Application of Lean Six Sigma Methodology in Defect Reduction: A Case Study of Kalahari Ash Salt Bagging Plant

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Abstract

The purpose of the current manuscript is to discuss the application experiences of Lean Six Sigma (LSS) process improvement methodology in defect reduction. The work discussed in the manuscript pertains to the results that were obtained in the quality control improvement project of the 50Kg Bagging Plant process of Kalahari Ash Processing Company, Botswana, to eliminate product defects. The defects in this case, were defined as the 50 kg filled salt bags not meeting the expected standard weight as per customer specifications. At any given month, these defects amounted to an average of 17.6% of the total production output with a yearly customer compensation loss of about US$40 000. Several LSS tools were applied within the DMAIC (Define-Measure-Analyze-Improve-Control) process improvement methodology from defining the problem through control and up to recommendations that could eliminate the process defects. Tools such as SIPOC (Supplier-Input-Process-Output-Customer) diagrams, Process Maps, Cause and Effect diagrams, Process Capability Analysis and Gage Repeatability and Reproducibility (Gage R&R) were applied in the project. A Solution Selection Matrix was then applied to provide concrete recommendations to eliminate the identified process defects. Through Stability, Linearity and Bias tests the results showed that the weighing equipment was a major source of process variation leading to the observed percentage defects. This variation was due to several factors, one of which was the frequency and timing of the calibration of the weighing equipment. The analysis showed that, by changing the frequency and timing of the calibration of the equipment, a significant defect reduction percentage and improvement in customer satisfaction ratings could be achieved.

Keywords
Lean Six Sigma, Process Improvement, Quality Control, Defect Reduction, and Measurement System Analysis.

1. Introduction
Defects are defined as products that fail to meet customer specifications or expectations and may lead to many customer complaints (Gijo et al 2018; Saleh et al 2018). Parts, assemblies, or products that do not conform and are consequently unusable or require rework are classified as defects (Lachance, 2018). Defective products must usually be replaced; they necessitate paperwork and human effort to handle; they risk losing consumers; and the resources invested in the defective product reworks are usually wasted because it is not utilized productively. Production wastes can be reduced or eliminated using Lean Six Sigma concepts (Dora and Gellynck, 2015). According to Pyzdek (2010) if the right methodology structure of LSS is effectively integrated and applied, the intended project under consideration will significantly succeed. Lean six sigma comprises of two methodologies, namely Lean Manufacturing methodology and the Six Sigma Methodology.

Six Sigma is a process improvement methodology that focuses on reducing variation (Desai et al 2015) while Lean was created to maximize resource usage by reducing waste (Sundar et al 2014). As a result, the Lean Six Sigma concepts together aid in improving the process efficiency and quality (Rastogi, 2020). Six Sigma began in Motorola's production division, where millions of parts were manufactured using the same procedure repeatedly (Prajapati & Desai, 2014). While the Lean concept is generally discussed as originating from the Japanese industry, particularly from the Toyota motor company. Today Lean Six Sigma concepts have been used in a variety of industries, including services, medical, insurance procedures, call centers, and so on with successful results (Shamsuzzaman et al 2018; Trakulsunti et al 2022; Kovach and Borikar, 2018). In this study, the Lean Six Sigma concepts were applied to Kalahari Ash Processing company with the major aim to reduce defects in their 50Kg salt bagging plant. Kalahari Ash Processing company is a soda ash and salt producing company based in Botswana and is considered as the largest company that extracts raw materials, processes, and supplies natural sodium products in the African region. Kalahari Ash Processing company produces around 300 000 tons of soda ash and 650 000 tons of salt per annum. With this production, the company derives around 20% of its revenue from salt production and the remaining 80% comes from soda ash.

The current manuscript focuses specifically on the work that was carried out in applying the Lean Six Sigma process improvement methodology at Kalahari Ash Processing company to reduce defects in one of their production processes. Kalahari Ash Processing company management had been continuously struggling with providing their customers with consistent salt bags according to their customers' specifications. From the data that was obtained from company records for a period of a month at the beginning of this study, the company's defect rate stood at 17.6% (176 000 DPMO), with a sigma level of 2.4. These defects were defined as a salt bag of 50kg not meeting the customer specification limits, set between a minimum of 49.75kg to a maximum of 50.25kg. From this defect rate, Kalahari Ash Processing company was continuously forced to compensate the customers with around 348 bags yearly, which amounted to a total of 19.2 tons and a monetary loss of about US$40 000 annually.

