

Waste and Cost Reduction for a Water Bottling Process Using Lean Six Sigma

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Abstract

In this paper, Lean Six Sigma tools and techniques were utilized to determine the root causes of waste in a water bottling process and proffer solutions to remove these sources of waste in order to produce only standard quality items with minimal to zero waste generated, and also to attain a reduction in production cost. The Value Stream Map (VSM) tool was used to highlight the sources of waste in the current state of operations at the plant, as well as to proffer an improved future state of the production processes at the plant. Also, the Define-Measure-Analyze-Improve-Control (DMAIC) framework of Lean Six Sigma methodology was employed to statistically analyze the root causes of waste in the plant. The analysis showed that the major sources of waste which constitute approximately 80 per cent of waste in the plant are water volume variation, alignment error in the shrink wrapping machine and manual inspection. After implementation of the proposed solutions, manufacturing lead time and cycle time are expected to reduce by approximately 42.1 per cent and 22.2 per cent respectively, with a reduction of 2 quality inspectors in the bottling process, leading to a drop in labour cost.

Keywords: Lean Six Sigma, Value Stream Map, Waste Reduction, Water bottling.

1. Introduction

Waste generated during production is a major concern in the manufacturing industry worldwide. Waste can be described as that aspect of the production process which adds no value to the product from the customer's perspective. Waste can occur in various forms, requiring varying methods to control, reduce or eliminate. At the case study water bottling company, waste is evident within the bottling plant primarily in the form of defects and increase in production cycle time due to waiting during machine failure. On one hand, these forms of waste negatively affect the output between the individual process steps, as well as the overall output of production shifts in the plant. On the other hand, customers experience delays in waiting, late deliveries and slow responses which negatively affect customer loyalty.

Therefore, it has become necessary to improve the production processes at the plant, so that only standard quality items are produced with minimal to zero waste generated. Hence, the aim of this project is to improve the state of production processes at the water bottling plant, by analyzing the root causes of waste in the plant, and consequently proffering effective solutions to the waste problem for implementation by the company. It is believed that if all the steps of the bottling process are completely capable, acting only when required, flowing perfectly, and performing exactly as required, the process will produce products perfectly, with no waste [1]. Moreover, reducing waste in the plant will have the ripple effect of improving employee and machine productivity, shortening production cycle time, providing higher consumer fulfilment and raising company revenues.

Lean Six Sigma consists of two process improvement methods known as Lean Manufacturing and Six Sigma methodology. The Lean manufacturing system is a process improvement practice concerned with building a capable and well-organized process, dedicated to constant optimization, and the eradication of various categories of waste [2]. It is a philosophy with the aim of significantly reducing cycle time and cost all through the whole value chain while continually optimizing process operations [3]. Lean Manufacturing has also been described as a manufacturing philosophy, which reduces the production lead time between a consumer order and the delivery of the products or parts, by elimination of various forms of waste. Thereby, aiding companies in decreasing cycle times, costs and needless, non-value added activities, leading to an organization that is more agile, competitive, and responsive to consumer needs [4]. On the other hand, Six Sigma is a controlled and data-focused way of eradicating defects in manufacturing processes [5]. It can be applied in all aspects of the production process for discovering and fixing the defects encountered during production of what the consumer desires [6]. Six Sigma has been described as a project-based management strategy that utilizes advanced tools for data analysis, as well as the tools and methods of project management, to focus on customer concerns, so as to enhance the products, services, and processes of a company, by constantly decreasing the defects in the company's production processes [7].

Therefore, the combination of Lean Manufacturing and Six Sigma methodology produces a scientific method which is fact-

based, relies on data, and is empirical, inductive and deductive [8]. It offers an all-encompassing improvement philosophy that solves problems and creates low cost rapid transformational improvements by utilizing powerful data-driven tools [9]. Lean Six Sigma is a process improvement strategy that combines two improvement programs, Six Sigma and Lean Enterprise, and is focused on enhancing quality, decreasing disparity and eradicating waste in an organization [10].

