Application Of Lean Six Sigma Methodology In Defect Reduction: A Case Study Of Botswana Shade Net Manufacturing 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 a Shade Net Manufacturing plant in Botswana, to eliminate product defects. The defects in this case, were defined as the snapping of the manufactured plastic threads used in the production of the shade nets. This snapping of the threads created holes on the knitted nets which also then led to inconsistencies in the knitted pattern of the nets. At any given month, these defects amounted to an average of 60% of the total production output which compounded to a yearly monetary loss of about US$290 250 to the company. 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, Gage Repeatability and Reproducibility (Gage R&R), Multiple Linear Regression and Design of Experiments (DOE) were applied in the project. Ultimately, a Failure Mode Effects Criticality Analysis (FMEA) was also produced which could help the company to maintain and control the process according to the recommendations that were produced. The main findings of the study revealed through regression analysis was that four major process variables affected the tensile strength of the threads, and this led to the observed defects. Through DOE the optimal settings of these variables were identified, and the tensile strength was observed to increase by 9.1% from an average of 35.8718 MPa to 39.1269 MPa. This result also led to a significant defect reduction from 60% to only 0.025% of the total production output and a jump in the process sigma level from 1.25 to 4.98.

Keywords

Lean Six Sigma, Process Improvement, Quality Control, Defect Reduction and Design of Experiments.

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 is the fusion of two popular business principles, lean and Six Sigma into one methodology, to improve organizational performance and eliminate waste processes (Barbara and Chuck, 2003).

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 a case study company in Botswana, producing shade nets for various applications. The major aim of the work was to reduce the production of defective shade nets, which presented as the snapping of the threads used to manufacture the shade nets. This snapping of the threads created holes on the knitted shade nets which then led to inconsistencies in the knitted pattern of the nets.

The current manuscript focuses specifically on the work that was carried out in applying the Lean Six Sigma process improvement methodology at the case study company to reduce the production of defects in their production line. The case study company is a new company which recently began production in 2021 and its management has been grappling with finding a standard production process which can produce a large proportion of defect free products. From the data that was obtained from the company records at the beginning of this study for a period of a month beginning 01st August to 31st August 2022, the company's defect rate stood at around 60% of defective production, which translated to 600 000 Defect Per Million Opportunities (DPMO) and a sigma level of 1.25. From this defect rate, the case study company lost around P338 625 per month translating to P4 063 500 per year due to scrap cost and rework costs. This total yearly amount translated to around $290 250 in US Dollars, therefore this was quite a significant amount which the company needed to be address.

1.1 Objectives

This study was aimed at finding solutions to reduce the defective products experienced by the company and help reduce the cost of poor quality that was suffered by the company. Following the Lean Six Sigma DMAIC methodology, the first objective of this study was to first study and map the shade net production process being followed by the company. After clearly mapping the process, the next step involved determining the possible factors that caused the production of defects in the production process. Once all these possible factors were identified and data was collected on them, statistical analysis was used to check the influence of the identified factors on the production output mainly utilizing multiple linear least squares regression. From there a Design of Experiments (DOE) method was used to investigate the optimal settings for the parameters that were found to be significantly affecting the variable of interest in the multiple linear regression analysis. Finally an Failure Mode Effects and Criticality Analysis (FMEA) was used to develop a control plan that can ensure the company was able to manage and control the process going forward.

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 (Baaisi, et al 2022; Jirasukprasert et al 2014; Adefemi 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. DMAIC Methodology

DMAIC PHASE	**OBJECTIVE**	**TOOLS USED**
DEFINE	To study and define the shade net production process.	Project Charter; Process Map; SIPOC Diagram
Measure	To identify and measure production data on the possible factors that are likely to be causing the observed defects in the production line.	Data Collection Plan; Measurement System Analysis; Statistical Process Control; Process Capability Analysis; Cause and Effect Diagram
Analyze	To analyze and investigate the possible problem-causing factors resulting in observed defects at the knitting stage of the production process through the application of several Lean Six Sigma tools.	Measurement System Analysis (MSA); Multiple Linear Regression; Two-Sample T-test; Design of Experiments (DOE)
Improve	To propose Lean Six Sigma techniques that can potentially improve the process yield through solution selection matrix.	Solution Selection Matrix, Brainstorming
Control	To recommend control measures that can be used to maintain the improved production process techniques.	FMEA 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 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 (Baaisi, 2022; 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. Two major techniques were used in this phase, the multiple linear regression, and the DOE technique. Multiple linear regression was used to identify the significant parameters from a list of 8 possible factors that could potentially be influencing the variable of interest which led to the large percentage of defects experienced. The DOE was used to identify the optimal parameter settings that the company had to use to significantly reduce the observed defects. A two-sample t-test was also employed to investigate the influence of other parameters on the variable of interest.