1.1 Objectives

This study was aimed at finding solutions to reduce the defective salt bag weights which were shipped to customers from the 50kg coarse salt line of the salt bagging plant. Following the Lean Six Sigma DMAIC methodology, the first objective of this study was to first study and map the coarse salt line production process being followed by the company. After clearly mapping the process, the next step involved determining the possible factors that caused the salt bagging bag filling defects in the production process. Once all these possible factors were identified and data collected on them, a statistical analysis was used to check the influence of the identified factors on the production output. From there a Solution Selection Matrix (SSM) was used to propose and prioritize the LSS techniques that could be used to reduce the observed defects in the production process. Lastly Standard Operation Procedures were recommended that could be used to maintain the improved production process.

2. Methodology

The Lean Six Sigma DMAIC methodology was used in this case study to fully investigate the possible factors that could be leading to the high defect rates that were observed. DMAIC is an acronym from the words Define-Measure-Analyze-Improve-Control, according to Deming cycle (Sokovic et al., 2010). DMAIC methodology has been widely used in many process improvement projects with significant success rates (Jirasukprasert et al 2014; Adeodu et al 2020; Aziz et al 2021). Table 1 gives a summary of the methodology as it was followed in alignment with the objectives of this study and the major tools that were used in the different phases of the project (Table 1).

Table 1. DMAIC Methodology

DMAIC PHASE	OBJECTIVE	TOOLS USED
DEFINE	Study and map the coarse salt line production process.	Project Charter; Process Map; SIPOC Diagram
Measure	Determine possible factors that cause salt bag filling defects in the production process.	Data Collection Plan; Measurement System Analysis; Statistical Process Control; Process Capability Analysis; Cause and Effect Diagram
Analyze	Analyze problem-causing factors through use of Lean and Six Sigma analytical tools.	Regression; ANOVA; Two-Sample T-test; Stability, Linearity and Bias

Improve	Propose LSS solutions that can be used to reduce defect production.	Solution Selection Matrix, Brainstorming
Control	Recommend Standard Operation Procedures that can maintain the improved production process techniques.	Monitoring and Control Plan

The Define phase was used to understand the process in which the production defects came from, and production historical data was first used to calculate the DPMO (defects per million opportunities) and the sigma level which the process had been operating at. Several tools as depicted in Table 1 were used for that in this phase. The Project Charter was created first to help focus the project team on the real problem affecting the organization and to communicate who will be needed in the project and for how long. Following the Project Charter, a high-level process map was generated to help understand the major steps within the process and get a good appreciation of the whole process. Lastly a SIPOC diagram was generated to help clarify the scope of the process being investigated within the project.

The Measure phase was used to determine the current process performance state and the possible causes that caused the observed defects. Several tools as shown in Table 1 were employed to carry out that investigation. Before any data could be collected, a data collection plan was produced, which was used to guide the type of data that was to be collected, the sampling plan and frequency of the collection of the data. Following the data collection plan, a Measurement System Analysis (MSA) was carried out. This was to ensure that the observed defects were real defects from the production process as opposed to mere variation which could have been introduced to the product measurements by the act of the measuring system in place. After the MSA investigation, Process Capability Analysis (PCA) was then carried out to assess the capability of the process inputs in delivering a product that met the customers specification at that current state. After the PCA was concluded, a brainstorming exercise with the project team was carried out to identify the possible root causes that were causing the observed defects through the Ishikawa diagram. Though majority of LSS studies employ the Ishikawa diagram in the Analyze phase (Gijo et al, 2018), in this study this tool was employed in the Measure phase so that all the possible root causes that led to the observed defects could be identified (Raman and Basavaraj, 2019) and data on them could be collected in preparation for the Analyze phase.

The Analyze phase was used to analyze the data that was collected during the Measure phase. Several statistical analysis methods and tools were employed in this phase depending on the nature and type of data that was collected following the root causes identified. Tools such as regression, ANOVA, two-sample t-test were employed. The project team also decided to perform some Stability, Linearity and Bias test on some of the equipment following statistical results which were obtained from the statistical tests.

