illustrates the application of customised DMAIC approach to solve the problem of variation. Section 4.1 indicates the define phase, Section 4.2 details the measure phase with baseline performance. The Analyse phase is explained in Section 4.3 with details of potential causes and its validation followed by the improvement phase in Section 4.4 with details of solutions implemented. Section 4.5 explains the controls introduced to ensure sustainability of the results. Section 5 presents the concluding remarks and discusses the benefits and limitations of the study

2. Literature Review

All processes in quality management exhibit some degree of variation (Deming, 1982). This observed variation in the process output is an accumulation of many different sources that would have occurred throughout the manufacturing process (Hutchinson, 2014). Analysing and acting upon the sources of variation is key for any initiative to improve the process (Rodriguez, 2010). Quality improvement is central to the systems approach thinking on variation reduction (Conti, 2010). Reducing variation requires the identification of key factors affecting the outputs and then establishing controls on these variables to ensure that the outputs conform to established specifications. The traditional approach has always been to buffer the variation through creating excess inventory and excess capacity (Standard and Davis, 1999). However, lean thinking is to reduce the special and common causes of variation and avoid excess inventory and capacity. We will understand process variation and analyse the various through different quality approaches available in the literature.

2.1. Understanding Process Variation

Variation has been studied for decades by different scholars; starting with Walter Shewart in the 1920s when he made his first contribution to the understanding of variation in manufacturing processes. Central to his views was that every process displayed some

degree of variation; a theme backed by other scholars who concur that in every process there can be two types of variation: common cause variation which is naturally present in all processes, and special cause variation, which is sporadic and not present all the times (Deming, 1982). The studies estimate special cause variations to cause 15% of the problems in a process, while common cause variations cause the remaining 85% (Gitlow and Hertz, 1983). Deming (1982) classified variation as a disease that causes waste and poor quality. When a process is not stable, it generates more waste and is unable to consistently produce to customer specifications (Hoerl and Snee, 2012). When special cause variation is eliminated, the process is said to be in a state of statistical control, which provides the stability needed for predicting the nature of future output (Rodriguez, 2010). On the other hand, reducing common cause variation enhances the capability of a manufacturing process to be able to produce products that consistently meet customer expectations. Various scholars have shown that when variation is present in a process the need for buffering excess inventory, excess capacity and excess lead time increases (Standard and Davis, 1999). Current market competition encourages excess inventory due to extended processing times for defective products. Customers expect the deliveries in time hence buffer stocks are kept as a contingency measure. The company buffers variation and uncertainty by investing in inventory to protect itself from variation problems. Understanding and improving quality are key factors that lead to business success, growth and an enhanced competitive position (Mahesh and Prabhuswamy, 2010). However, the scholars that have studied variation are not united behind one effective method of eliminating variation in processes. This problem still exists even in modern factories.

2.2. Analysis of Existing Quality Approaches

Many approaches for improving quality have been in existence for years and have found some application in various industries. The common fibre behind TQM and Six sigma approaches is understanding and reducing variation (Su and Chiu, 2008). Though there has been advances over the last three decades, these approaches still exhibit weaknesses in understanding, reducing and controlling variation in different processes. Some of the methodologies and tools that have been deployed to solve the problem of variation are Six Sigma, Lean Six Sigma, DMAIC (Define, Measure, Analyse, Improve and Control), statistical process control (SPC) and process capability studies.

2.2.1. SIX SIGMA builds on prior approaches of quality management practices and principles (quality control, TQM, zero defects) and offers a new structure for quality improvement (Schroeder et al, 2008). Şenvar and Tozan (2010) asserts that Six Sigma methodology focuses on reducing variation, eliminating nonconforming items and improving the quality of process output and/or services in an organisation. It is data-driven and is defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997% where *sigma* is a term used to represent the variation about the process average. In recent days, six sigma is seen as a quality symbol in have customer satisfaction (Nakhai and Neves, 2009). In Six Sigma there are six standard deviations between the process mean and specification limits, when the process is centred. The six-sigma metric uses defects per million opportunities (DPMO):

$$\text{DPMO} = \frac{\text{total number of defects}}{(\text{Number of units x number of opportunities})}$$

Here, opportunities represent the number of potential chances within a unit for a defect to occur.

Six Sigma methodology uses standard quality tools such as Failure modes and effects analysis (FMEA), cause-effect diagram and statistical process control (Schroeder et al 2008). These tools are used in identifying and eliminating root causes of defects by examining the inputs and outputs of a process. The scholars argue that Six Sigma methodology come with its inherent limitations and as such cannot be regarded as a universal solution for any process in any situation. To enhance its effectiveness, Six Sigma should integrate the human and process elements of process improvement (Cherrafi et al., 2016). The human elements are teamwork, organisation culture and customer focus. On the other hand, the process elements include the understanding of variation types in the process, process capability analysis, and design for experiments (DOE) for identifying and reducing process variation.

2.2.2. LEAN SIX SIGMA have evolved from different paths and combining the two approaches can offer companies various advantages. Lean focuses on eliminating waste from processes and six sigma philosophies are central on reducing variation in the processes (Pojasek, 2003; Hoerl and Snee, 2012). Six Sigma uses statistical tools to establish the root causes for variation, and provides metrics to mark progress. On the other

hand, lean methodologies are used to identify and remove non-value adding activities in the processes. Use of both approaches together leads to continuous improvements in businesses (Pojasek, 2003). Cudney et al., (2006) support the arguments and state that the two approaches are useful tools for improving quality, productivity, profitability and market competitiveness. However, the Lean Six Sigma projects often take relatively long time to complete. In recent years, the food industry has started to apply the lean six sigma methodologies to numerous projects (xx). Due to insufficient data or a misunderstanding of the combined approach, some of the project have failed. This research seeks to use some of the Lean Six Sigma tools and contribute to the knowledge of its application in food manufacturing.

2.2.3. DMAIC (Define, Measure, Analyse, Improve and Control) was developed by Edward Deming in 1950s and involves improving the existing processes by eliminating nonconforming items without changing the fundamental structure of the process. This methodology is often described as a problem-solving method that focuses on identifying the root causes of a problem, reducing or eliminating the causes and sustaining the improvements. Mast and Lokkerbol (2012) has highlighted the characteristics of the DMAIC approach and its limitation, specifically from problem solving perspectives. It is applicable to semi-structured and well-structured, but not to subjective problems. The advantage of this method is its versatility. Table 1 below highlights the different phases of DMAIC methodology and the tools used.

Table 1: DMAIC Phases and tools used

DMAIC Phases	**Tools Used**
D - Define Phase: Define the problem.	
• Define problem by developing a problem statement • Define the goal by developing a goal statement • Define process by developing maps of the process • Identify customers and define their requirements (CTQS)	• Project charter • Process flowchart • SIPOC diagram • Stakeholder analysis • CTQ definitions • Voice of the customer gathering

M – Measure Phase: Measure the process to determine current performance; quantify the problem.	
• Select measure - defect, opportunity, unit and metrics • Create a data collection plan • Ensure the data is reliable • Collect the baseline data • Update project charter • Determine process capability and sigma baseline	• Data collection plan • Benchmarking • Measurement definitions • Value stream map • Process sigma calculation
A – Analyse Phase: Analyse and determine the root cause(s) of the defects.	
• Closely examine the process • Identify value/non-value-added process steps • Brainstorm potential causes of variation • Verify the causes of variation	• Process analysis • Data analysis • Pareto chart • Time series/run chart • Cause and effect/fishbone diagram • 5 whys • Process map review and analysis • Hypothesis testing (continuous and discrete)
I – Improve Phase: Implement and verify solution.	
• Brainstorm potential solutions • Perform design of experiments, a powerful tool to use in this phase (Ahmed, 2013). • Select best solutions • Assess failure modes of potential solutions • Implement the solutions • Measure improvement	• Brainstorming • Mistake proofing • Design of experiments • Impact Effort Matrix • QFD • Failure modes and effects analysis (FMEA) • Simulation software
C - Control Phase: Maintain the solution.	

• Define and validate monitoring and control system • Develop standards and procedures • Implement statistical process control • Ensure the process is being managed and monitored properly • Expand the improved process throughout organisation • Apply new knowledge to other processes in the organisation • Close project, finalize documentation	• Documentation • Response plan • Control charts (variable and attribute) • Cost savings calculations • Control plan

Source: Adapted from Yang and El-Haik (2003, p42-46).

Gijo et al (2011) argue that there has been attempts to solve the problem of variation by using different methodologies, which were unsuccessful. The DMAIC methodology is recommended when the cause of the problem is unclear. We will use the principles of DMAIC methodology and related tools in solving the problem of variation in the process.