2. Materials and Methods

The overarching framework that was used to proffer improvement solutions to the production processes at the water bottling plant is a Lean Six Sigma framework known as the DMAIC framework. DMAIC is an acronym for Define, Measure, Analyze, Improve and Control. Therefore, it consists of five (5) phases.

Define Phase

In the Define phase, the waste reduction problem to be solved was described based on observation of the process. In this phase, data was obtained by using Lean Six Sigma tools and techniques such as Process stapling, Value Stream Maps, 5 Whys and cause-and-effect diagram, in order to identify problems.

The process stapling exercise involved walking through the entire production processes step-by-step in order to see first-hand what really happens, who does what and why, how, where and when they do it. By carrying out process stapling, an understanding of the steps in the process and also information such as how much time and movement is involved in carrying out the various production operations were obtained, thereby helping to identify opportunities to improve the production system.

A value stream map shows all tasks including value-creating and non-value-creating, which take the product from the idea stage to the launch stage, or from the consumer order stage to the delivery stage [11]. The value stream map was used to show all major work flows, information flow, flow of materials in process and important process measurements, so as to create a representative operational state. Fig. 1 shows the common symbols contained in value stream maps and their meanings.

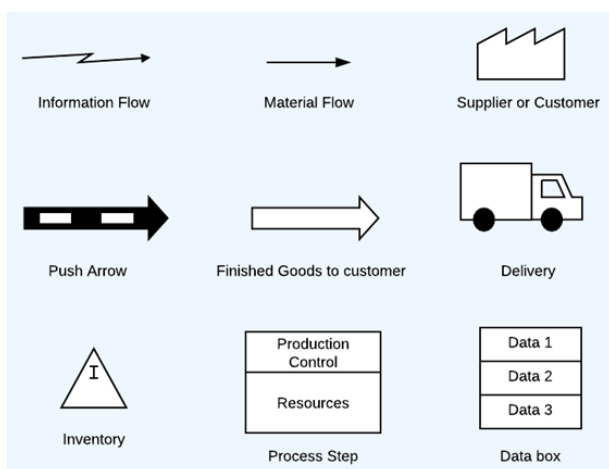


Fig. 1. Value Stream Map symbols.

In constructing the cause-and-effect diagram, a brainstorm was carried out and the possible major causes of the waste problem were grouped under Personnel, Machines, Methods and Materials headings. The 5 Whys technique was used together with the cause-and-effect diagram, to generate ideas for root causes of the waste problem during the brainstorm sessions. Each possible cause was examined and the list of root causes was gradually narrowed down.

Measure Phase

After defining the problem, how and how well the work gets done was clarified in the Measure phase of the DMAIC framework. Therefore, the Measure phase consisted of collection of data, gathering information of the process, measuring the critical factors that affect productivity and presentation of the data, so as to identify variation in the process. The Lean Six Sigma tool and technique that were utilized for data collection are: Check Sheets and Process Sampling. A basic check sheet was used to record the number of times a particular error occurred, along a time sequence. Data from the check sheet was represented on a Pareto Chart for analysis.

Since the water bottling processes at the bottling plant are high-volume processes, looking at each and every product, was

considered impractical, and so the Sub-group process sampling method was adopted. Equation 1 [11] was used to determine the minimum sample size of continuous data for a stable process.

$$n = \left(\frac{2s}{d} \right)^2$$

Where, 'n' is Minimum sample size, '2' is a constant representing a 95% confidence interval, 's' is an estimate of standard deviation data, 'd' is the difference (level of precision desired from the sample) being detected (in the same unit as 's') [11].

Water volumes of products in each sample were measured by using 1000ml (10^{-3}m^3) volumetric flasks. While process cycle time and manufacturing lead time were measured by using a stopwatch.

After data collection in the Measure phase of DMAIC the next step was presentation of the data in such a way that variations can easily be identified and understood. The Lean Six Sigma tools that were employed in the Measure phase for data presentation are the Pareto Chart and Control charts. All data were analyzed and presented by utilizing Minitab statistical software.

Basically, the Pareto chart tool aided in focusing on the vital few causes which were largely responsible for the waste problem. When providing solutions to these few causes is prioritized, a large reduction in the waste generated in the water bottling plant will be achieved. Moreover, the Pareto chart was used as the primary source of ranking data.