The Improve phase was used to select the best solutions that could resolve the problems that were identified through the Analyze phase. For this a Solution Selection Matrix was used following a brainstorming exercise and analysis by the project team.

Lastly through the Control phase, a Monitoring and Control Plan was created which could ensure the process continued to perform in a stable and sustainable manner.

3. Results and Discussion

This part of the manuscript presents the results and discussions following the application of the different sections of the DMAIC methodology.

3.1 Define Phase

After careful selection and formalization of the project team through the project charter, a high-level process map was created to help focus the project and get a clear picture of the process that was to be improved. Figure 1 was created following Gemba investigation and discussion with company management. The production process as shown involve retrieving brine, which is a high concentration salt solution, from the wellfields of the Kalahari ponds. The first step involves the harvesting of brine and processing it into raw salt before washing it to remove any impurities. From there, the salt is dehydrated to eliminate moisture content and is screened to separate the different grain sizes (coarse and fine). After that the coarse salt could either be sent to storage or otherwise sent to the bagging plant for packaging and loading onto customer trucks. During the times when the plant is in partial shutdown, the salt can then be retrieved from storage and sent to the bagging plant to continue servicing customers (Figure 1).

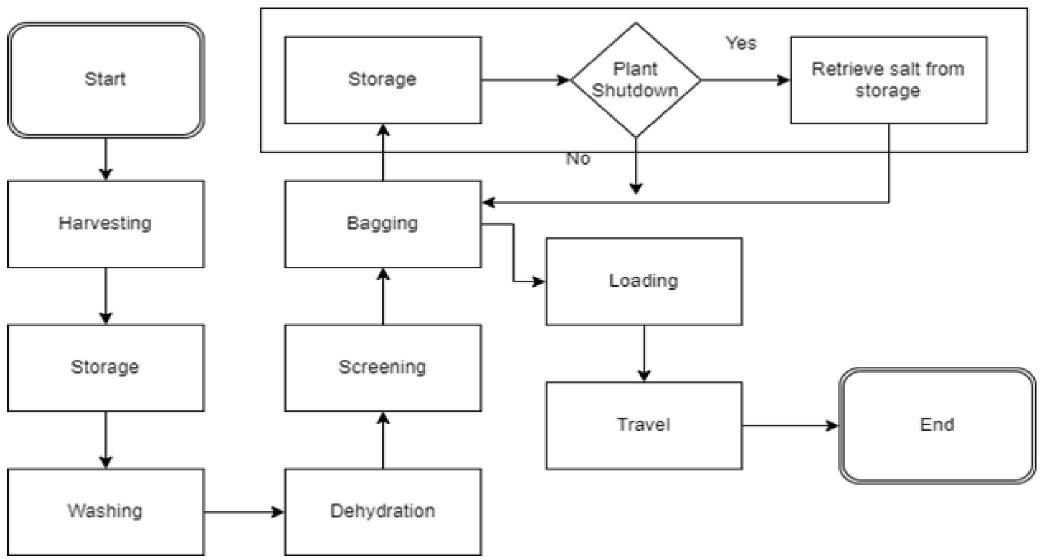

Figure 1. Kalahari Ash Salt Processing Map

Following the creation of the process map, a SIPOC (Supplier-Input-Process-Output-Customer) diagram was then created as a major step towards identifying the possible causes that could be causing the observed defects. The SIPOC diagram shown in Table 2, was created to help ensure all the major linkages between the suppliers and customers, and the inputs, and outputs could be easily explored and identified. The SIPOC diagram is a powerful tool that not only allowed the project to learn about the suppliers-inputs-processes-outputs but also the environment in which the value was realized and captured. This became vital later when we investigated the possible root causes.