2.2.4. STATISTICAL PROCESS CONTROL (SPC) was developed by Shewart in 1920s and is widely used for analysing quality problems and improving process performance (Mahesh and Prabhuswamy, 2010). This technique uses control charts to define the nature and type of variation (Ryan 2011). Control charts are very useful for establishing a baseline of process performance and further used for monitoring the process to show the effects of changes on process performance (Şenvar and Tozan, 2010; Joghee, 2017). The control charts identifies when a change has occurred in the process that results in a process variation. The concept of control charts was introduced by Shewhart in 1924. This conceipt asserted that bringing a process into a state of statistical control and keeping it in a controlled state is necessary for reducing waste and improving quality. The major objective of SPC is to quickly detect the occurrence of special cause variation in the process so that investigation and corrective action can be taken before many non-conforming units are produced. Despite being around for decades and its popularity in many industries, variation problems still exist in processes.

2.2.5. Process capability analysis (PCA) is a prominent technique that is used to determine how well a process meets the defined specification limits (Şenvar and Tozan,

2010). The specification limits (lower specification limit (LSL) and upper specification limits (USL)) are a direct expression of what the customer needs and is willing to pay for (Chen and Tseng 2005). PCA has been widely adopted as a measure of performance to evaluate the ability of a process to meet customer specifications; to establish new specifications or modify existing specifications and for constructing process control charts (English et al 1993; Joghee, 2017). Juran (1991) recognizes that evaluation of process capability is critical for improving process quality. With continuous data, process capability is defined in terms of defects under the process capability curve and outside of the specification limits (Muralidharan, 2015). The process under investigation generates continuous data and therefore the defects can be measured using process capability.

2.3. Quality Improvement Initiatives in Food Industry

Desai et al (2014) argue that the food industry has a strong link to quality improvement practices. The authors cite successful stories of Lean Six Sigma implementation in other industries and have shown potential of continuous quality improvement in the food industry (Kovach and Cho 2011). The authors state the importance of continuous quality improvement in the food industry, focusing on specification, customers' expectations and the variations during manufacturing. Hung and Sung (2011) argues that the firms need to focus on enhancing its operational quality to meet customers' increasingly sophisticated demand for high quality products. Chakrabortty et al. (2013) did some work around reducing process variation in one of the food manufacturing companies in Bangladesh using Six Sigma methodology. Tylutki and Fox (2002) implemented a quality management programme in a dairy farm using DMAIC methodology to improve the feeding system of a dairy farm. However, the implementation of DMAIC methodology in the food industry remains limited.

2.3.1. Tackling Variation in Processes

Although variation is not a new concept, most manufacturers are having challenges in dealing with variation in their processes. The control charts which is widely used for identifying the existence of special cause variation (Rodriguez, 2010) is facing the challenges of the market dynamics which are always changing hence the need for continuous improvement through variation reduction. Deming (1982) highlights the benefits of taking a targeted system view approach to removing variability from the process; stressing the importance of the customers and suppliers in the value chain.

Rodriguez (2010) argues that the key to process knowledge and improvement is identifying and eliminating the sources of variation. Hoerl and Snee (2012) bring the dimension of statistical thinking in variation reduction. The authors assert that the statistical thinking approach is particularly important as it identifies the process with variation, the sources of the variation, and uses data gathered to make decision on how to deal with the variation. Variation can be reduced as much as possible through process monitoring and improvements (Tannock et al., 2007). Hoerl and Snee (2012) recommend a generic framework referred to as SIPOC model, which maps the process from the suppliers, inputs, process, output and customers. This study used process mapping review and analysis to identify all the critical stages of the process with potential sources of variation; a cause-and-effect diagram to identify the root causes of variation; and brainstorming to establish potential solutions and means of controlling and sustaining the improvements. Various other Six Sigma tools such as Pareto analysis, control charts, time series and process capability analysis were employed in this study.

3. Problem description – An experimental case study approach

A detailed literature review helped us to identify the existing approaches for addressing process variation. We plan to test the applicability of process variation reduction in the case of a chocolate company. This particular research is based on experimental case study research with primary data obtained in real time from the researcher's workplace based on a true experiment. Case study was chosen as a research strategy due to its strength in detailed and intensive analysis of a single case—a single process (Bryman and Bell, 2015). Voss et al., (2002) opined that the case study strategy is useful if the aim of the study is to gain a rich understanding of the research perspective and the process being investigated.

The case company being studied operates a chocolate manufacturing plant with two distinct process; P1 and P2. However, this study focused on P2 process, which is a multistage and continuous; making product quality a critical issue since quality characteristics are measured at the end of the process (Bazdar et al, 2015). This chocolate plant is experiencing relatively high variation in the quality of chocolate produced; the quality characteristics measured are yield value (YV), plastic viscosity (PV) and particle size (D90). The variation is not limited to any specific chocolate recipe; indicating that there is an issue within this process. For the period January – June 2016, the quality failure

rate was at 8%. The current scenario on P2 process encourages keeping excess inventory as stock gap measure due to high failure rate.

A detailed study of the process flow map (Figure 1) for chocolate manufacture was carried out with the involvement of key personnel from production process, quality management, product & process development, and process engineering. Brainstorming sessions were also conducted with the team members to identify potential 'red flag' and measure points.

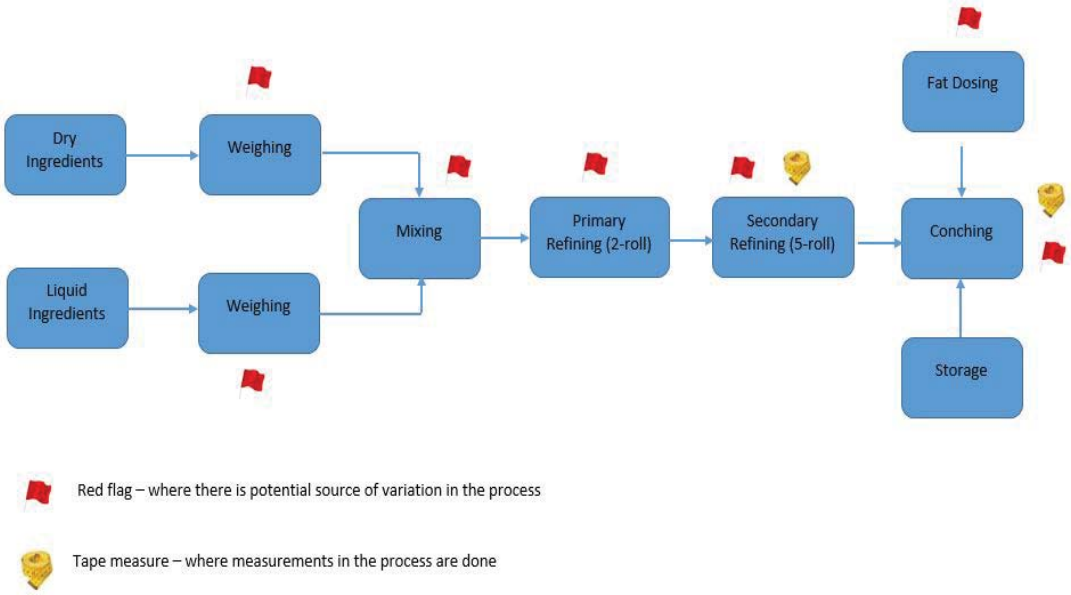

Figure 1: Flow Chart for Chocolate production process

Process Description

1. Weighing - The dry and liquid ingredients are weighed separately using high precision scales with tolerance limit of ±1%. The scales are calibrated once every week. The ingredients are weighed into a mixing vessel, starting with liquid ingredients followed by dry ingredients.
2. Mixing - At this stage the dry ingredients are mixed with a proportion of liquid ingredients to form chocolate paste. The percentage of fat in the mix determines how well the refining process works i.e. too little fat means no control over the particle size and too much fat will compromise the conching process.
3. Refining - This stage determines the smoothness of the finished chocolate. The two-roller refiner and five-roller refiners are used in series to reduce the particle size of

the paste. A sample is collected from every batch of chocolate and tested for the particle size using Laser diffraction method.

4. Conching – This process is normally carried out by agitating chocolate at temperatures >50 °C for few hours (Beckett, 2009). Conching contributes to the development of viscosity, final texture and flavour of the chocolate, and helps with removal of volatiles and moisture. Additional cocoa butter and lecithin is added towards the end of conching to give chocolate a suitable viscosity (Beckett, 2009 and Whitefield, 2005). A sample is collected from every batch of chocolate and tested for viscosity using a rotational viscometer called Haake. Chocolate is a non-Newtonian fluid (Beckett, 2009). The viscosity is expressed in terms of plastic viscosity (PV) or yield value (YV). PV is the force required to keep chocolate flowing and YV is the force required to get chocolate to flow.