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 an FMEA was constructed to help manage the identified process parameters and reduce any risk of them being out of control in the ongoing management of the process as a management control plan.

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 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 starts by weighing and mixing the HDPE granules with color pellets on the hopper mixer. After mixing, the hopper turns off indicating that the mixture is evenly mixed and then transferred to the extruder where they are melted and turned into threads. The extruder should not under heat or overheat the threads or they will not come out of the die head, the extruder barrel is set at temperatures between 250-270 degrees Celsius, if the extrude hopper runs dry of raw materials, the hopper re-fills itself automatically. The threads are then quenched to harden them at a temperature not exceeding 30.5 degrees and not less than 27.5 degrees Celsius. From there, they are passed through the first group of rollers to stretch them, motor speed is set not to overstretch or under stretch them and its limits are 230-250 rpm then the threads are annealed (at a temperature ranging from 80.5-90.5 degrees Celsius) so that they can be soft when stretched further by the second group of rollers to harden them for maturity, from there they are then wound on to bobbins. The draw warping process is then carried out to take threads from bobbins and put them on beams (with revolutions settings between 1000-2500 revs) which are then taken to the knitting machine where the threads are woven into a finished shade net roll.

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 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 in LSS studies 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 analysis became vital later when investigating the possible root causes through the Ishikawa diagram.

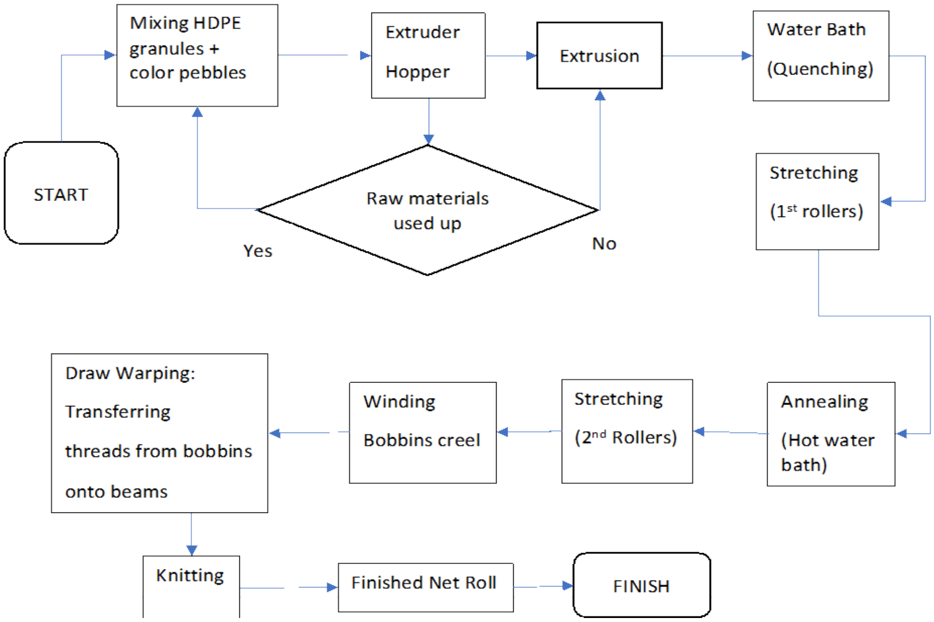


Figure 1: Shade Net Production Process Map

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 the tensile strength of the threads 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. Data was collected over a period of 13 days and a crossed MSA was carried out. From 300 bobbins at the end of each shift, 15 samples were collected randomly, and each sample was divided into two sub samples which were then given at random to the operators to measure and record the measurement readings obtained.
Table 2 and Figure 2 shows part of the results that were obtained from this analysis. It can be seen from Table 2, that there is a statistically significant difference between the 15 samples being measured and that there is no statistically significant difference between the results obtained by the different operators performing the measurements.

Table 2: Gage R&R Crossed For Tensile Strength Measurements

Source	**DF**	**SS**	**MS**	**F**	**P**
Sample	389	1050.34	2.70009	67.8387	0.000
Operator	1	0.00	0.00467	0.1174	0.732
Sample * Operator	389	15.48	0.03980	1.1617	0.042
Repeatability	780	26.73	0.03426		
Total	1559	1092.55			

While Figure 2 shows that from the variation being observed in the measurements, a large proportion of the variation is due to part-to-part variation as opposed to the variation observed from the measuring system itself represented by repeatability and reproducibility of the measurements.