Table 2. Kalahari Ash Salt SIPOC Diagram

Process: Salt Refining and Packaging			Date: 20-04-2022	
Scope: Coarse Salt Plant				
Suppliers	Inputs	Processes	Outputs	Customers
Who supplies the process inputs?	What inputs are required?	What are the major steps in the process?	What are the process outputs?	Who receives the outputs?
Mechanical Harvester	T-Brine	Harvesting	Raw Salt	Bell Hoppers
Bell Hoppers	Raw Salt	Storage	Salt Stockpile	Bridge Scraper
Bridge Scraper	Raw Salt from Stockpile and Wash Liquor (N-Brine)	Washing	Washed Salt and spent Wash Liquor	Coarse salt Centrifuge
Coarse salt Centrifuge	Salt (High-Moisture Content)	Dehydration	Dry Salt	Coarse Salt Stockpile
Coarse salt stockpile	Dry Salt	Screening	Coarse salt and Undersize salt	Salt Bagging Plant – Weighers
Salt Bagging Plant – Weighers	Coarse salt	Bagging	Unsewn Salt Bags	Sewing Machine

3.2 Measure Phase

Before any data could be collected, a data collection plan was created to guide the type of data that was to be collected, how it was to be collected, the sampling plan and frequency of the collection of the data. The data collection plan ensured that all the data collected was valid, meaningful and that all the relevant data and reliable data was collected. Before data on the identified root causes was collected, a Measurement System Analysis (MSA) on the Critical To Quality (CTQ) variable was carried out. MSA was carried out to quantify any possible variation that could be caused by the act of measuring the CTQ variable and not necessarily because of the effect of the identified root causes. The nested Gage R&R was chosen rather than the crossed Gage R&R because not all operators could be able to appraise all the samples collected as there were different operators for different shifts. The results that were obtained as shown in Figure 2, and Tables 2, 3 and 4 showed that the measurement system for the weight of the salt bags coming out from the production line was capable to distinguish defective bags from non-defective bags.

Gage R&R report of Figure 2 show different graphs for measurement system analysis which includes components of the measurement variation, R-chart, X-bar chart, measurement by parts, and measurement by operators. Zooming on the most important graph here, which shows sources of measurement error (components of variation), we can see that the largest part of the measurement variation is from the part-to-part variability, and that the Gage R&R variability seems to be very small which indicates the measurement system was capable, further explained through Tables 2, 3 and 4.

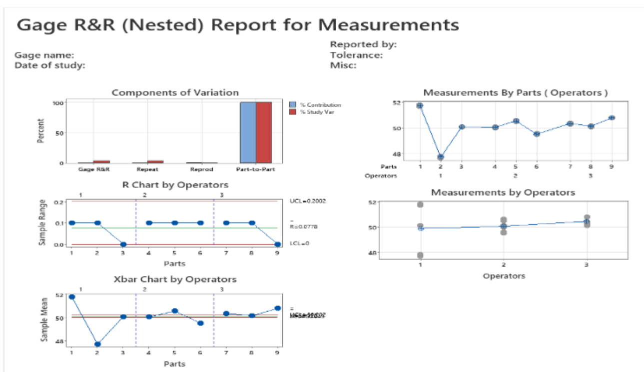

Figure 2. Gage R&R Report

The ANOVA result in Table 3 inferred that, there is no statistical difference among the competence of the operators in obtaining the measurements from the production output at the test statistic of 0.05, with an observed p-value of 0.8444 for the Operators source of variation.

Table 3. Gage R&R Nested For Measurements

Source	DF	SS	MS	F	P
Operators	2	1.5622	0.78111	0.17	0.844
Parts (Operators)	6	26.8778	4.47963	1727.86	0.000
Repeatability	18	0.0467	0.00259		
Total	26	28.4867			

From the observed Total Gage R&R % study variation in Table 4, which compares the measurement system variation to the total process variation, according to Automotive Industry Action Group (AIAG) guidelines the measurement system was deemed to be acceptable since the Total Gage R&R was 4.16% which was less than the 10% of the process variation as recommended for a good measuring system.

Table 4. Gage R&R % Study Variation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.05092	0.30551	4.16
Repeatability	0.05092	0.30551	4.16
Reproducibility	0.00000	0.00000	0.00
Part-To-Part	1.22162	7.32970	99.91
Total Variation	1.22268	7.33606	100.00

Given the observed data in Table 5, which shows the variance components and the percentage contribution from each component to the total variation observed, it was also concluded that the measurement system can reliably distinguish between defective and non-defective parts. The percentage contribution from repeatability is almost negligible at 0.17% whereas the percentage contribution from part-to-part variation was almost 100% at 99.83%. The repeatability percentage shows the percentage contribution when one operator measures the same part repeatably.