Both quantitative and qualitative methods were used to obtain and analyse data in this study. The quantitative method involved measuring the quality characteristics of the chocolate samples collected at defined intervals and analysed the results using Minitab statistical software. This research method involves data that is expressed as numbers. The results were plotted in control charts to determine whether or not the variation in the process was within the control limits. In this study, the individuals and moving range charts were used to monitor individual values and the variation of a process based on samples taken from the process over time. The initial series of observations was used to estimate the mean and standard deviation of the process, which is then used to produce control limits for the individual values and ranges. The process capability analysis reports was used to determine how well the P2 process meets a set of specification limits. The qualitative method was used mainly during brainstorming sessions. Group brainstorming was chosen due to its ability to allow diversity of views and its strength in exploring the effects and unintended consequences of an issue (McGlynn et al, 2004). The brainstorming team was made up of four people drawn from different speciality areas such as operations, new product & process development, engineering, and quality assurance. Brainstorming sessions were conducted at different phases of the project, mainly at define and analyse phases, to generate ideas and prioritise solutions.

4. Proposed DMAIC approaches in chocolate processing

4.1 Defining the Process – SIPOC Model (DEFINE)

The Six Sigma tool SIPOC (supplier, input, process, output, and customer) was used for mapping E2 chocolate manufacturing process. SIPOC model in Figure 2 clarified the key processes that the study focused on. Every item in the SIPOC categories are potential sources of variation. However, due to time and resource constraints, the scope of the project was limited to the processes highlighted in dotted green line, which are process and outputs part of the SIPOC model. Reducing variation in process and output requires identifying the sources of variation, which is where the SIPOC model was useful. The researcher created the SIPOC diagram and assessed how each of the elements within scope influenced the quality of process output.

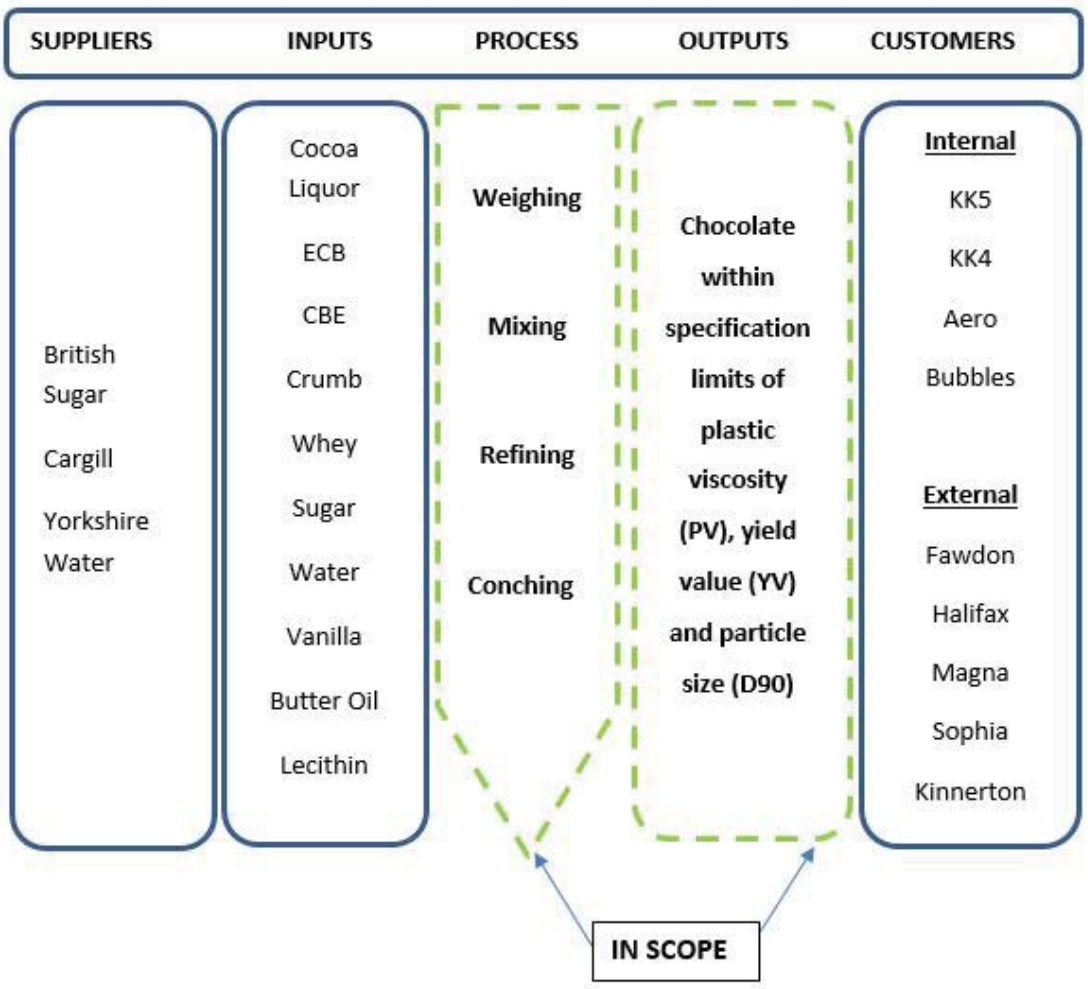

Figure 2: SIPOC Map for E2 Process

SIPOC model (Figure 2) and process map (Figure 1) were merged to identify the sources of variation and the measurements to be taken as in Table 2.

Table 2: SIPOC Addressing Sources of Variation

SIPOC Category	Items	Sources of Variation	Mitigation	Measure
Process	Ingredients weighing	Variation induced by weighing	Adherence to equipment calibration schedule	Weighing accuracy
	Mixing of dry and liquid ingredients	Variation in mixing base settings	Adherence to standard base settings	Mixing consistency
	Refining the chocolate paste	• Variation in refining base settings • Skills set and experience of the operator in charge of the process	• Adherence to standard base settings • Skilled operators running the process	D90
	Conching	• Variation in fat addition • Variation in conching conditions	• Adherence to calibration schedule for dosing equipment • Monitoring system for fat addition	Fats addition accuracy PV YV
Outputs	Quality products	Not applicable	• Particle size within specification • Yield Value within specification • Plastic Viscosity within Specification	D90 YV PV

4.2. Data collection techniques (MEASURE)

Data was collected for every batch of selected product type at refining and conching stages of the process flow map using a structured observation technique. In this study,

primary data was collected through direct plant observation. The researcher had an advantage of working within the area where the study took place hence real-time data was collected (Voss et al., Saunders et al, 2009). The chocolate making process was thoroughly observed with a view of examining the variations, if any, and samples were collected at defined points for testing. Quantitative method involved measuring the quality characteristics of the chocolate samples collected at defined intervals. Data analysis was conducted using Minitab, a statistical software. We also exercised a qualitative research method for brainstorming sessions to generate and prioritise ideas.

The researchers identified the measures to be used as the focus for this study through determining the variability of each measure identified in Table 2. The measures with high variability, YV and PV, were shortlisted and the data on quality records is plotted. This graph is used to select the product and defect to be the centre of focus in this study. The Pareto chart on Figure 3a was used to highlight the defect with the highest failure rate and as such plastic viscosity (PV) was chosen to be the focus of the project.

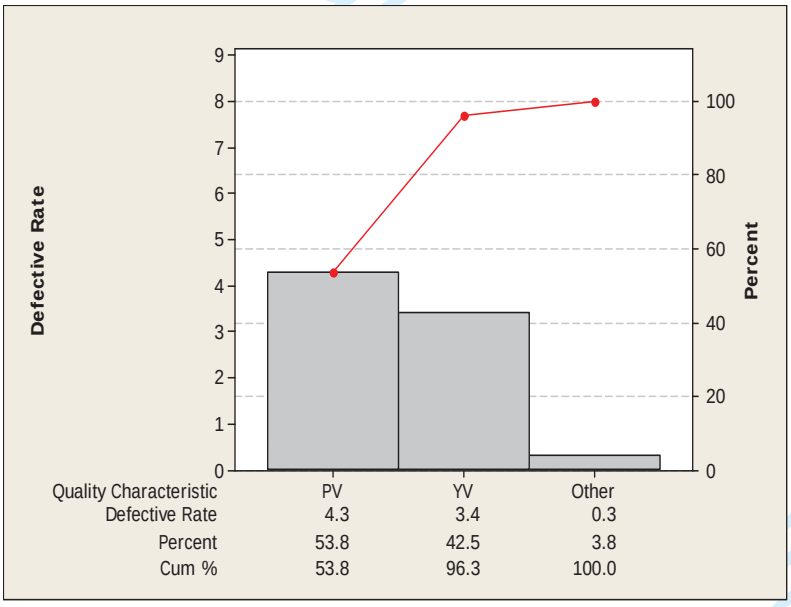

Figure 3a: Pareto Chart of quality defects in chocolate production

The company produces a wide range of product types (chocolates), most of which exhibit a certain level of defects and the graphical representation is provided in figure 3b. Pareto analysis highlighted that Chocolate A has the most defects among all the products made on P2 process; hence it was chosen to be the focus of the project.