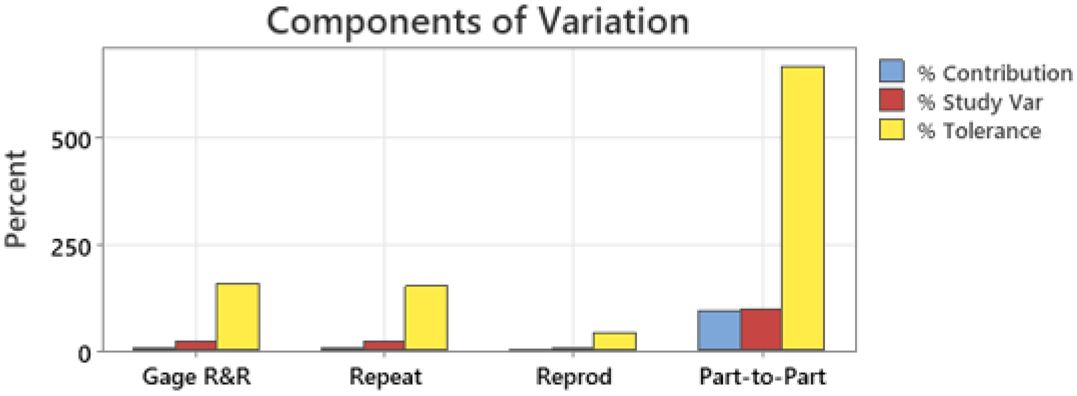
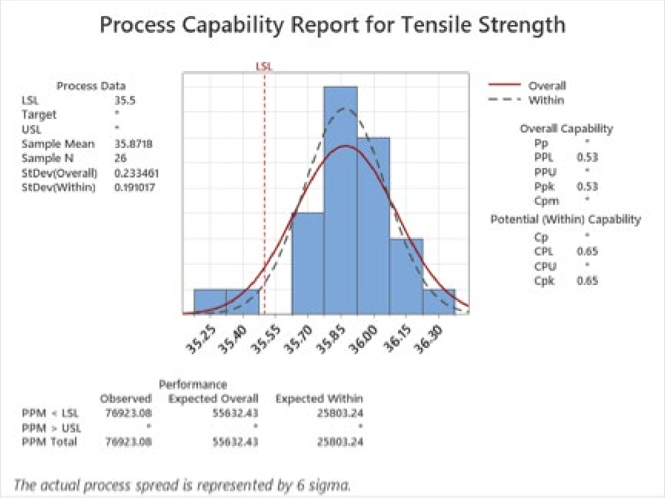


Figure 2: Tensile Strength Measurement System Variation Components

From the observed results, according to Automotive Industry Action Group (AIAG) the results showed that the measuring system can be relied upon for further analysis to be performed on the data to be obtained. That being the case, however the results also did indicate a need for further improvement on the measuring system particularly on the measuring equipment itself since from the Gage Evaluation results, the %study variation for Total Gage R&R and Repeatability were more than 10% though between 10 – 30% according to the acceptable standard.

Following the MSA, Process Capability Analysis (PCA) tests were carried out on the collected tensile strength 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, only the lower specification limit is shown since the process did not need to have a higher specification limit, the higher the tensile strength the better. It can be seen from Figure 2 that the Cpk = 0.65 which is less than one and far much less than 1.33 indicating that the process is currently not capable to produce defect free products (Weiss, 2019).


Process Capability Report for Tensile Strength

Process Data	
LSL	35.5
Target	*
USL	*
Sample Mean	35.8718
Sample N	26
StDev(Overall)	0.233461
StDev(Within)	0.191017

Overall Capability	
Pp	*
PPL	0.53
PPU	*
Ppk	0.53
Cpm	*

Potential (Within) Capability	
Cp	*
CPL	0.65
CPU	*
Cpk	0.65

Performance

	Observed	Expected Overall	Expected Within
PPM < LSL	76923.08	55632.43	25803.24
PPM > USL	*	*	*
PPM Total	76923.08	55632.43	25803.24

The actual process spread is represented by 6 sigma.

Figure 3: Tensile Strength 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.