Table 5. Gage R&R % Contribution

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.00259	0.17
Repeatability	0.00259	0.17
Reproducibility	0.00000	0.00
Part-To-Part	1.49235	99.83
Total Variation	1.49494	100.00

Following the MSA, Process Capability Analysis (PCA) tests were carried out on the collected salt bag weight measurements to investigate the current process capability given the customer specification limits. For a PCA to be carried out, the data first had to be checked for distributional assumptions and whether the process was in control. The normality test showed that the data was normally distributed, and the Statistical Process Control (SPC) charts showed that the process was in control. Figure 3 shows the results that were obtained from running the Process Capability Analysis tests on the data, both the Cp and the Pp showed that the process was nowhere near being capable with both values being far less than 1 at 0.19.

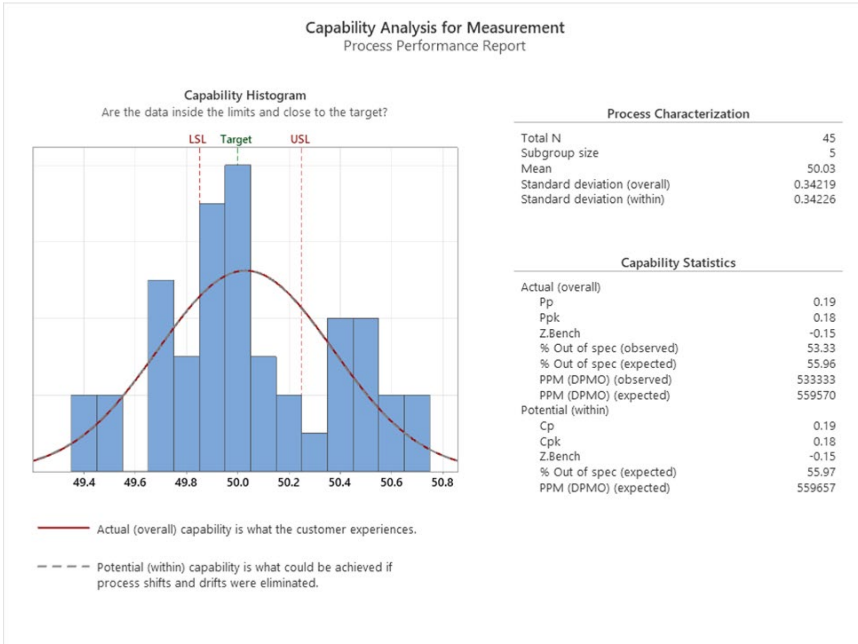

Figure 3. Kalahari Salt Process Capability Analysis

The Ishikawa diagram was then employed to brainstorm on possible causes of the observed defects in the production process. Figure 4 shows the results of the brainstorming exercise using the cause-and-effect diagram.

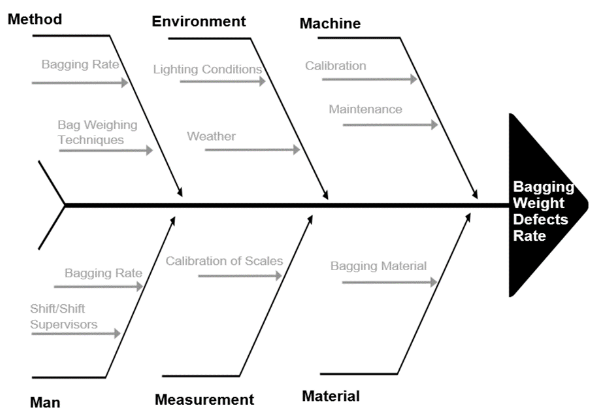

Figure 4. Kalahari Salt Process Root Cause Analysis

3.3 Analyze Phase

To test whether the production method being used influenced the defect rate being observed, the bagging rate and bag weighing techniques were investigated. The bag weighing techniques were investigated through the MSA analysis and the results indicated that the weighing technique being used was adequate, while a regression model was used to test the effect of the bagging rate on the rate of defects observed. The bagging rate is linked to the operators (man) operating the equipment and the method being used to operate the machines, and the hypothesis was that the rate of bags filled per hour could have an impact on the variation in the bagging weights observed. The regression model could only explain 3.3% of the observed variation in measurements and the conclusion was that the bagging rate does not significantly affect the defect rate being observed.