The specific control chart that was used to detect special cause variation is the ImR chart. It comprises of two charts: the Individuals (I) chart and the moving Range (mR) Chart. The formulae for calculating the chart centerline and control limits for continuous data [12] are as shown in equations 2, 3, 4, 5, 6 and 7.

For the mR-Chart, the centerline is given by the average of moving ranges calculated as follows:

$$\overline{mR} = \frac{\sum_{i=1}^n mR_i}{n} \quad (2)$$

Where, $\overline{mR}$ is the moving range average, mR is the moving range, n is the number of observations.

Upper Control Limit (UCL) is calculated by:

$$UCL = D_4 \overline{mR} \quad (3)$$

Lower Control Limit (LCL) is calculated by:

$$LCL = D_3 \overline{mR} \quad (4)$$

The values of the constants D_3 and D_4 can be obtained from tables of control chart constants.

For the I-Chart, the centerline is given by the average of data points calculated as follows:

$$\bar{X} = \frac{\sum_{i=1}^n X_i}{n} \quad (5)$$

Where, $\bar{X}$ is the sample average, X_i is a data point, n is the number of observations.

Upper Control Limit (UCL) is calculated by:

$$UCL = \bar{X} + 2.66 \overline{mR} \quad (6)$$

Lower Control Limit (LCL) is calculated by:

$$LCL = \bar{X} - 2.66 \overline{mR} \quad (7)$$

Analyze Phase

In this phase, an analysis of the data obtained in the measure phase was carried out in order to identify, verify and validate the root causes of the problems in the production process. The Lean Six Sigma tool and method that were employed in this phase are: box plots and hypothesis testing.

Box plots were used to provide a graphical representation of the characteristics of sample groups for easy analysis and comparison between the data sets. The box plots of data sets obtained were created using Minitab statistical software.

On the other hand, hypothesis testing was used to determine whether a particular value of interest is contained within the confidence interval. For hypothesis testing, the 1-sample T-test and One-way Analysis of Variance (ANOVA) were sufficient to confirm or reject the null hypothesis at a particular confidence level. Tukey's Pairwise comparison test was also carried out to determine which sample means in the ANOVA test differ. Hypothesis testing and Tukey's Pairwise comparison test were carried out using Minitab statistical software.

For the 1-sample T-test, the null hypothesis [12] takes the basic form of equation 8:

$$H_0: x = \text{a target value} \quad (8)$$

While the alternative hypothesis [12] takes the form of one of equations 9, 10 or 11:

$$H_a: x > \text{a target value} \quad (9)$$

$$H_a: x < \text{a target value} \quad (10)$$

$$H_a: x \neq \text{a target value} \quad (11)$$

For ANOVA, the null hypothesis [12] takes the basic form:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_k \quad (12)$$

The alternative hypothesis [12] takes the form:

$$H_a: \text{at least one pair of } \mu \text{ is different}$$

Where, μ is the sample mean.

Improve Phase

In this phase, the Future Value Stream Map (FVSM) was created. The FVSM was developed to provide a graphical representation of the future state of operations of the plant, and proffer solutions to the sources of waste identified in the CVSM. Also, improvement solutions were recommended based on customer priorities, cost, speed, ease of implementation and effectiveness in solving the problem, satisfying customers, as well as management.

Control Phase

This is the final phase of the DMAIC framework. In this phase, a control plan was proposed to ensure that the gains from the improvement exercise are secured and the new process is effectively deployed. The control plan ensures that the improvement process is carried out and sustained consistently.