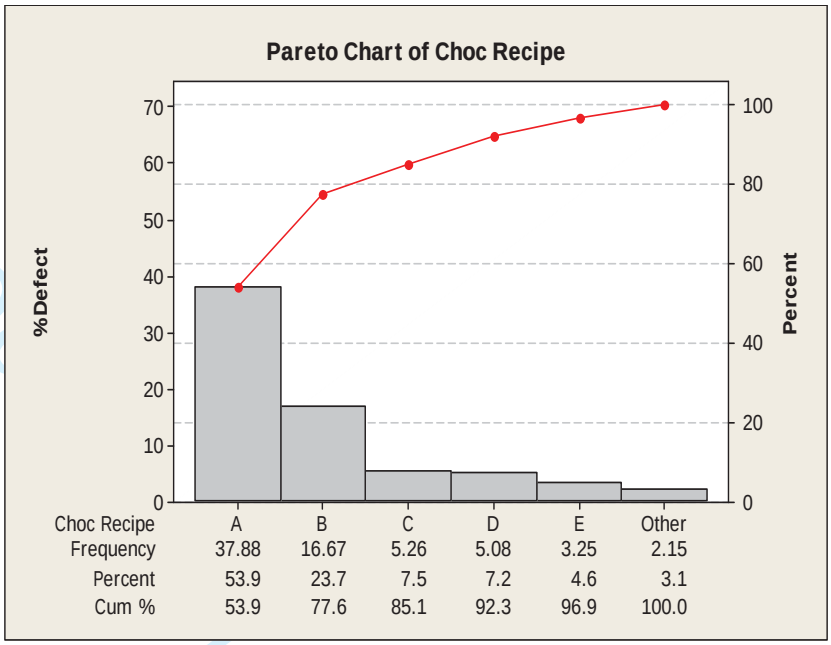

Figure 3b: Pareto Chart of chocolate type

The opportunity derived from the above Pareto analysis was to concentrate on process steps that had direct impact on plastic viscosity. The next stage was to formulate a focused problem statement based on main research objective which is to reduce defects by 40% or more. Using information on Figure 3a, to achieve the research objective, the researcher focused on reducing plastic viscosity defects by 75% as follows:

4.3% x 75% = 3.2%

By targeting process steps impacting on plastic viscosity and reducing the defects by 75% an improvement of 3.2% was expected. This is considered enough to reach the 40% pledged reduction of the defects in finished products.

4.3. Results and Data Analysis (Analyse)

Quantitative data in its raw form is meaningless unless it has been processed and analysed (Saunders et al, 2009). Quantitative analysis techniques that included process capability, control charts, time series, and Pareto charts were used to convert the collected data into meaningful information which allowed the researcher to examine trends within the data. This was achieved through using Minitab statistical software. The sampling plan involved collecting the population data on 102 consecutive batches of Chocolate-A made during the 6 weeks period. At storage stage of the process, the chocolate was allowed to mix

thoroughly in a 20 tonnes storage tank for 60mins and 2 x 250g samples collected for testing. The time series data is shown in Table 3.

Table 3: PV Results for Chocolate A

Batch No	PV	Batch No	PV	Batch No	PV	Batch No	PV	Batch No	PV
1	7.50	**21**	8.79	**41**	6.58	**61**	6.72	**81**	7.12
2	7.08	**22**	6.78	**42**	6.60	**62**	7.53	**82**	7.27
3	7.00	**23**	7.21	**43**	8.11	**63**	7.81	**83**	6.99
4	7.32	**24**	7.16	**44**	8.06	**64**	7.42	**84**	6.87
5	7.87	**25**	6.63	**45**	7.48	**65**	8.56	**85**	6.78
6	7.10	**26**	7.31	**46**	7.35	**66**	7.78	**86**	7.39
7	10.18	**27**	8.34	**47**	7.87	**67**	7.12	**87**	9.35
8	8.72	**28**	6.82	**48**	7.25	**68**	7.37	**88**	9.73
9	8.68	**29**	7.50	**49**	7.61	**69**	7.52	**89**	7.48
10	7.37	**30**	7.11	**50**	7.74	**70**	6.55	**90**	6.50
11	7.50	**31**	6.47	**51**	7.07	**71**	6.69	**9**	6.88
12	8.84	**32**	7.50	**52**	7.82	**72**	7.19	**92**	6.73
13	8.96	**33**	6.78	**53**	7.27	**73**	7.99	**93**	6.40
14	9.24	**34**	7.50	**54**	7.00	**74**	6.75	**94**	6.93
15	6.72	**35**	6.54	**55**	6.58	**75**	6.50	**95**	6.40
16	9.16	**36**	8.75	**56**	9.32	**76**	6.76	**96**	7.31
17	8.42	**37**	7.21	**57**	7.78	**77**	6.84	**97**	7.14
18	7.35	**38**	7.50	**58**	7.18	**78**	7.01	**98**	7.14
19	10.49	**39**	7.22	**59**	6.44	**79**	6.84	**99**	9.11
20	6.53	**40**	9.70	**60**	7.17	**80**	8.30	**100**	8.21
								101	8.52
								102	7.15

The collected data showed that the rejection in the process was 33.3% as provided in the process capability diagram in Figure 4. The Cpk value -0.01 and Sigma level -0.06, implying that the process is producing output that is outside the customer specification limits. Defective products are found on the upper specification limit end of the histogram.

The process is not centered between the specifications; the histogram and corresponding normal curve are wider than the distance between the specification limits, which indicates that there is also variability in the process. There is a need to center the process by moving the mean to closer 6.5 (halfway between the specification limits) and reduce the variation. The defect rate of 33.3% formed the process baseline and the target was to reduce it by 75%.

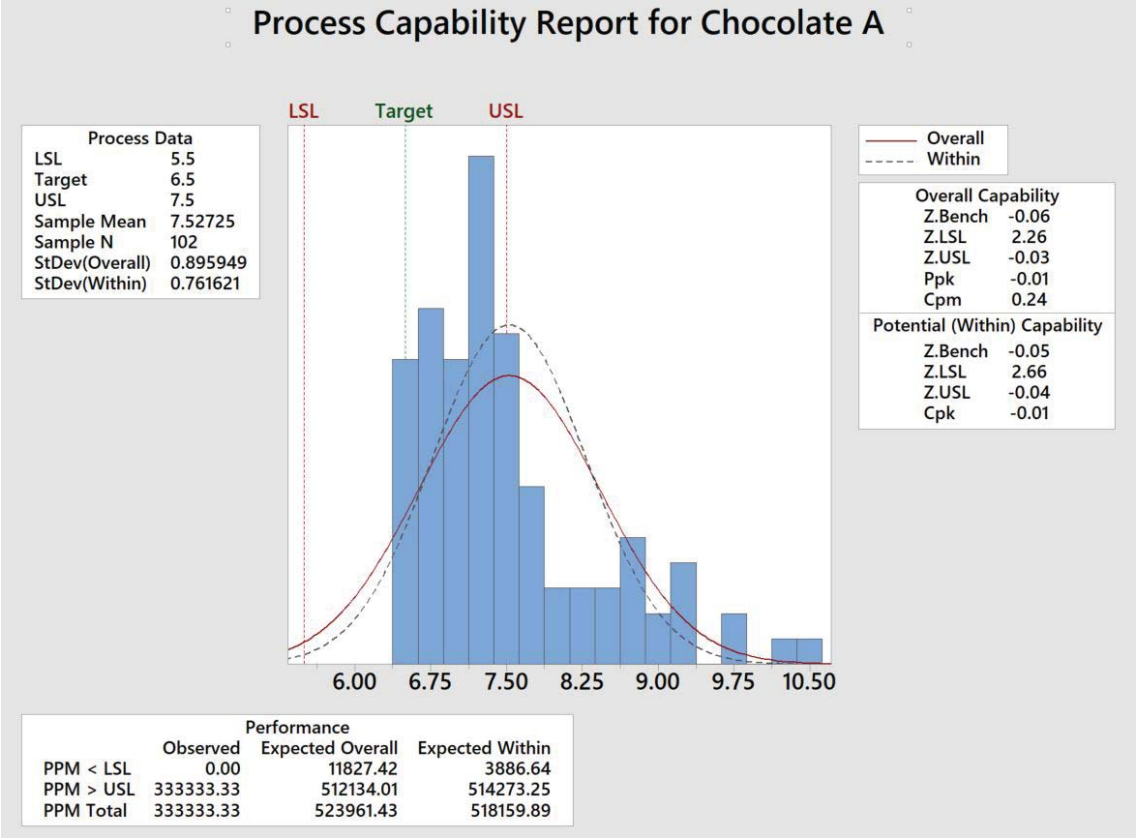

Figure 4: Process Capability for Chocolate-A

The graphical representation of the data in control chart with both lower and upper control limits is given in Figure 5. There is one point more than 3.00 standard deviations from the centre line and 9 points in a row on same side of the centre line. The mean of the process is 7.52, which is more than the upper specification limit and this formed the project baseline.