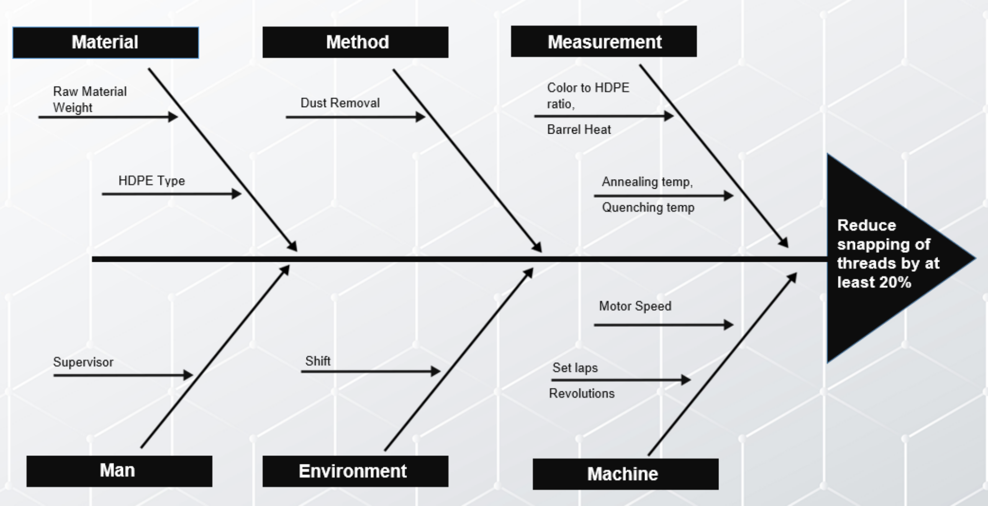


Figure 4: Shade Net Process Root Cause Analysis

3.3 Analyze Phase

From Figure 4, 12 variables were identified as potential causes of the observed defects using the 6 M fishbone diagram. These 12 variables were then divided into numerical and categorical variables, with 8 variables falling under the numerical group and four variables falling under the categorical variables. Two sample t-tests were then performed on all categorical variables influence on the tensile strength and all of them returned results in favour of the null hypothesis indicating that we can conclude that tensile strength is not affected by which supervisor is leading the shift, or by which shift was responsible for production, or by the HDPE raw material type used in production and also the type of dust removal method from the raw materials fed into the hopper.

To test whether the numerical variables influenced the tensile strength being observed, multiple linear regression technique was then employed. According to Anderson (2017), regression analysis is used to predict the value of a variable based on the value of another variable. The regression equation obtained from the analysis is shown below and Table 3 shows the ANOVA table obtained from the regression results. It is clear from the ANOVA table that only four variables, that is Motor Speed, Quenching Temperature, Annealing Temperature and Barrel Heat were significant at an alpha of 0.05 on the tensile strength observed. The regression equation showed an adjusted R-square value of 4.71% indicating that the model can explain a large proportion of the observed variation on the variable of interest.

Tensile Strength = -27.9 - 0.1010 Motor Speed - 0.381 Q-Temp + 0.697 A-Temp + 0.035 Raw Mat Weight + 0.0255 Color to HDPE Ratio - 0.000275 Revolutions + 0.000882 Set laps + 0.1181 Barrel Heat

Table 3: Tensile Strength Analysis of Variance Regression Table

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	8	78.4848	9.81060	56.92	0.000
Motor Speed	1	1.5383	1.53835	8.93	0.008
Q-Temp	1	2.2232	2.22325	12.90	0.002
A-Temp	1	1.1596	1.15958	6.73	0.019
Raw Mat Weight	1	0.0189	0.01889	0.11	0.745
Color to HDPE Ratio	1	0.3507	0.35068	2.03	0.172
HDPE type	1	0.046	0.046	1.10	0.152
Revolutions	1	0.2221	0.22211	1.29	0.272
Set laps	1	0.3614	0.36138	2.10	0.166
Barrel Heat	1	1.2243	1.22434	7.10	0.016
Error	17	2.9299	0.17234		
Lack-of-Fit	12	2.9071	0.24226	53.23	0.000
Pure Error	5	0.0228	0.00455		
Total	25	81.4147			

To check the multiple linear regression model for adequacy, standardized residual plots for tensile strength and a scatter plot of residuals versus the fitted value were created and a check for heteroskedacity was carried out. Figure 5 and Figure 6: indicated that the model was adequate, and the results could be accepted and used for further analysis.