3. Results and Discussion

Define Phase

The result of the process stapling exercise carried out at the water bottling plant is the Current Value Stream Map (CVSM) shown in Fig. 2. The CVSM in Fig. 2 shows the current state of operations at the bottling plant which was producing bottled water of $5 \times 10^{-4} \text{ m}^3$ (50cl) volume, in order to highlight the opportunities for improvement. The map shows the flow of information that begins with the individual customer at the right side of the map, then goes to information exchange in the plant, then up to the six (6) raw material suppliers (on the left). Basically, the water bottling process begins at the Preform Tipping operation, where approximately 17,000 preforms are loaded, into the Preform hopper, in about 3 minutes. The CVSM in Fig. 2 shows that one (1) operator carries out the Preform Tipping operation. Also, the operation has a yield of 87 per cent. Further, the loaded preforms are transported on a conveyor into a Krones Contiform Bloc blow moulder where they are blown to form the water bottles. To do so, the preforms are first carried through the modular linear oven where they are heated up to their optimum processing temperature by infrared radiation. From here, they are transferred to the blowing wheel, where they are placed in moulds to be moulded into containers by compressed air, in 12 blowing stations. From Fig. 2, a single operator monitors the operation, and the operation has a yield of 90 per cent.

Thereafter, the bottles are conveyed to a Krones Modulfill filler, where water is fed into the bottles until they are filled to the required specification. The bottles are then capped and sent on to the next process step for inspection. The filling and capping operation was monitored by two (2) operators, and the process had a yield of 45 per cent, while the inspection step required one inspector. Further, the filled and capped bottles are conveyed to a Krones Contiroll machine where the product labels are glued over the products. The labeling process step had a yield of 95 per cent and had one operator to monitor the process and an inspector to inspect the labelled products. Thereafter, the products were conveyed into the Krones Variopac Pro machine, a shrink wrapper, where bottles were grouped in twelves and shrink wrapped. The shrink wrapping process had two operators monitoring the process, with a yield of 55 per cent. Finally, bottles were packed and prepared for distribution to individual customers. First, the products were then conveyed to be palletized, and finally stretch wrapped, with a PRS Stretch Wrapper machine. The palletizing and stretch wrapping operations had one operator each, with yields of 100 per cent. Therefore, it is necessary to optimize processes with low yields.

The 5 Whys problem-solving technique was used and a cause-and-effect diagram was constructed to identify the causes of the waste problem in the bottling process. The cause-and-effect diagram is shown in Fig. 3. Therefore, the plant operations needed to be observed in order to identify and measure these sources of waste, and their frequency of occurrence.