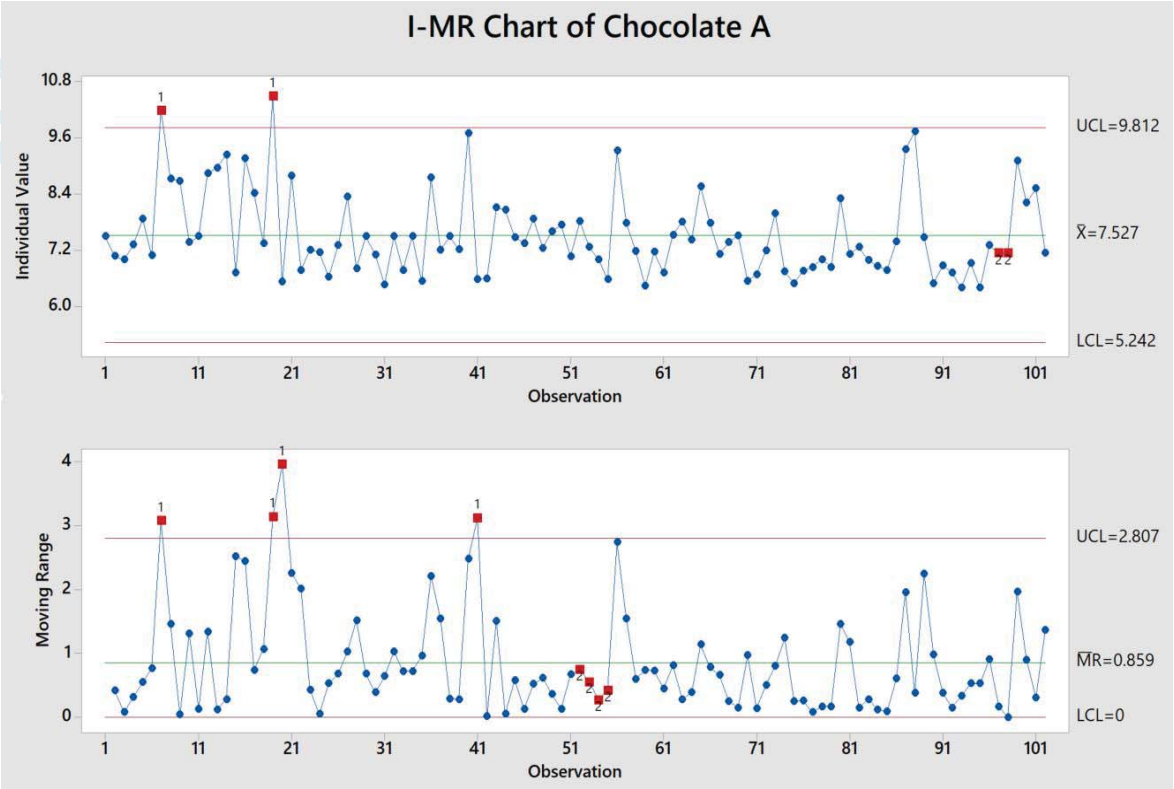

Figure 5: Control Chart for PV of Chocolate A

4.3.1. Possible Causes – Cause and Effect Diagram

Using the flow chart in Figure 1, a cause and effect diagram was prepared through brainstorming sessions with the process operators, engineers and quality representatives. Gijo (2005) asserts that the output of the cause and effect diagram depends on the quality and creativity of the brainstorming sessions. Figure 6 illustrates the cause and effect analysis prepared during the brainstorming session.

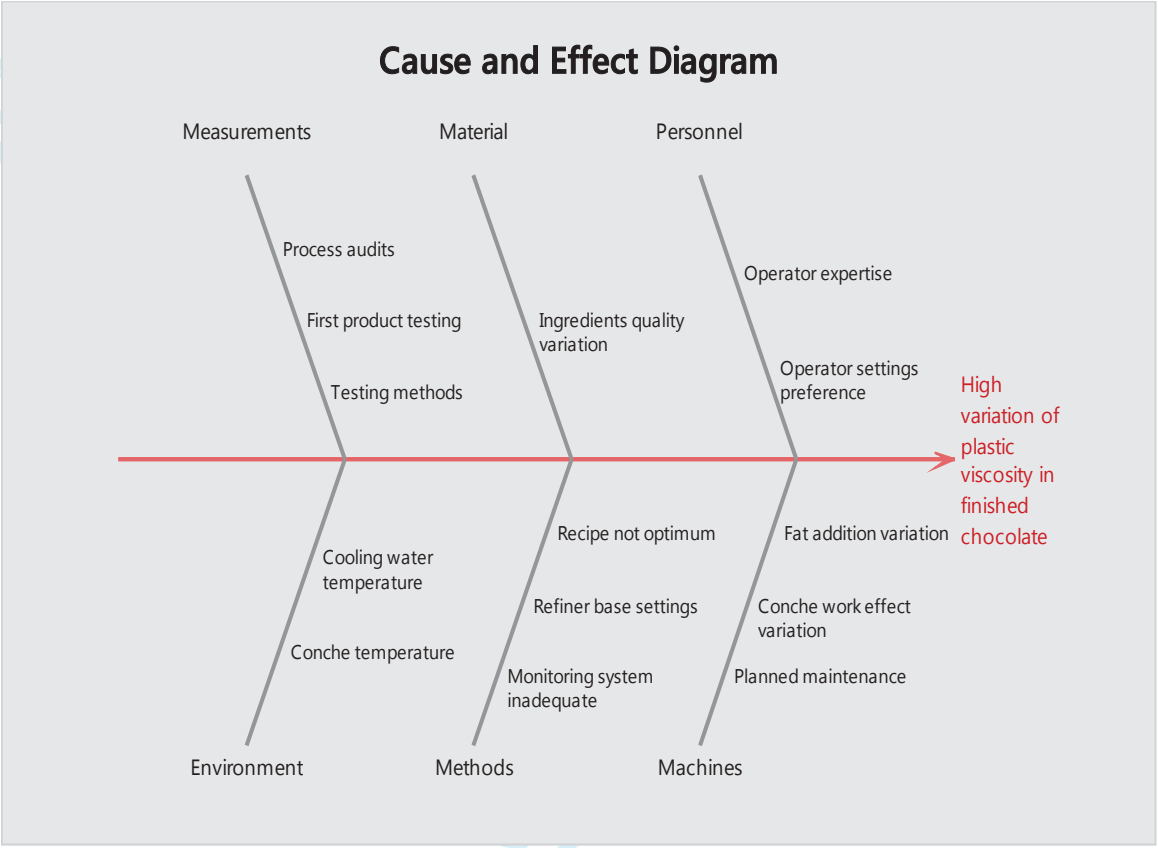

Figure 6: Cause and effect diagram for high PV defects in Chocolates

The process personnel were asked which causes they thought contributed to the quality defects of finished products, based on their point of view and years of experience. The potential causes were then categorised in terms of priority using impact and controllability criterion.

4.3.2. Prioritisation of Possible Causes

The next step in this analyse phase was to prioritise the potential causes from the cause and effect diagram by placing them into high, medium and low priority quadrants as shown in Figure 7, through brainstorming and discussions with experienced process personnel. The high and medium priority causes were progressed to verification stage while low and low to medium priority causes were dropped.