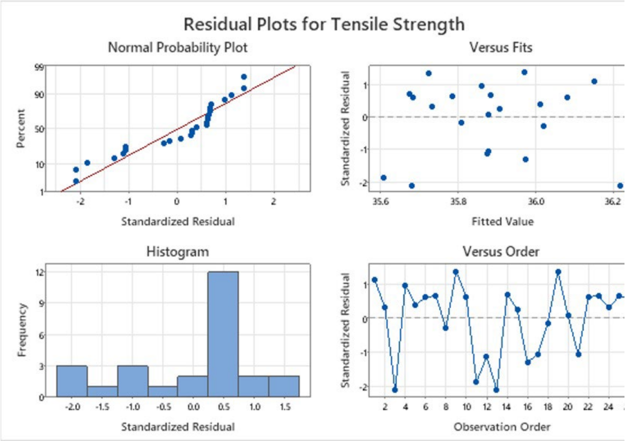


Figure 5: Residual Plots For Tensile Strength

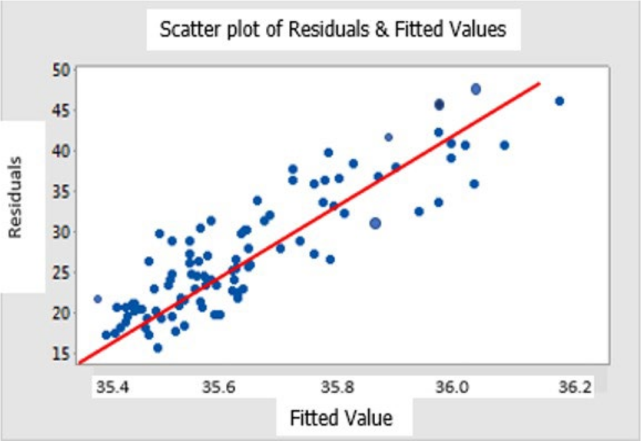


Figure 6: Scatter Plot of Residuals And Fitted Values

To determine the optimal settings of the four variables that were identified to be significant by the multiple linear regression analysis, a DOE analysis was set up with the four factors Motor Speed, Quenching Temperature, Annealing Temperature and Barrel Heat. The maximum and minimum levels of these variables were chosen to run the experiments. Since there were only four variables a full factorial design of $2^4 = 16$ experimental set up was used. Several results were achieved from the DOE analysis and only some of the results will be presented here due paper limitations. Figure 6 shows the normal plots of all the effects from the experimental set up on the tensile strength of the threads. It can be noted that all the main effects and their interactions are all significant at an alpha of 0.05 as they all deviate from the red line in the graph (Horse et al, 2020).

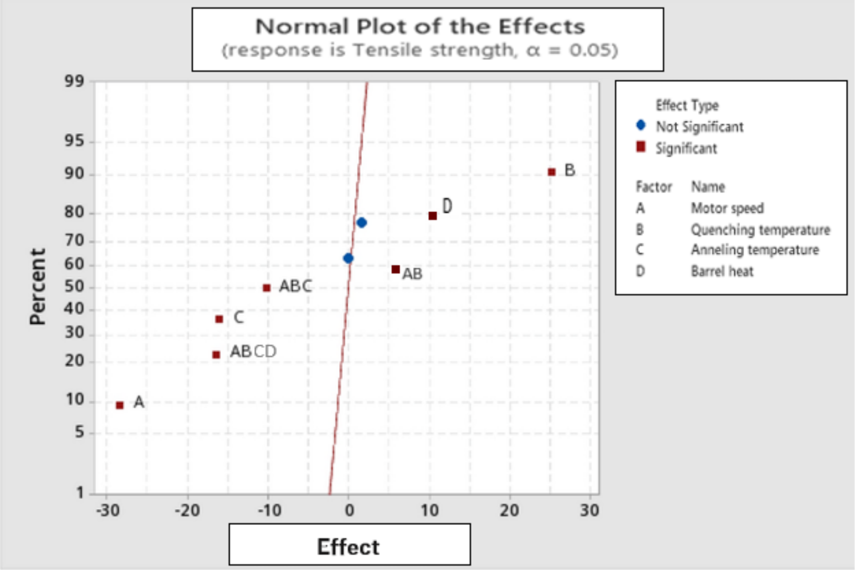


Figure 6: Normal Probability Plot Of Effects

A cube plot shown in Figure 7 was also obtained, which indicates all the 16 experimental runs carried out. Each corner of the cube is the tensile strength measured from each experiment and the connecting lines indicate the variables at their respective settings. The first cube has 8 corners, and the second cube also has 8 corners making a total of 16 tensile strength results from the 16 experiments. The cube plot indicates which combination of factors yielded the highest tensile strength and from careful analysis the highest reading is 39.4 Mpa on the bottom left inside corner of the second cube. The variables settings combination for that corner is Motor Speed of 280 rpm, Quenching Temperature of 27.5 °C, Annealing Temperature of 90.5 °C and Barrel heat 270 °C.