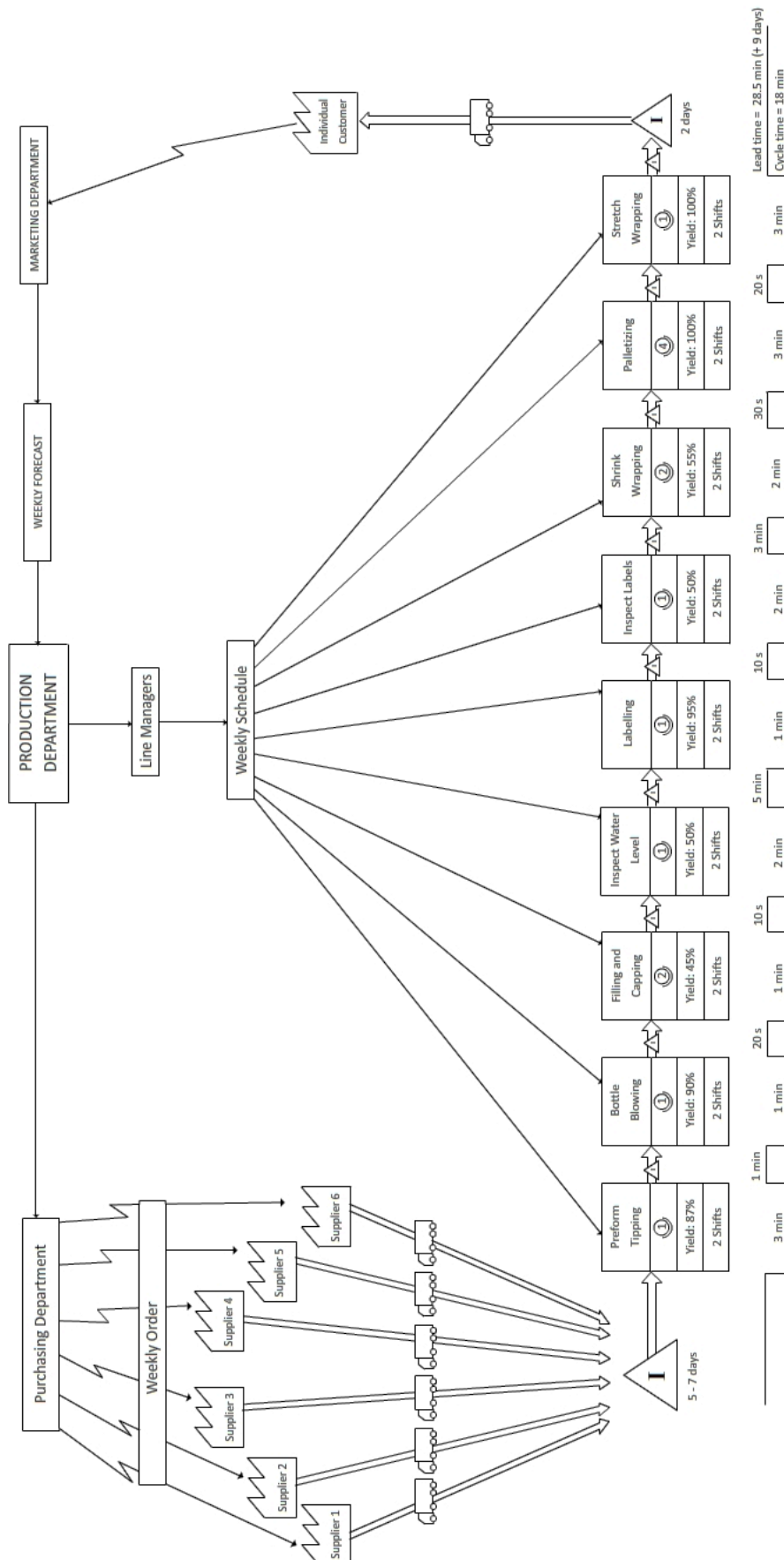


Fig. 2. Current Value Stream Map of production processes.

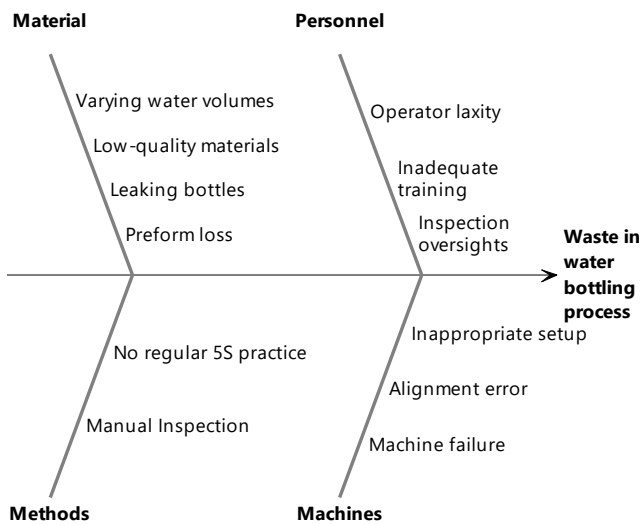


Fig. 3. Cause and effect diagram showing causes of waste in the water bottling process.

Measurement Phase

From the results obtained in the define phase, processes with low yields generated large amounts of waste within the plant. Therefore, the plant operations were monitored for a week to identify and measure the major sources of waste and their frequency of occurrence. The data obtained was ranked in the Pareto chart shown in Fig. 4.

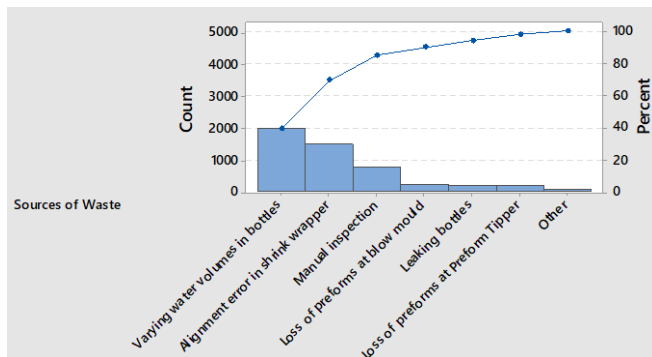


Fig. 4. Pareto chart showing the major sources of waste.