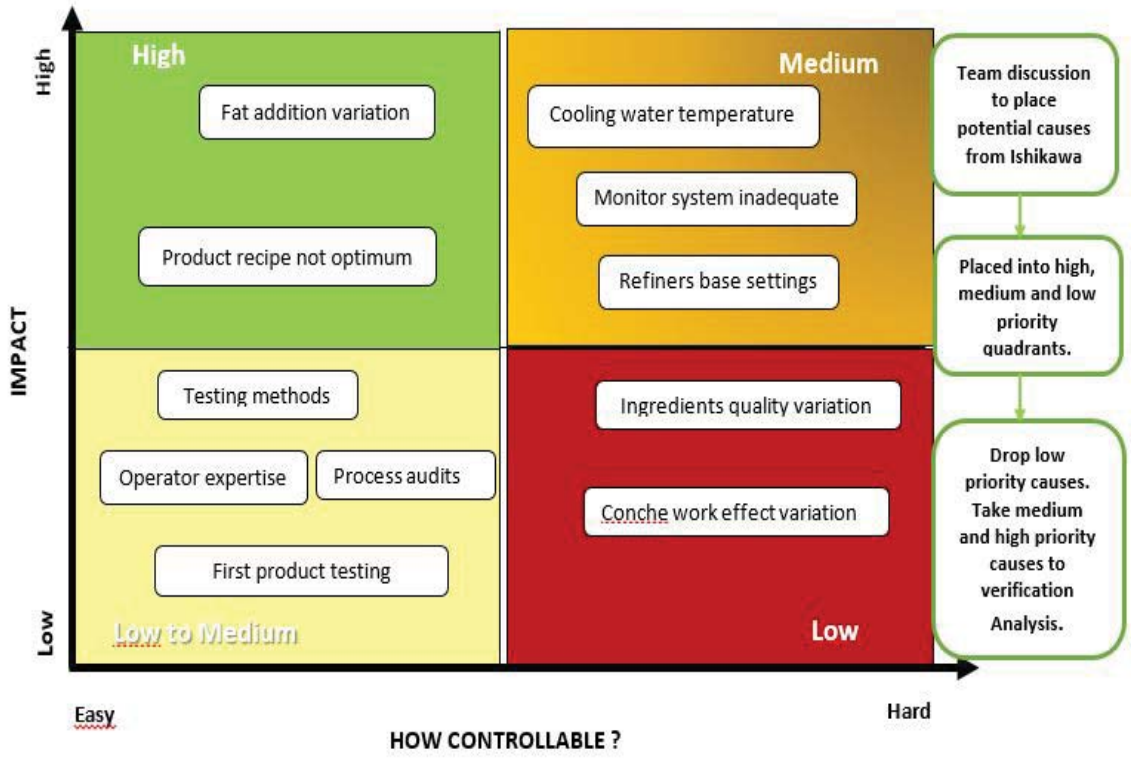

Figure 7: Prioritisation Quadrant for Possible Causes

High priority quadrant causes are 'quick wins' and as such solutions must be implemented immediately. The causes such as 'Fat addition variation' and 'product recipe not optimum' were prioritised. The solutions to medium priority quadrant causes were scheduled for implementation after the high priority causes have been addressed.

4.3.3. Verification of Possible Causes

The potential causes in high priority and medium quadrants were further subjected to a cause-verification exercise as shown in Table 4. A cause verification plan was prepared to detail the type of data to be collected and the type of analysis used for each cause. The causes that included 'fat addition variation', 'product recipe not optimum', 'refiner's base setting', and 'cooling water temperature' were verified using design of experiments (DOE). DOE is a technique in which factors are systematically and simultaneously manipulated while the variability in outputs is observed to determine which factors have the biggest impact (Montgomery, 2005). The 'monitoring system inadequate' cause was verified by observing the process (GEMBA).

Table 4: Summary of cause verification and proposed solutions

Root Cause	Method used for verification	Results	Proposed Solution
1. Fat addition variation	Process monitoring	Root cause	Improve communication between PLC's & IP21 by redirecting the messages to reduce congesting the Ethernet network.
2. Product recipe not optimum	Design of Experiments (DOE)	Root cause	Change cocoa butter and lecithin addition to towards end of conching.
3. Cooling water temperature	Design of experiments (DOE)	Not root cause	-
4. Monitor system inadequate	Observing the process (GEMBA)	Root cause	Improve process monitoring system.
5. Refiners base settings	Design of experiments (DOE)	Root cause	Create uniform base settings for the refiners.

4.4 Implementing Solutions (IMPROVE)

This phase of the project is aimed at implementing the proposed solutions and measuring the improvements. A risk analysis was carried out to identify any potential side effects of each proposed solution during implementation and it was concluded that there were no significant risks associated with the selected solutions. An implementation plan was developed for these solutions, with clear responsibility and time frame for completion of each solution using a tool called 5W1H (What, Where, When, Who, Why, and How). A time frame of three weeks was provided for implementing these solutions. Table 5 shows the implementation action plan with the specific steps used for this project to make the improvements.

Table 5: Solutions Implementation Plan (5W1H)

What (Solutions)	How (Specific steps)	Who (Responsible person)	Where (Specific location)	When (Specific dates)	Why (Justification)	Status
Improve communication between PLC's & IP21 software	Re-route the messages to reduce congesting the Ethernet network	PLC expert	PLC sub-station	07/11/2016	Achieve consistent addition of ingredients	Completed
Change cocoa butter and lecithin addition to towards end of Conching	Move the addition of cocoa butter and lecithin from Step 2 to Step 9 in Conching	Product Development expert	Recipe Management System (RMS)	14/11/2016	Adding cocoa butter and lecithin towards end of Conching aids liquefaction of chocolate	Completed

All actions completed!

4.4.1. Results after Improvements

Once all the solutions were implemented as per the plan, the next step was to measure the improvements made and determine if the aim of reducing the PV defective rate by 75% was achieved. The sampling plan involved collecting the population data on 64 consecutive batches of Chocolate A over a period of 3 weeks. The same procedure of collecting samples, which was deployed in section 4.3, was repeated. The time series data is shown in Table 6.

Table 6: PV Results after Improvements

Batch No.	PV	Batch No.	PV	Batch No.	PV
1	7.44	**22**	7.50	**43**	6.82
2	6.87	**23**	6.91	**44**	6.86
3	7.44	**24**	6.70	**45**	6.06
4	6.96	**25**	6.30	**46**	7.22
5	6.75	**26**	6.83	**47**	6.87
6	7.05	**27**	6.32	**48**	6.50
7	6.44	**28**	7.13	**49**	6.92
8	7.27	**29**	7.27	**50**	7.21
9	7.18	**30**	6.81	**51**	6.50
10	6.40	**31**	6.96	**52**	7.34
11	7.06	**32**	6.95	**53**	7.17
12	6.94	**33**	6.83	**54**	7.23
13	6.50	**34**	6.86	**55**	6.50
14	7.40	**35**	7.27	**56**	6.91
15	7.23	**36**	7.06	**57**	6.50
16	6.26	**37**	7.19	**58**	7.31
17	7.26	**38**	7.36	**59**	7.07
18	6.35	**39**	6.50	**60**	6.97
19	6.31	**40**	7.20	**61**	6.99
20	6.71	**41**	7.06	**62**	6.50
21	7.10	**42**	6.88	**63**	6.34
				64	6.46

Figure 8 shows a massive reduction in spread of plastic viscosity scores within a set of data collected i.e. before improvements the overall standard deviation was 0.90 and after

improvements, it reduced to 0.36, which is a 60% reduction. The results indicate that the solutions implemented in this study improved the chocolate manufacturing process by reducing the variation, with PPM reducing from 523961 to 43612. The PV values are within specification limits and both Cpk (0.55) and Sigma level (1.7) increased after the improvements, showing that the process is now performing within customer specification range. However, the histogram still shows that the process is not perfectly centred, the mean value of PV is 6.9 against a target value of 6.5 and the PV values are slightly biased towards the upper specification limit (7.5), and therefore, presents a possibility of producing output that is outside specification limits.