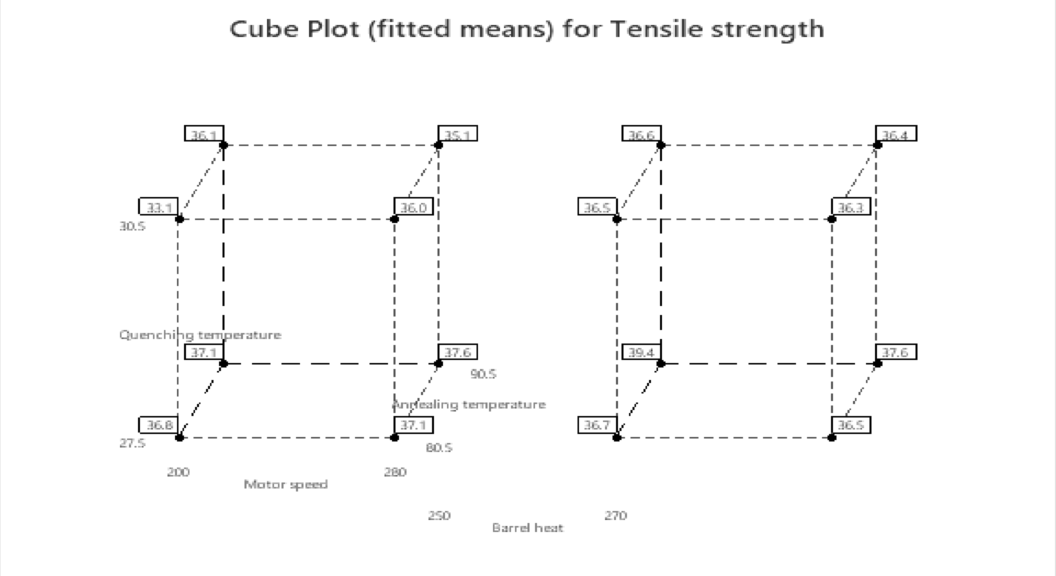


Figure 7: Tensile Strength Cube Plot

Following the DOE analysis a pilot test was of the settings was run for a full week and tensile strength results were collected from the production output as before. A paired t-test was then carried out to compare the before values (tensile strength data collected at the start of the project) and the after values (tensile strength data collected after finding optimum settings). According to Akdeniz et al (2019), a paired t-test is used to determine whether the mean of a dependent variable is the same in two related groups. It evaluates the before and after of a situation, treatment, or condition. A paired t-test analysis ran at an alpha value of 0.05 returned a p-value of 0.001 indicating that there is a statistically significant difference between means of before the optimal settings treatment and the after optimal settings treatment of the tensile strength values. Therefore, this showed a significant improvement on the tensile strength values of the threads. It was decided to then run another process capability analysis test on the tensile strength values and Figure 8 shows the results that were obtained.