The Pareto chart in Fig. 4, shows that the vital few sources of waste in the plant which are responsible for majority of the problems in the plant are waste due to varying water volumes in the bottles, alignment error in shrink wrapper and manual inspection. These sources constitute an estimated 80 per cent of waste in the plant, therefore, it is necessary to concentrate on them.

In order to measure the problem of varying water volumes in the bottles, during a production shift, a sample was collected consisting of the first 40 products from the 40 fillers of the Krones Modulfill filler machine. The data is shown in Fig. 5, which is an ImR chart showing the varying water volumes in the bottles.

From the ImR chart shown in Fig. 5, fillers 14, 20, 23 and 29 are out of control due to special cause variation. This means that products from fillers 20 and 29 tend to have excessively filled bottles, while fillers 14 and 23 tend to produce insufficiently filled bottles. However, more analysis is required to confirm these assertions.

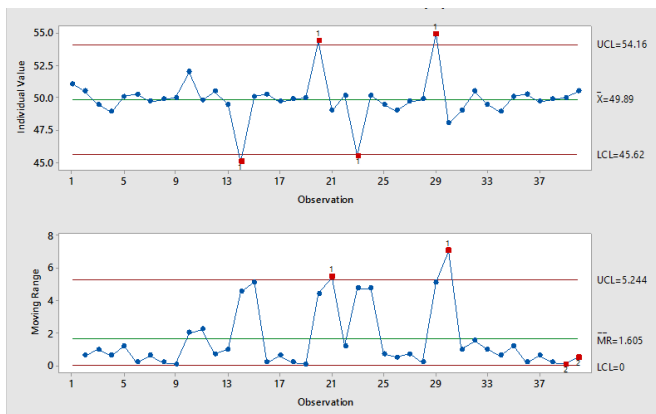


Fig. 5. ImR chart showing varying water volumes.

Analysis Phase

In this phase it was necessary to dedicate significant attention to the water volume variation problem in order to determine its root causes, as this was the most important problem identified in the Measure phase. However, the shrink wrapper alignment problem and the manual inspection problem were also analyzed in order to determine their root causes.

Water Volume Variation

A 1-sample T-test was conducted to determine if water volumes in bottles from Filler 8 were significantly different from the $5 \times 10^{-4} \text{ m}^3$ (50cl) CTQ requirement. Since the P-Value from the experiment was greater than 0.05, it was concluded that there is no significant difference between the mean of samples from Filler 8 and the 50cl CTQ requirement, at the 95 per cent confidence level. Therefore, Filler 8 was suitable as a control.

Using Filler 8 as the control, a box plot was created to compare the variation in the water volumes of products from Fillers 8, 14, 20, 23 and 29. The sample size was calculated from equation 1, using an estimate of standard deviation (s) of $1.63 \times 10^{-5} \text{ m}^3$ (1.63cl), calculated from data of the first 40 products from the 40 fillers, and a level of precision (d) of $5 \times 10^{-6} \text{ m}^3$ (0.5cl), at the 95 per cent confidence interval. The calculation is as follows:

$$n = \left(\frac{2 \times 1.63}{0.5} \right)^2 = 42 \text{ bottles}$$

Therefore, 42 bottles were collected at random, from each filler and their volumes were measured. The box plot of the variation in water volumes from the fillers is presented in Fig. 6.

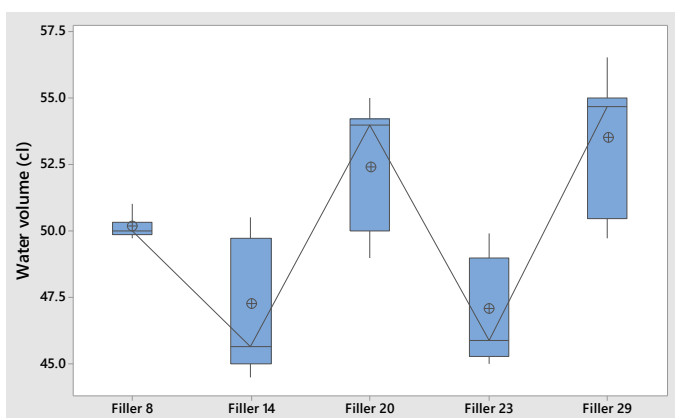


Fig. 6. Box plot of water volumes of products from Fillers 8, 14, 20, 23 and 29.