To test whether the different shifts and shift supervisors had a significant impact on the observed defect rate, an ANOVA test was run on the shift data collected. To test whether the ANOVA test could be used, the data was first checked for randomness through a Run chart, then an equality of variances test was also performed on the data. The data displayed on the Run chart had no observable patterns and all the p-values were greater than 0.05 except for clustering which was around 0.039. The test for equality of variances returned a p-value of 0.663 in favor of the null hypothesis that all the different groups had equal variances as shown by Figure 5. The ANOVA test then returned a p-value greater than 0.05 at 0.182 which showed that the different shifts or supervisors had no significant impact on the observed defect rate.

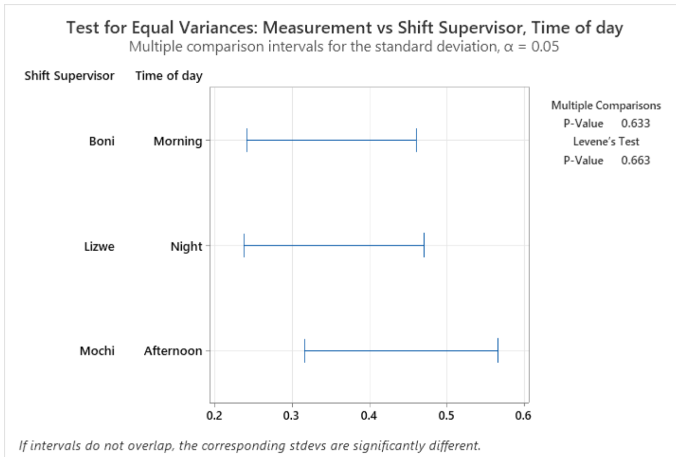

Figure 5. Equal Variances Test

To test whether the environment represented by the plant lighting conditions affected the observed defect rate, a two-sample t-test was performed on the number of defects produced by the day and night shift. The two-sample t-test returned a p-value of 0.828 in favour of the null hypothesis that the lighting conditions do not have any impact on the observed defect rate.

To test whether the equipment being used did not influence the observed defect rate, a Gage R&R test was carried out on the moisture testing apparatus and calibration, stability and linearity tests were performed on the bag filling equipment. The Gage R&R analysis was performed because it was important to know if the amount of moisture within the salt that exited the dehydration process step was within acceptable limits given that the amount of moisture in the salt at this stage would ultimately affect its mass with the passage of time. The Gage R&R results indicated that the percentage study variation was greater than 10% but less than 30% at 12.3 %. These results, although outside the 10% range which is normally seen as excellent, were still lower than 30% which is seen as a cut off for a good measuring system according to AIAG. The conclusion was that the measurement system was good enough to discriminate between good or bad parts according to the set moisture content specification limits.

For the bag filling equipment, calibration of this equipment was of paramount importance because the standard weight was supposed to be filled every time if the process was to have no defective products at the end of the line. This equipment was seen as one of the major equipment within the production process and it had three head weighers as shown in Figure 6. The equipment was used to weigh the amount of salt to be put in the 50kg bags before they are sewn for closing and readied for transportation to customers.

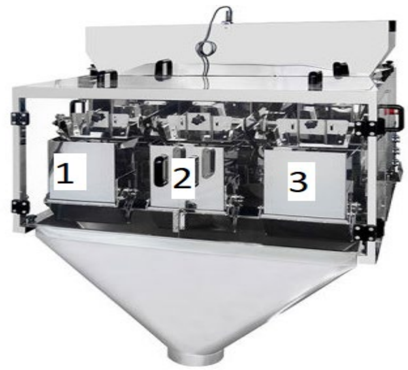

Figure 6. Three Head Weigher

Stability was performed across all the collected measurements whereas Linearity and Bias tests were performed for the different sections of the weighing equipment since all of them were used to measure and fill the bag in tandem. The results for the Stability test shown in Figure 7 indicated that the stability lowered by 0.00667 Kg daily around 0.01334% of the total expected bag weight. This result is quite significant because it showed that over a long period of time the drift will be significant and could reach around -0.2 Kg in a month's time. With the plant's current calibration regime of twice a year during plat-wide shutdowns this drift would significantly affect the production output and lead to the high observed defects.