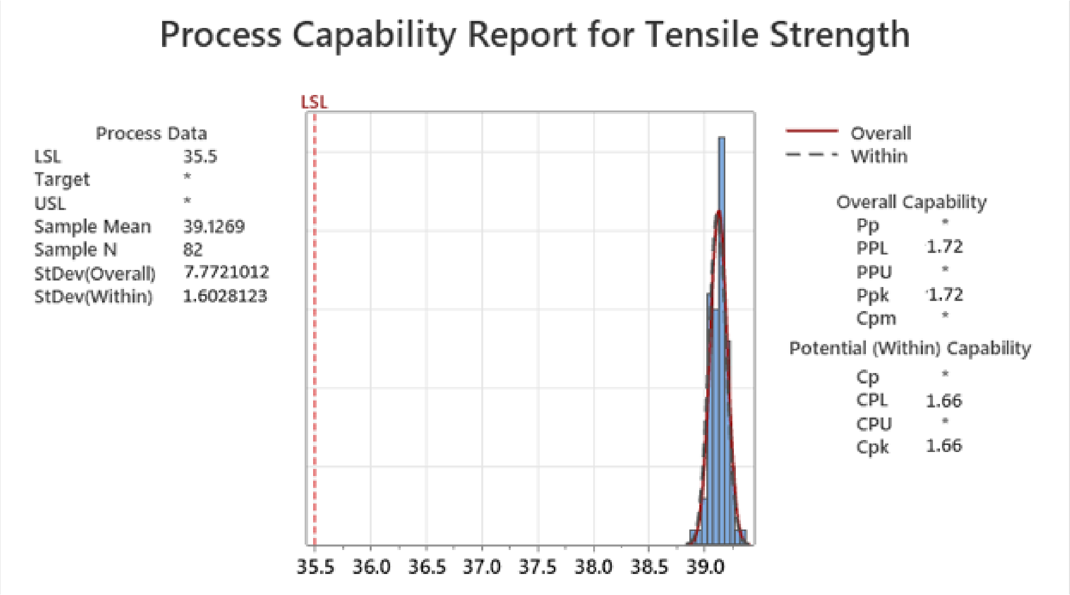


Figure 8: Tensile Strength Process Capability Analysis Of Optimum Settings Data

From Figure 8, the process capability output indices, C_{pl} and C_{pk} are equal to 1.66, the figure is above the standard cut off 1.33 which indicates that the process is now capable. The process has a lower specification limit of 35.5 Mpa but does not have an upper specification limit since achieving a high tensile strength is more than desirable. It can be noted that no values fall below the lower specification limit. From the C_{pk} of 1.66, the new process sigma level is now 4.98 ($C_{pk}\times3= 1.66\times3= 4.98$). Using the 4.98 sigma level the new DPMO was derived as 250.75 and DPU of 0.00025. Deriving percentage defects calculations from the DPMO the process now has an average percentage of defects of 0.025% which is far much smaller than the initial 60% defect production which the company was experiencing at the beginning of the project.

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 followed from the analytical findings that were obtained from the DOE investigation and a brainstorming exercise with the production team. It was observed that to effectively control the Motor Speed, Annealing Temperature and Barrel Heat, there were no major investments that would to be made into the current production process, but there will be a need to make some adjustments to the equipment used for controlling the Quenching Temperature. It was observed that there will be need to get a larger water tank more than 2 500 L than the current one that the company used. This conclusion was made because according to Rajan et al (2018), quenching for continuous processes that take material greater than 25 kg for more than 5 hours directly from an extruder require water volume that is larger than 3 000 L assuming an initial water temperature of room temperature 26-27 degrees Celsius.

3.5 Control

To sustain the process improvements that could be achieved by utilizing the recommendations from the study, an FMEA was constructed that also took into consideration all the other process steps of producing a shade net and Risk Priority Numbers (RPN) values were calculated. Apart from the four variables that were identified to be critical by multiple linear regression and DOE, the knitting step showed to be the most critical to be also managed closely. The potential failure of this process step could also lead to improper knitting structure of the shade nets even if all the other variables as identified have been effectively managed and controlled. The cause of the failure being due to threads not being inserted properly in all the needles used for knitting the shade net. The recommended action for this was for the company to investigate the use of pressure sensors that could detect that all threads has gone through the all the needles successfully. It was also suggested that the company invest in a quality control system that could employ the use of Statistical Process Control charts and collect a minimum of 15 samples to be tested at the end of each shift every day at the beginning.

4. Conclusion

The current manuscript discussed the application of Lean Six Sigma DMAIC methodology in solving a real-life practical problem 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 developed and piloted for a week, which led to significant achievement being realized. The approach adopted in the study and solutions recommended can be applied to similar processes to potentially reduce production defects in similar settings. For a follow up similar study, there might be a need to also include in the parameters to be investigated the residence time of the material in the quenching and annealing media process steps.

References

Anderson, R. K. (2017). The impact of regression analysis on predictive modelling. *Quality research*. 55(2), 232-44.

Akdeniz, Bilge, K., Dilek, M.T., Neriman, B (2019). Use of factorial design for analysing the effect of storage conditions on color quality of sun-dried tomatoes. Scientific Research Essays. 7. 477-489. 10.5897/SRE11.1376

Aziz, N. A., Ahmad, R., Mustafa, S. A., Sin, T. C., & Jusoh, M. S. (2021). Application of lean six sigma methodology to improve the weight inconsistency problem of coffee powder packaging. *Journal Sistem dan Manajemen Industri*, 74-86.