The box plot in Fig. 6 shows that there is little variation in the water volumes of bottles filled with Filler 8, when compared to those filled with Fillers 14, 20, 23 and 29. The box plots of Fillers 14 and 23, confirmed that water volumes in bottles from these fillers tend to be below the 50cl CTQ requirement, while those from Fillers 20 and 29 tend to be above the 50cl CTQ.

In order to show that the water volumes from these fillers are significantly different One-way ANOVA was conducted, with Tukey pairwise comparisons test. The P-Value of the ANOVA test was less than 0.05, therefore the means of samples from Fillers 8, 14, 20, 23 and 29 were deemed significantly different. The Tukey pairwise comparisons confirmed that the means of samples from Fillers 20 and 29 are not significantly different from each other, but are significantly different from the means of samples from Fillers 14, 23 and 8. Also means of samples from Fillers 14 and 23 are not significantly different from each other, but are significantly different from the means of samples from Fillers 20, 29 and 8. Thereby confirming that products from fillers 20 and 29 tend to have excessively filled bottles, while fillers 14 and 23 tend to produce inadequately filled bottles, when compared to products from Filler 8, the control.

From the foregoing, it is clear that machine failure is the reason for the varying water volumes. The root cause of machine failure was observed to be faulty inductive flow meters at Fillers 14, 20, 23 and 29 of the Kronos Modulfill filler machine. The inductive flow meter or mass flow meter is responsible for precisely determining the quantity of water to be filled into the bottles. Once the container has been centered, the filling process starts: the Proportional Flow Regulator (PFR) valve is opened and the product flows into the bottle. Once the required fill volume has been reached, the flow meter provides a signal to the PFR valve, to be closed and the filling process completed. As there is a fault with the flow meters of Fillers 14, 20, 23 and 29, this leads to varying water volumes from these fillers.

Shrink Wrapper Alignment Error

By carefully examining the shrink wrapping machine, it was noticed that there were tears on the belt of the belt drive. This caused the wrapping film not to properly transfer across the belt drive to the wrapping bar, leading to improperly wrapped packs. Also, the locking screw on the film roll holder was missing, therefore misalignment occurred due to improper replacement of film rolls, and also due to vibration of the running shrink wrapping machine. This led to defects in the shrink wrapped items, and consequently waste in the shrink wrapping process step.

Manual Inspection

It was observed that the inspection sensor devices which automatically detect and eliminate defective products were turned off, and instead quality inspectors were employed to detect defective products manually. The inspectors detect and eliminate defective products at a lower rate than the inspection sensor devices leading to waste in the form of overprocessing.

Improvement Phase

The improvement phase involved creating the Future Value Stream Map (FVSM) and recommending other ways of improving the current state of the water bottling process.

The Future Value Stream Map

In the analysis phase, the root causes of the forms of waste identified in the Current Value Stream Map have been examined and some improvement recommendations are shown in the Future Value Stream Map (FVSM) in Fig. 7. As shown in Fig. 7, the method of inspection has been changed to the use of inspection sensor devices to check the water levels and labels, and instantaneously eliminate defective products from the production line. The bottling plant already have the inspection devices installed, however they were turned off because of the varying water volume problem, and instead human inspectors were engaged to carry out inspection of the products. Fixing the root cause of the water variation problem and using the inspection devices will reduce the need for two (2) inspectors and the associated cost of paying these inspectors. Moreover, lead time will be reduced by 42.1 percent while cycle time will reduce by approximately 22.2 percent, if the future state map is implemented.

Other Improvement Recommendations

From the analysis phase, it was found that for the filling and capping process step the root cause of variation in water volumes in the bottles is the faulty inductive flow meters at Fillers 14, 20, 23 and 29. Therefore, it is necessary to replace the flow meters at each of these filling points, in order to achieve accurate fill volumes from the fillers.