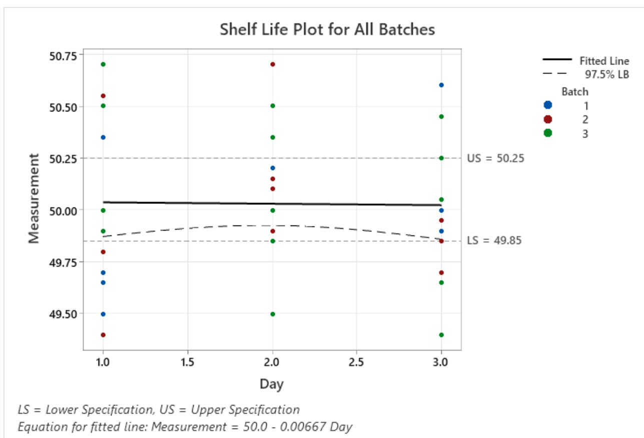

Figure 7. Stability Test Result

Table 6 shows a summary of the Linearity and Bias test p-values across the different weighing sections. The results show that the weighing equipment suffered heavily from linearity and bias across all the weighing sections, which meant the accuracy of the measurements across the expected range was questionable. Section 1 had a highly significant linearity which means it is not meaningful to interpret the average bias p-value. For the individual reference values, the lower values showed a positive bias, whereas the higher values showed a negative bias. This meant that this section continuously shows high bag weights while the actual bag weight was lower, and for the high bag weights, it showed a lower value. Section 2 had both significant linearity and bias. The bias showed an average of -0.79333 which basically meant that this section continued to give high weight bags low weight values. This result basically meant that Kalahari Ash was continuously giving away free product on the bags that were not part of the sampled products. Section 3 also had both significant linearity and significant bias. The average bias was 0.70667, this result meant all the bags that had to pass through this section were given high values when in fact they were lower than the required customer specification limits. These were the bags that brought customer complaints when they passed through the inspection process undetected.

Table 6. Linearity and Bias Test p-value results ($\alpha = 0.05$)

Weighing Section	Linearity	Bias
Section 1	0.000	0.097
Section 2	0.044	0.000
Section 3	0.000	0.000

3.4 Improve
Following the results obtained and the analysis done, a Solution Selection Matrix (SSM) was employed to formulate a cost-effective solution to solve the observed problem. The proposed solutions that followed a brainstorming exercise included repairing of load cells, recalibration of the load cells, cleaning the inside of the weigher, and replacing the load cells. Through the SSM the recalibration of the load cells using either the International Organization of Legal Metrology (OIML) RII F1 Class or the American Society for Testing and Materials (ASTM) E617-13 Class 1 was identified to be the best solution in overall. The solution was arrived at taking into consideration several factors which included the potential to meet the goal, cost to implement and time that could be required to implement the solution. Although cleaning the inside of the weigher to remove accumulated salt dust was also a potential solution, it was believed it could contribute to drift and bias in measurements, and its effectiveness could be low depending on how it is done.

3.5 Control
To sustain the improvements after recalibrating the load cells, a thorough monitoring and control plan was suggested. This could be done by adopting a new paradigm of calibration and maintenance. This new regime should include daily data collection sessions to monitor system performance with the use of rational subgrouping data. By employing SPC charts, the process monitoring could ensure the organization gets to see the changes and drifts in the process output in time and allow recalibration and maintenance of the load cells before defective products are produced. This way the recalibration and maintenance could be done according to the voice of the process rather than being done during plant wide shutdowns as it with the current regime.

4. Conclusion
The current manuscript discussed the application of Lean Six Sigma DMAIC methodology in solving real life practical problems by careful selection of the LSS tools and the systematic procedure of utilizing these tools throughout the life of a project. Production challenges that were experienced by the case study company were fully investigated and a solution was recommended to address the challenges that were experienced. The approach adopted in the study and solutions recommended can be applied to similar processes to potentially reduce production defects in similar settings.

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Kobamelo Mashaba currently works as a Lecturer at the Department of Mechanical Engineering, University of Botswana. Mashaba recently completed his PhD in mathematical modelling and currently does research in Manufacturing Engineering, Industrial Engineering and Control Systems Engineering.

Jerekias Gandure is a Professor in the Department of Mechanical Engineering, University of Botswana, and a registered Professional Engineer holding BEng (Industrial), MEng (Industrial), and PhD (Engineering) qualifications, and has experience in manufacturing systems, operations management and bio-fuels.

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