Adefemi, O, A., Mukondeleli, G, K-K., & Redani, M. (2020) Implementation of Lean Six Sigma (LSS) Methodology, through DMAIC Approach to Resolve Down Time Process; A Case of a Paper Manufacturing Company. *Proceedings of International Conference of Industrial Engineering and Operations Management. Harare, Zimbabwe, December 8 -10*

Baaisi, P., M., Monageng, R., O., K., Mashaba, K., Kommula, V., & Jerekias, G. (2022) Application of Lean Sigma Methodology In Defect Reduction: A Case Study of Kalahari Ash Salt Bagging Plant. *Proceedings of the First Australian International Conference on Industrial Engineering and Operations Management, Sydney, Australia, December 20-21, 2022*

Barbara W., M. C., and Chuck M, 2003. *Leaning Into Six Sigma: A Parable of the Journey to Six Sigma and a Lean Enterprise*, McGraw Hill.

Desai, D. A., Kotadiya, P., Makwana, N., & Patel, S. (2015). Curbing variations in packaging process through Six Sigma way in a large-scale food-processing industry. *Journal of Industrial Engineering International,* 119-129.

Dora, M., & Gellynck, X. (2015). Lean Six Sigma Implementation in a Food Processing SME: A Case Study. *Quality and Reliability Engineering International*, 1151–1159.

Gijo, E., V., Raniprasad, P., & Antony, J. (2018) Lean Six Sigma approach in an Indian auto ancillary conglomerate: A Case Study. *Production Planning & Control*, 29 (9); 761 - 772

Horse, J., Pinkman, J., White, W., Shredder, H., Lospolos, H. G,.(2020). *Exploring the Normal Effects of Experimental Designs*. Journal of Experimental research. 12(4), 121-132.doi: 10:13233/jer.2020.10.2.212.

Jirasukprasert, P., Garza-Reyes, J. A., Kumar, V., & Lim, M. K. (2013). A Six Sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process. *International Journal of Lean Six Sigma*, 2-21.

Kovach, J., and Borikar, S. (2018) Enhancing Financial Performance: An Application of Lean Six Sigma to Reduce Insurance Claim Denials. *Quality Management in Healthcare*, 27 (3), 165 - 171

Lachance, E. A. (2018). Types of Waste in Lean Manufacturing - Part 1 - Defects Waste. Worximity. *Retrieved from https://www.worximity.com/en/blog/defects-waste-in-lean-manufacturing*

Prajapati, N. J., & Desai, D. A. (2014). A Review of Six Sigma Implementation at Exporting Industries. *International Journal of Emerging Technology and Advanced Engineering*.

Pyzdek, T. A. K., P. A. 2017. *The Six Sigma Handbook: A complete guide for Green belts, Black Belts, and Managers At All Levels*, New York, Ny, Mcgraw-Hill Companies Inc.

Rajan. T. V., Sharma, C. P., & Sharma, A. (2018). *Heat treatmet: Principles and techniques. Prentice-Hall of india* priate limited, 23(3), 123-134

Raman, R, S., & Basavaraj, Y. (2019) Defect reduction in a capacitor manufacturing process through Six Sigma concept: A Case Study. Management Science Letters, 9, 253 - 260

Rastogi, A. (2020). A Brief Introduction to Lean and Six Sigma and Lean Six Sigma. *Retrieved from https://www.greycampus.com/blog/quality-management/a-brief-introduction-to-lean-and-six-sigma-and-lean-six-sigma*

Shamsuzzaman, M., Alzeraif, M., Alsyouf, I., & Boon-Chong-Khoo, M. (2018) Using Lean Six Sigma to improve mobile order fulfillment process in a telecom service sector. *Production Planning & Control*, 29: 4, 301 - 314

Saleh, G, M., Abohashima, H, S., & Aly, M, F. (2018) Defect reduction using Six Sigma Methodology in home appliance company: A Case Study. *Proceedings of the International Conference on Industrial Engineering and Operations Management*. Washington DC, USA, September 27-29

Sokovic, M. Pavletic, D. & Pipan, K. K. (2010). Quality improvement methodologies–PDCA cycle, RADAR matrix, DMAIC and DFSS. *J Achiev Mater Manuf Eng* 43(1):476–483

Sundar, R., Balaji, A. N., & SatheeshKumar, R. M. (2014). A Review on Lean Manufacturing Implementation Techniques . *Procedia Engineering* 97, 1875-1885.

Trakulsunti, Y., Anthony, J., Edgeman, R., Cudney, B., Dempsey, M., & Brennan, A. (2022) Reducing pharmacy medication errors using Lean Six Sigma: A Thai Hospital Case Study. *Total Quality Management & Business Excellence*, 33: 5 - 6, 664 - 862

Weiss, R. E., & Lazaro, C. G. (2019). *Residual plots for repeated measures*. Statistics in production, 11(1), 115-124.

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