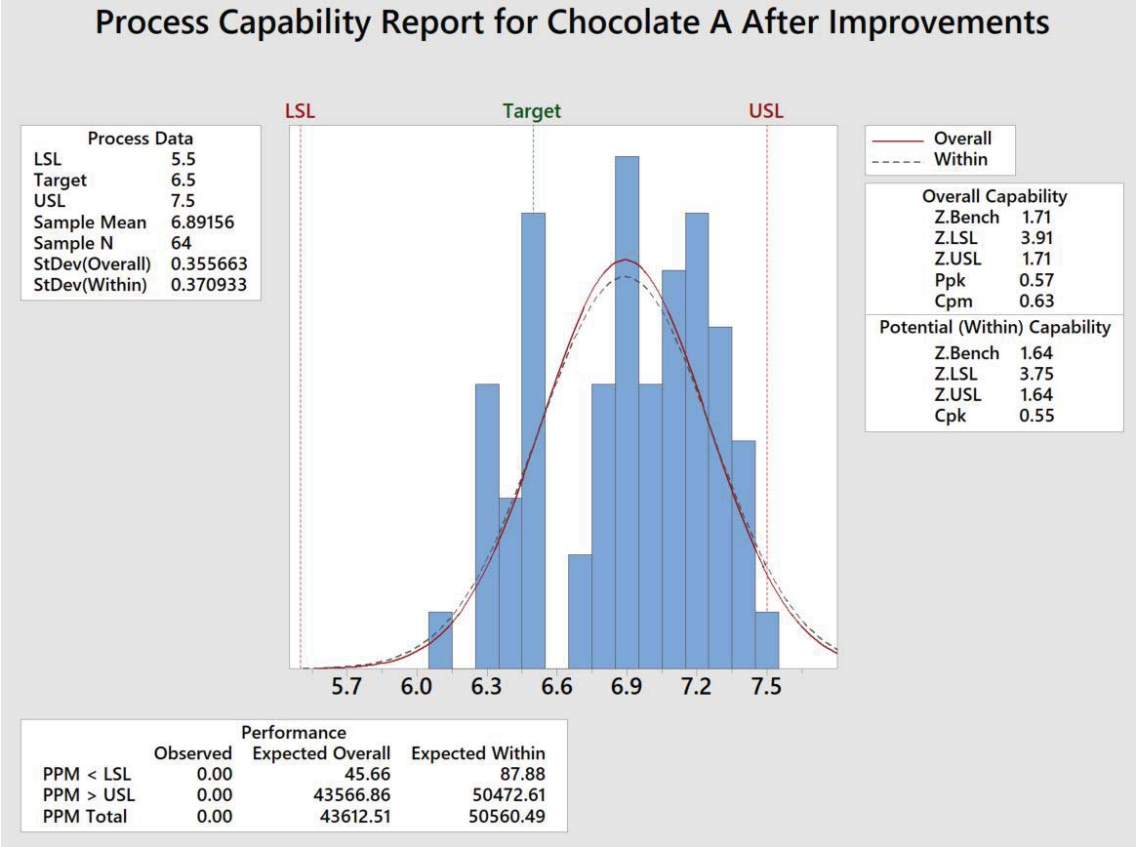

Figure 8: Process Capability for Chocolate A – after improvements

The graphical comparison of the plastic viscosity results before and after improvements is provided in Figure 9.

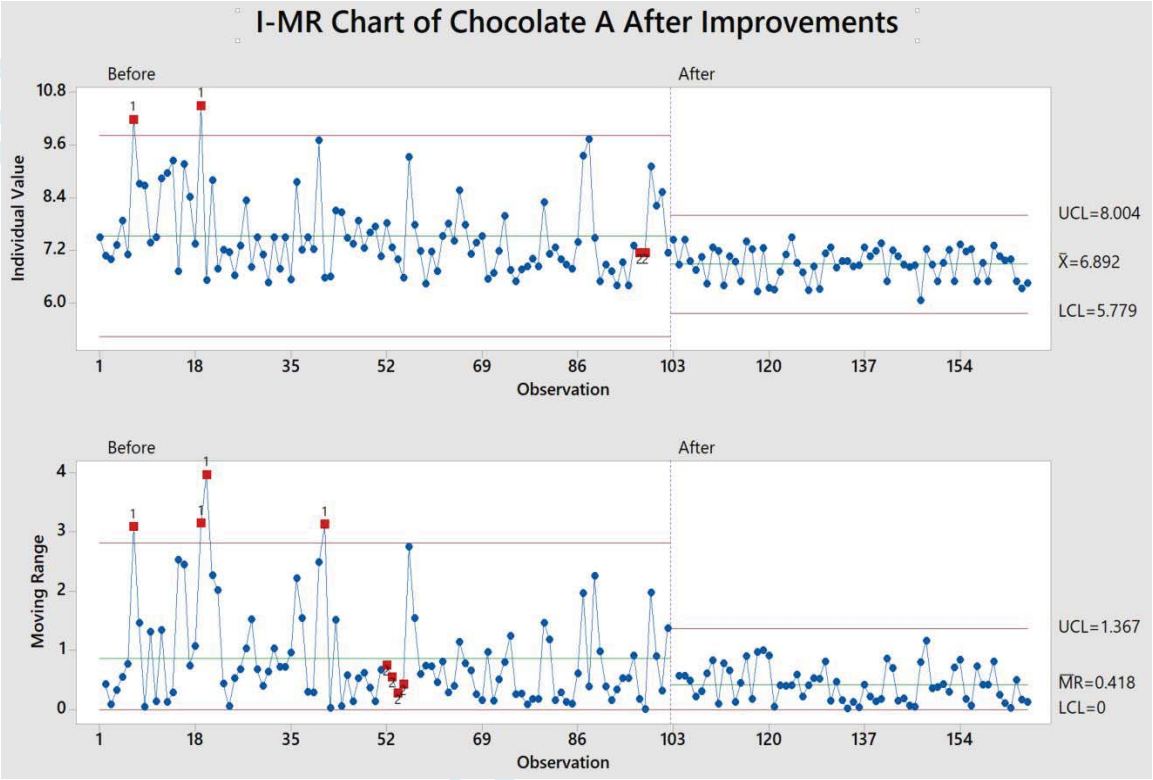

Figure 9: Plastic Viscosity Control Chart - Before and After Improvements

The chart shows the average for the individual PV measurements went down to 6.89 and, by examining the lower chart, the variation among the PV results is reduced. Because of this particular experimentation project, the overall defect rate of output from P2 process was reduced from 33.3% to 0%, which translates to 100% reduction. This was better that the projected reduction of 75% for defects associated with plastic viscosity. The overall reduction is as follows:

$$4.3\% \times 100\% = 4.3\%$$

Using the baseline of 8%, the defect rate was reduced to 3.7% which translates to 53.8% reduction. This shows a significant improvement in product quality. A control system to monitor and control the process was developed to ensure the improvements are sustained. A method of review and escalation was introduced for use by the process operators.

4.5 Sustaining the Change (CONTROL)

The key deliverables from this stage are set of controls to sustain the improvements made on P2 process. Muir (2005) asserts that controls must be put in place to prevent the process from backsliding to the way it was before improvement project began. The objective of this phase is to implement ongoing measures and actions to sustain the improvements made by monitoring, standardising, documenting and integrating the new

process on daily basis (Narasimhan, 2013). Lack of good control plan and sustaining of the results achieved are the biggest challenge for all improvement projects. Quite often maintaining consistent results can be difficult due to variety of reasons, such as change of personnel working on the process, key people transferring to other departments of the organisation, lack of ownership by new personnel in the process and change of focus by the individual in charge of the process (Gijo, 2005). Therefore, sustainability of achieved results requires standardisation of the new methods of working and introduction of monitoring mechanisms for the key results achieved. It also requires changing the mind-set of the people performing the activities (Gijo et al, 2011). A well-executed control plan put the process in the hands of the process owners and enable them to identify problems before they occur, and define the roles and responsibilities of the process owners and management (Muir, 2005). Developing control charts, creation of new standard operating procedure (SOP) and training plans for process personnel are frequently used as control mechanism of improvement projects. In our research the experiments in case company helped developing a control plan which included the following:

1. A control system that provides live information about the ingredients being added to each product during manufacture was developed. This is called process order reporting. The process order reporting allows early identification of ingredients variation. The process personnel were coached on how to use and interpret it. A method of review and escalation was introduced.
2. The SOP for improved processes are revised and training is being provided for the process personnel about the improved methods so that they can manage the process effectively.
3. Control charts for monitoring the process along with reaction plan are introduced so that any variation within the process can be noticed and corrective actions taken immediately. The reaction plan is displayed near the process, giving direction for identifying the action required for addressing the variation cause.
4. The visual control system with quality metrics is introduced to monitor and track process performance. This gets discussed in daily operational review (DOR) meetings.

The investigation established that inconsistent fat addition at conching stage of chocolate manufacturing process was one of the root causes of variation. The control chart (*Figure*

5) shows two outliers, which can be attributed to special-cause variation. Product recipe was also found to be another source of variation. The chocolate type with fat addition in the earlier steps of conching tends to have viscosity on the higher end of the specification. The control chart and process capability diagram plotted both showed most of the plastic viscosity results biased toward the upper specification limit, meaning the product was not achieving a normally distributed viscosity across all batches. This concurs with what Beckett (2009) and Whitefield (2005) recommend about adding cocoa butter and lecithin towards the end of conching to give chocolate a suitable viscosity. Whereas Beckett and Whitefield have been generic about fat addition in conching, the researchers went further to establish the specific point in conching (Step 9) where fat addition can yield the optimum viscosity. Once the solutions were implemented, the improvements were measured. Figure 9 provides the graphical comparison of the plastic viscosity (PV) results before and after improvements. The specification limits, lower specification limit (LCL) and upper specification limits (UCL), are an indication of what the customer perceives to be acceptable.

5. Practical implications and Conclusion

This paper presents a structured step-by-step application of the tailored DMAIC methodology for reducing the defects of P2 manufacturing process. We used experimental case study approach to show actual use of customized quality frameworks. We also used other statistical tools and techniques, such as SPC and Pareto chart to analyse and improve the quality during the study. Process variation, which is the objective of the study has been reduced thus improving the quality of finished products without investing in new equipment or extra personnel resource.