Also, the locking screw for the film roll holder and the belt of the belt drive for the Kronos Variopac Pro shrink wrapping machine both have to be replaced, in order to eliminate defects and increase yield in the shrink wrapping process step.

Control Phase

After implementing the solutions proffered in the improvement phase, it is necessary to control the gains from the improvement exercise in the control phase. In this phase, control measures such as employee training should be carried out to educate employees on proper manufacturing practices and the importance of carrying out short term process improvement activities, to ensure that the improvement gains will be sustained.

4. Conclusion

Lean Six Sigma tools and techniques have been utilized to determine the root causes of waste in a water bottling process, as well as to proffer solutions to eliminate these sources of waste and attain a reduction in production cost. From the analysis, the major sources of waste which constitute approximately 80 per cent of waste in the plant are water volume variation, alignment error in the shrink wrapping machine and manual inspection. A more efficient process was proposed through a future state map. The proposed process required 2 less quality inspectors, eliminating the labour cost of paying these inspectors. Moreover, the lead time and cycle time will be reduced by 42.1 per cent and 22.2 per cent respectively, if the proposed process is implemented.

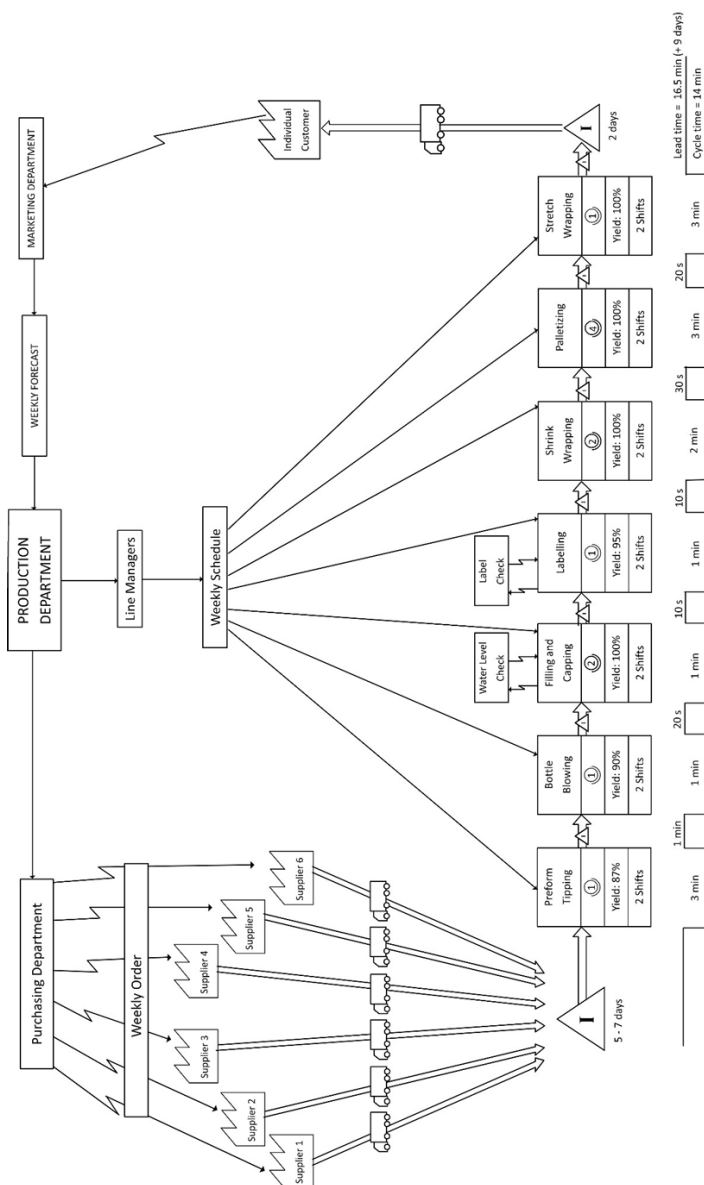


Fig. 7. Future Value Stream Map of production processes.

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