Variation reduction brings consistency and predictability to the process, allowing it to produce products of consistent quality when compared with the previous situation. The reduced variation in the process improves the company's capability of manufacturing products that consistently meet customer requirements and shortens processing time through elimination of out-of-specification products which may require reprocessing. The process improvements made are being monitored on regular basis and the process owners have been trained to ensure these improvements are sustained for the future. Sustaining change on P2 process depends much on engaged employees who continually search for ways to improve the process. New ideas or concerns are channelled via handover boards

and/or shift operational review (SOR) meetings held at the beginning of every 12-hour shifts. Process mapping facilitated the identification of sources of variation and brainstorming with key process personnel helped in establishing and prioritising the solutions. Due to time and resources constraints, two solutions were chosen for immediate implementation which yielded improvements in process variation and defect rate.

Some of the solutions have been shortlisted and recommended for future consideration such as optimising the refiner base settings. Because of this project, the defect rate on P2 process was reduced from 8.0% to 3.7%, which is 53.8% reduction. Although this study was conducted using one process, the results are generalizable to other chocolate making processes. The researcher has used a systematic approach in reducing variation in one case company and found it easy to use and has practical implications to product quality, cost of quality, processing time and customer service. Process knowledge was key for this process, people with process expertise were brought in for brainstorming sessions. The desired results were achieved through engaging and involving people at different levels of the organisation. The major contribution of this study is the use of structured for reducing variation in a chocolate manufacturing process that resulted in reduced defect rate and improved product quality. However, reduction of process variations is a continuous process.

This research uncovered that process operators preferred different refining settings and that there were no standard base settings in place. This tends to cause variation in particle size of the product at refining stage. On this background, it is recommended to have uniform base settings for the refiners so that the process can be better managed. However, due to the amount of work involved in validating and establishing the optimum base settings, this solution is recommended for future implementation.

Also earmarked for future consideration is expanding the scope of the project to cover other processes provided in SIPOC model. The quality of ingredients was mentioned as having potential impact on particle size and viscosity of the chocolate. However, due to the current complexity of the process of controlling ingredients quality, the project found a gap that requires further work to be considered in this area.

Though there were significant improvements in variation, there is still a need for a more controlled process that can yield a normal distribution. With this success in reducing variation on P2 process, the project can be rolled out to cover the other chocolate process. Process centering can be explored as an opportunity to eliminate the bias towards the upper specification and out-of-control points.

The major contribution of this study is the use of control charts and a customised DMAIC methodology to reduce variability in PV of a multistage chocolate manufacturing process and hence reduce waste. Our research has practical contributions that included reduction in defect rate and quality cost, and improved product quality. This particular research complements the existing work done by Chakrabortty et al. (2013) and Tylutki and Fox (2002) in food industry (though no specific to chocolate manufacturing) around reducing process variation. The research is one of very few studies with experimental case that investigates the underlying causes of variation in a chocolate process using a structured and systematic approach through the experimental case study. (Kovach and Cho 2011) argues for the potential of continuous quality improvement in the food industry. This research makes a significant contribution by providing a case-study based analysis of a chocolate manufacturing process using primary data. Also, this research clearly specifies the importance of customized quality management approaches that can improve the quality and hence the customer satisfaction in different industries.

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Manuscript ID IJQRM-12-2018-0332 entitled "A holistic approach of process variation reduction: A case of UK chocolate manufacturing"

Dear Reviewers, editors and guest editors,

We would like to thank you all for your valuable and constructive feedback on the paper we submitted to IJQRM. We have improved the paper as much as possible to a high standard, in line with the reviewers' comments. We hope that now our article reads well to reach many readers in academics and practitioners community. We hereby record our response to each of the comments:

Reviewer: 1

Recommendation: Minor Revision

Response:
Thanks for this decision.

Comments:
A "tasty" case study that can be useful. Highly recommend at least addressing the potential for centering the process to completely eliminate exceeding control limits and further improve process capability. Grammar and syntax errors need to be corrected.

Response:
We accept and value this suggestion of addressing 'centering the process'. This is discussed in our revised version of the paper in page-25 to explain Figure 8.

A thorough proof-reading is done.

Additional Questions:
1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes in that the paper provides a new example of applying improvement methods that may resonate with a portion of the audience.

Response:
Thanks for this comment.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes. The paper demonstrates a broad range of understanding relevant literature.

Response:
Thanks for acknowledging strength of this article.

The paper does appear to miss the clear potential opportunity for centering the resulting process which could eliminate variation outside of specification altogether.

Response:
New version of the paper has discussed this in pages 12 and 17- 18.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: Yes. The paper is built on appropriate theory and concepts and the methods employed are appropriate. However, the paper should also address the significant potential of centering the process.

Response: Thanks for acknowledging the positive aspects of our article. As suggested, centering the process has been discussed in the paper (page -25) to explain the Figure 8.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Yes. The results are presented clearly and tie very well to the elements of the paper. The only error is analysis is the error of omission in not addressing the potential of centering the process.

Response: in the revised version of the paper, we discussed, potential of centering the process in page -25 to explain the Figure 8.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: The paper does bridge the gap well between theory and practice and will provide a useful example.

Response:
Thanks for this positive feedback.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: The paper is clear and understandable. A thorough review of grammar is still needed since there were grammatical an syntax errors in the paper.

Response:
A thorough proofreading is done.

Reviewer: 2

Recommendation: Accept

Comments:
The structure, flow, contents of the research article adequate.
Response:
The authors would like to thank this reviewer.

Additional Questions:
1. Originality: Does the paper contain new and significant information adequate to justify publication?: yes

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: yes

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: yes

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: yes

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?:

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: yes

Reviewer: 3

Recommendation: Major Revision

Comments:
The paper needs improvement in the analysis and results parts. The following subjects related to process variation and quality control needs clarification in the methodology and results sections: sampling plan, selection of control chart type, analysis of statistical process capability index, statistical specification limits VS control limits, DOMP calculation and analysis, data distribution, and common causes and out special causes treatment for out-of-control events.

Response:
In revised version of our paper, we strengthened the analysis and writing to inform practical applications of the findings more effectively. For example, we introduced some literature on quality improvement initiatives of food industry in page-9 (section 2.3) and discussed centering the process in page-25 to discuss the results of the analysis in relation to Figure -8.

Additional Questions:
1. Originality: Does the paper contain new and significant information adequate to justify publication?: The paper needs improvement in the analysis and results parts. The following subjects related to process variation and quality control needs clarification in the methodology and results sections: sampling plan, selection of control chart type, analysis of statistical process capability index, statistical specification limits VS control limits, DOMP calculation and analysis, data distribution, and common causes and out special causes treatment for out-of-control events.

Response:

We tried to improve quality of the paper by including more explanation as required by the review in different sections.

We thoroughly checked the whole document and strengthened the analysis. Extra writing on selection of control chart type explained in last paragraph on page 12. We also included a brief writing on 'Analysis of statistical process capability index', PPM and Sigma level covered in page 16-18 and 25. As specified by the reviewer we clarified the use of specification limits and control limits in page 12.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: The literature didn't include related work in chocolate or food industry that demonstrate the need quality control or quality improvement. Also, a similar implementation of DMAIC in food industry were not discussed in the literature.

Response:
Thanks for pointing out this gap. We added a new section 2.3 in page-9 particularly to specify practical implication of the quality aspects in food industry. This also discusses literature of quality improvement in the chocolate/food industry.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: The sampling plan for the collected data in table 3 and table 6 were not illustrated.

Response: In the revised version of the article, the sampling plan for the collected data is explained in page 16 and 24.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: 1-The results of process capability in figure 4 and figure 8 were not discussed based on the statistical findings from Cp and Cpk values.

Response: Figure 4 (page 17-18) and Figure 8 (page-25) are now discussed in detail within the text to show process capabilities.

2-The analysis and calculation of sigma level and the progress of sigma level after implementing the improvement plan were not presented in the paper.

Response:
In the revised version of the paper, we discussed the results after implementing the improvement plan in section 4.4.1 (pages 24-26).

3-The criteria that used to select the defects in figure 3a was not discussed. The paper showed several measures in table 2; however, the method used for concentrating only on PV and YV were not clear. Thus, of defect and defective has to be clearly defined, distinguished, and discussed in the paper.

Response:

In the revised version of the paper, we have clarified the method for concentrating on PV and YV ahead of other measures in section 4.2 (page 15). The reason for focusing on PV was mainly because it exhibited a high variability.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: In section # 5, it did It did demonstrate the impact and the contribution to the commercial impact but not to the body of knowledge of process variation and quality control.

Response:
The revised version of Section 5 includes some references in relation to process variation along with practical impact. We also included a few new references to strengthen our analysis and discussion. Desai et al, 2014; Hung and Sung , 2011; Kovach and Cho, 2011; Tylutki and Fox, 2002.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: