A Six Sigma Project on the Improvement of a PVC Pipe Production

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Abstract

This paper explains our project about a six sigma application to improve a PVC pipe production process. We began with introducing the company that we chose which is the National Industry Company (NIC) and their production process of both PVC pipes and fittings. Then we used the DMAIC methodology to define the problem that they are facing which is defective pipes and fittings and in the measure phase we collected data regarding both productions and calculated the average defective pipes per month with their associated costs and decided to focus on pipe production lines. After that, in the analyze phase, we looked into the factors and found the root cause of the defective pipes are torque and feeder speed levels. In addition, we used Minitab to draw X bar-R charts and found that the process was out of control, hence we used contour plots to find the optimal settings of both torque and feeder speed levels. Finally, in the improve phase, we removed the out of control points that were out of the optimal settings found earlier and the process became in control indicating 89% improvements. Finally, we provided an out of control action plan for when an outlier appears on the X bar charts during the monitoring of the process.

Keywords: Pipes, defect rate, torque, feeder speed.

1. Introduction

A Plastic manufacture company was established in the 1960's in Kuwait which is one of the well-known companies that focuses on manufacturing and marketing of construction materials. It has two main factories which are located in Mina Abdullah and Sulaibiya; they also own 16 smaller factories which produce plastic, paint, ceramics, and interlocks. We chose to apply six sigma application on the production process of both pipes and fittings in this company as we found that they have a range of defective pipes and fitting products with an average of 2-2.2 % per month which is causing loss of customer ratification and loss of profit as well. Our main goal is to minimize the defective pipes produced by the company by 10% to improve their production line in order to gain customer satisfaction and to reduce their losses and increase their profits.

2. Literature Review

Nowadays, manufacturing industries are widely spread and since we will apply six sigma on a manufacturing industry, then most of our articles are under this topic. Gupta et al, (2017) applies six-sigma to decrease the variations in bead splice of a tire manufacturing company in India. After using DMAIC methodology the standard deviation decreased significantly from 2.17 to 1.69 and the process capability increased from 1.65 to 2.95 indicating a capable process with a lower defective rate. Moreover, Girmanova et al, (2017) implemented six-sigma to improve the metallurgic product quality of a company. They used both DMAIC and failure mode and affect analysis and the sigma level increased to 13%, lowering the defective rates and processing cost. Raman and Basavaraj, (2019) used six-sigma methodology to decrease the capacitor rejection issues in a manufacturing company in India. DMAIC strategy was used and great improvements in quality product were seen as well as a high reduction in cost and an increase in customer satisfaction.

In addition, Abbes et al. (2018) conducted six-sigma study on a small-medium sized enterprise to improve the quality of their clothes production by using DMAIC. In return, their process capability increased from 0.20 to 1.47 and the DPMO (defects per million) decreased from 780,000 to 308,000. Similarly, Prabu et al. (2013) applied six-sigma on a manufacturing company in India to overcome ovality in stage casting components. They used DMAIC as well as failure mode and affect analysis to improve the sigma level from 3.90 to 3.97. Zasadzień, (2015) applied six-sigma methodology to improve the machine failures and decrease their downtimes in the production process. After using DMAIC analysis, the machine failures reduced from 23 factors to only 2 factors and the downtime duration decreased from 18 to 9 hours. This resulted in an increase of machine availability and in a decrease of downtime duration as well as the removal of failure.

To add to the above article, Küçük and Orbak, (2011) studied the reduction of transportation costs in a pipe manufacturing company by using six-sigma methodology. The reason that transportation costs are high is because of the loading and unloading time of the vessel. The daily rate of loading the vessel is 1253 ton of pipes and the average waiting time was 26%. After applying the best solution they were able to load 2470 tons of pipes daily with an average waiting time of 13% only. More studies were recognized by Amri, (n.d) Amrianalysed a lean Six Sigma for improving pipeline project performance at a Project Site ABC base on Balance Score Card Framework. The company's objective is to reduce the reject rate of pipeline welding process and reject material for pipe replacement. Before implementation, welding had a defect rate of 14% and material had a defect rate of 7%. After improvements the defect rate for rejected welding decreased to 3% and material rate decreased to 0%, savings for the project increased to $23,000 for welding and $16,000 for rejected material. Likewise, Rehman et al, (2012) conducted a Six Sigma process on a cell site construction of a telecom company to find the factors that are causing the cell sites to break down and require maintenance. After the implementation of the six-sigma, cell sites breakdown and maintenance reduced to 48 defects in 80 cell sites resulting in a 5.02 sigma level and increasing company savings to $0.45 million.

In addition, Choomlucksana et al, (2015) studied a case study about manufacturing and they applied six-sigma to improve the efficiency of the production of sheet metal stamping. By using Poka-Yoke, 5s and lean manufacturing principle the processing time of a polishing stage was reduce by 62.5%. John and Areshankar, (2018) studied the reduction of the bearing end plate reworks in a machining process, by reducing the rework due to thickness and diameter variation. By using the six-sigma methodology the process met their requirements, improving thickness and diameter and reducing rework. Oguz et al., (2012) applied Six Sigma to the concrete- panel production system in a multi-housing complex project to decrease the number of projects behind the schedule. By using the combination of DMAIC methodology and by taking the variation of panel production as a critical total quality (CTQ) they were able to increase the panel production from 18/day to 75/day which decreased the number of projects delayed.

3. Methodology

We used the approach of six sigma application in specific DMAIC methodology tool in order to improve the company's production process and these phases are explaine below.

3.1 Define

After visiting NIC Company, we found that they have two main production lines, one for pipes and the other for fittings; hence we provided a flowchart for both production processes as shown in figure 1 below. The production process of both products start off similarly by oppening the resin bags, mixing them with the required materials, heating them and storing them for later use. Then when they are needed they are reheated and each production has its own separate line, for instance, the fittings go to the injection modling process and the pipes go to the extrusion line process. After both products are manufactured they are tested in the lab for their quality and if they are of acceptable quality then they are sent to the warehous, otherwise they are recycled.

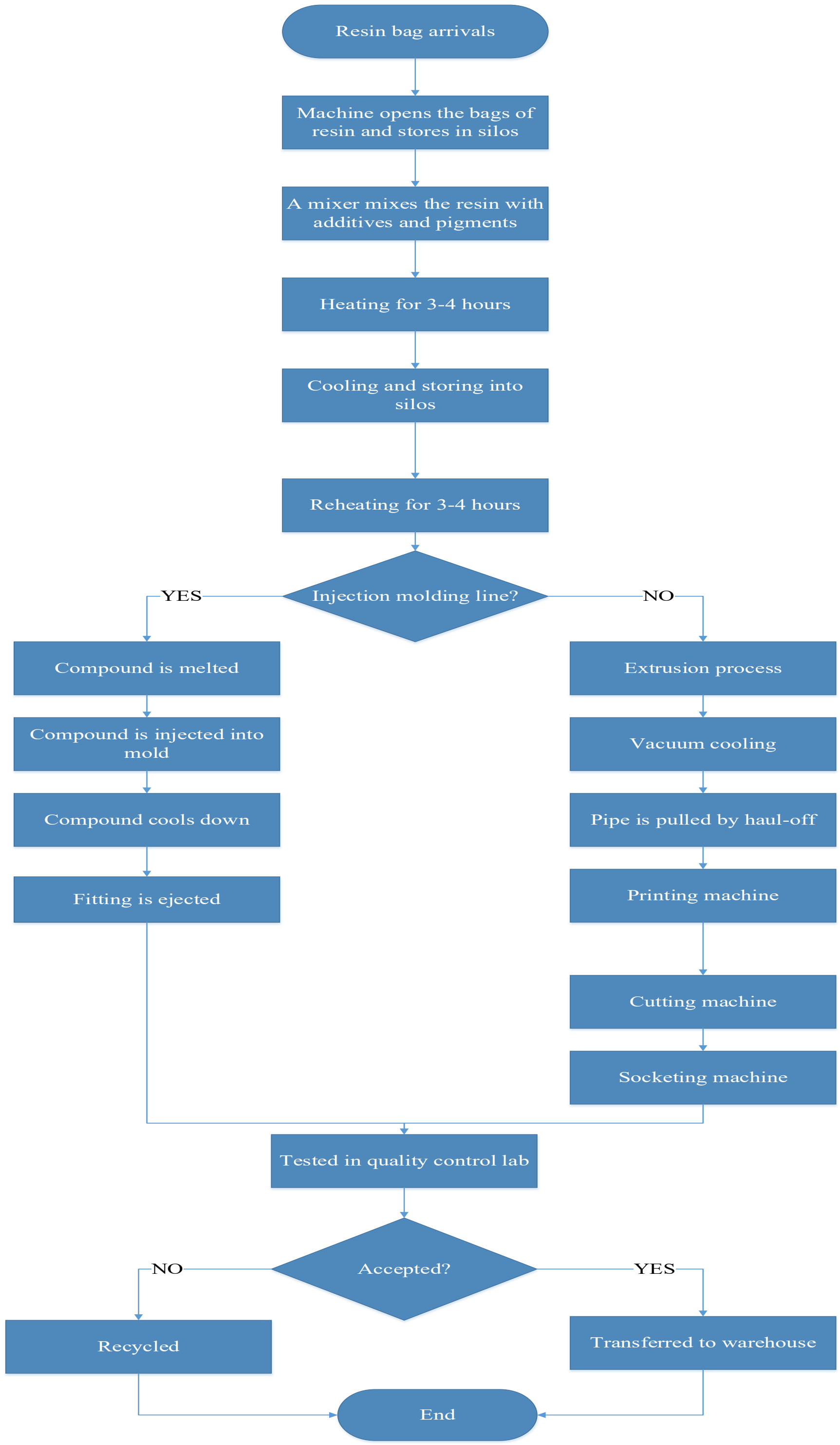

Figure 1: Process Map

We also illustrated the initial stage of both pipe and fitting industry to the final stage and this is shown in table 1 below. The company recieves their resins, pigments, lubricants and stabilizers from SABIC Company in Saudi Arabia and these products are used for both iinjection molding and extrusion process to produce pipes and fittings which are distributed to Sewage Companies.

Table 1: SIPOC table

Supplier	Input	Process	Output	Customer
SABIC Company in K.S.A. →	Resin Pigments Lubricant Stabilizer →	Injection molding process → Extrusion process →	Pipes Fittings →	Deliver to Sewage Companies

After meeting with manager of the company, we understood that he is concerned about the number of defective products in both the fittings and pipe industry and this is how we stated our problem statement, business case, goal statement, project scope and project plan as shown below in the project charter table 2.

Table 2: Project Charter Table

Opportunity Statement: National Industries Company is having a range of defective pipe and fitting products with an average of 2-2.2 % per month.	Business Case: The company has an opportunity to reduce the number of defects by studying the pipe and fitting production processes using the application of six-sigma.
Goal Statement: Our aim is to improve the defect rate of the pipe products by 10% and decrease the financial losses.	Project Scope: The boundaries of our study are the different pipes and fittings processes and their finished products.
Project Plan: (see below)	Team Members: Eng.Mohammad Kanso Anwar AlMerri Dalal AlAttar Kawthar AlSayegh Loulwah AlDoukhi Moneera AlSabah

Project Plan:

Phase	Start Date	End Date
Meeting with company	March 27, 2019	March 27, 2019
Define	Feb 11,2019	April 8, 2019
Measure	March 4,2019	April 11,2019
Analyze	October 1, 2019	November 5, 2019
Improve	October 28, 2019	November ,30 2019

3.2 Measure:

In this stage, we measured the defect rates in both the uPVC pipes and the fittings. We also drew some bar graphs to identify whether the production lines are producing a higher defect rate or whether specific products are.

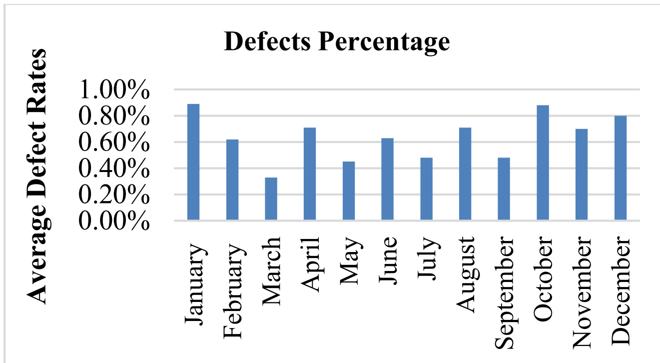

Figure 2: Average defect percentage of each month in 2018

From the graph above, we understand that throughout the year 2018, the minimum defect rate is seen in March (0.33%) and the maximum in January (0.89%). Therefore, we decided to look at the daily rejection summary for the entire month of January since it has the highest defect rate.

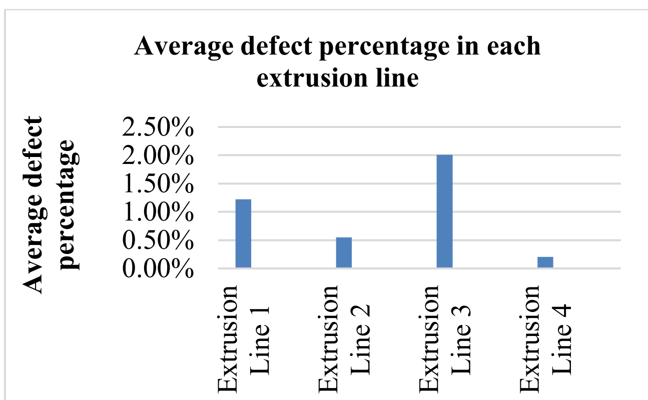

Figure 3: Average defect percentage in each extrusion line in January 2018

Figure 3 above, shows the average defect percentage in each extrusion line regardless of the type of pipe being produced. We can see that extrusion line 3 has the highest rejection percentage which is 2.01% compared to the other extrusion lines and hence we calculated it cost as shown in table 3 below.

Table 3: Cost of each pipe in extrusion line 3

Extrusion line 3 products	Rejected quantity	Cost/unit (KWD)	Total cost (KWD)
225x10.0x6000 Blue	1	10.9	10.9
160x7.7x6000 DG	7	8.8	61.6
200x14.0x6000 DG	9	9.5	85.5
200x4.5x6000 LG	31	8.2	254.2
315x7.7x6000 LG	13	12	156
		Sum	568.2

Table 3 shows the calculation of the cost of the rejected pipes that were produced in extrusion line 3 and we found it to be a total of 568.2 KWD. This means NIC Company has lost 568.2 KWD in one month on 61 defective pipes produced by extrusion line 3 only.

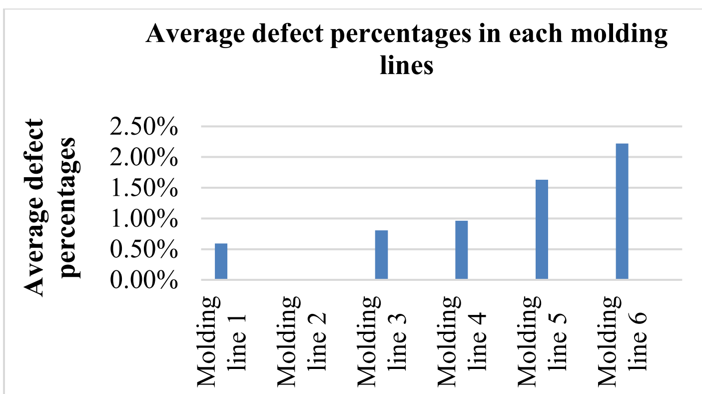

Figure 4: Average defect percentage in each molding line in January 2018

Figure 4 above, shows the average defect percentage in each molding line and we can see that molding line 6 has the highest rejection percentage which is 2.22% and the cost associated with this line is 17.87 KWD as shown in figure 5 below.

Table 4: Cost of each fitting in molding line 6

Molding line 6 products	Rejected quantity	Cost/unit (KWD)	Total cost (KWD)
110 COUPLER LG	35	0.45	15.75
110 COUPLER GB	4	0.53	2.12
		Sum	17.87

Table 4 shows the cost associated with molding line 6 and we can see that the total cost is 17.87 KWD. Therefore, comparing the costs of the highest defective extrusion line with highest deective molding line, we can see that altough molding line 6 has a higher defect rate of 2.22%, it costs only 17.87KWD, where as extrusion line 3 costs 568.2 KWD and this is why we chose to focus on extrusion line 3, in specific the 200mm pipe with 4.5mm wall thickness.

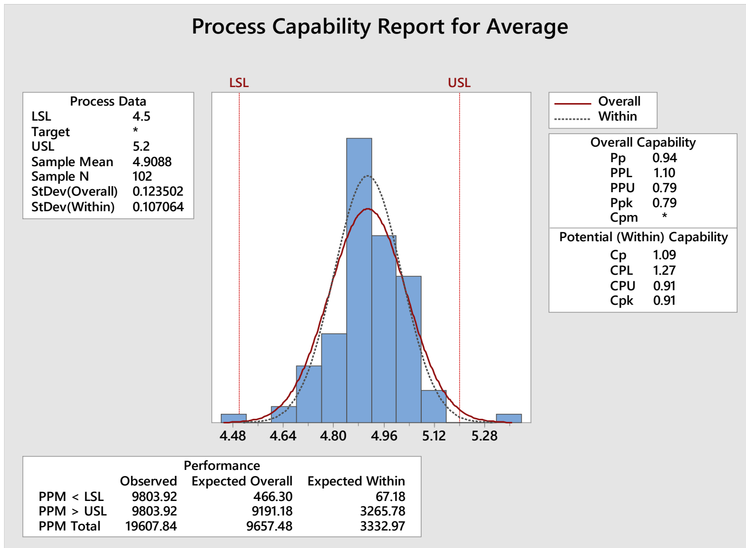

Figure 5: Process capability for average wall thickness of 200 mm pipe

We can see from figure 5, that the average wall thickness of some pipes are out of the acceptable range of specification limits (4.5mm up to 5.2mm) and the actual process capability is 1.09 which is acceptable but since the process capability index is 0.91, which is not equal to the actual process capability value then this means that the process is not centred and the average value of the wall thickness is below the lower specification limit. We can also see that the expected overall defective parts per million is 9,657 which is very large and by multiplying the process capability index value by three we understand that the company is operating at 2.73 sigma level currently which is very low and requires improvements.

3.3 Analyze:

In this phase we want to find the root causes of the problems so we had to check the factors affecting the extrusion process and we found that torque and feeder speed were the two factors that are closely related to our defect which is less wall thickness. In addition, we understood that every two hours the quality control inspector checks the pipe's wall thickness at eight different points (as shown in figure 6 below) using a vernier calliper and if one point is above or below the specification limit then it is recycled.

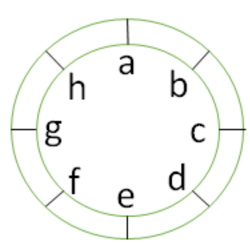

Figure 6: Pipe's dimension

We constructed an Ishikawa diagram to show the main reasons of the 200mm defective pipes and these were categorized into different headings which are; machine, method, manpower, environment and material. All the reasons below contribute to less wall thickness; however, after talking to the manager of the production process, we understood that the main root cause was the method where the feeder speed and torque factors exist.

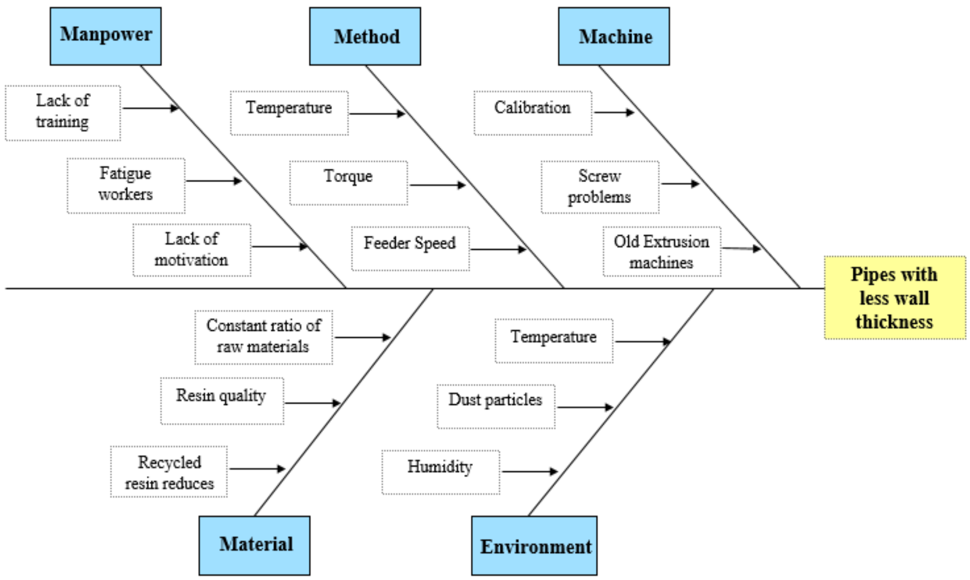

Figure 7: Ishikawa diagram

Response surface Methodology:

In order to check whether these two factors affect our response, we collected data regarding the current factor levels and wall thickness measurements for the 200mm pipe, and used Response Surface Methodology.

Response surface methodology is used to determine the effect of several factors and their interaction on one or more response variable. It uses the actual data which is measured throughout the laboratory control checks, which is the total opposite of the design of experiment that requires setting high and low levels for the factor, implementing them and measuring the response variables that they produce. RSM uses a regression equation that relates the independent input variables to the output variables in order to optimize the response.

Hypothesis Testing

H_0: Torque, feeder speed and their interaction has no significant effect on the wall thickness of the 200mm pipe at each specific point.

H_1: Torque, feeder speed and their interaction has a significant effect on the wall thickness of the 200mm pipe at each specific point.

Table 5: Response surface methodology results:

Point	P-value	R-squared	R-squared (adjusted)
A	0.234	6.76%	1.9%
B	0.207	7.17%	2.29%
C	0.086	9.43%	4.72%
D	0.36	5.47%	0.55%
E	0.58	3.85%	0%
F	0.58	3.81%	0%
G	0	20.37%	16.23%
H	0	23.19%	19.19%

From table 5, we can make a decision to reject the null hypothesis for the specific point's c, g, and, h since the p-value is relatively small and the maximum error that we might face in rejecting H_0 is only 8.6%. In addition, the r-squared values range from 9.43% up to 23.19% so we can say that between 9.43% up to 23.19% of the variations in the wall thickness of the pipes are explained by the torque and the feeder speed. Hence, we conclude that torque, feeder speed and their interaction significantly affects the wall thickness of the 200mm pipe at these points (c, g and, h).

Contour Plots:

In the figures 8,9, and 10 below, we drew contour plots for the significant points (c,g, and, h) that we found in the 200mm pipes to find the optimal settings of the two factors in order to minimize the defective pipes. From customer specification limit, we know that the pipes lower specification limit is 4.5mm and the upper specification limit is 5.2mm and after observing all the graphs shown in figures 8, 9, and 10. We perceived that on average the optimum limit for the torque is from 60% to 62.5% and the optimum limit for the feeder speed is from 28rpm to 29.5rpm to avoid defective pipes due to large/small wall thickness.

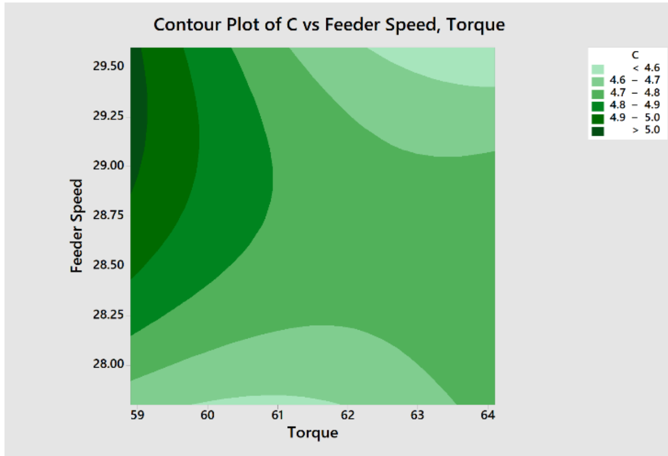

Figure 8: Contour plot for point c of the 200mm pipe

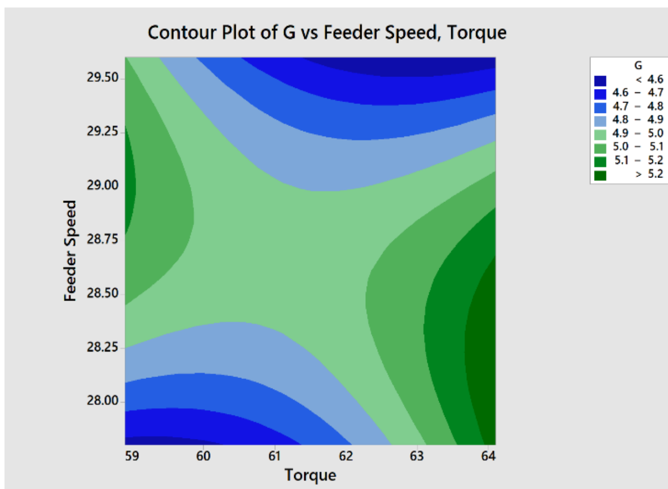

Figure 9: Contour plot for point g of the 200mm pipe

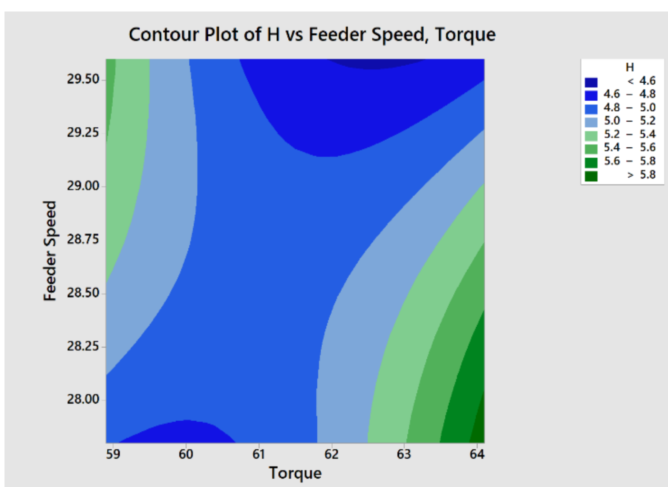

Figure 10: Contour plot for point h of the 200mm pipe

X-bar & X-bar R Charts:

X-bar and X-bar R charts were used to check whether the current process is in control or out of control for the significant points found earlier and the equations with their specific values for A2,D3,D4 were derived from (Web.mit.edu, 2019). The Xbar and Xbar-R charts shown in figures 11,12, and 13, are for the points c, g, and h of the 200mm pipe and they all have a minimum of two outliers per chart with point h having the most outliers. Therefore, we can understand that the process is out of control and we will check the torque and feeder speed level for each outlier to see whether they are defective because their settings are out of the optimal ranges we found from the contour plots.

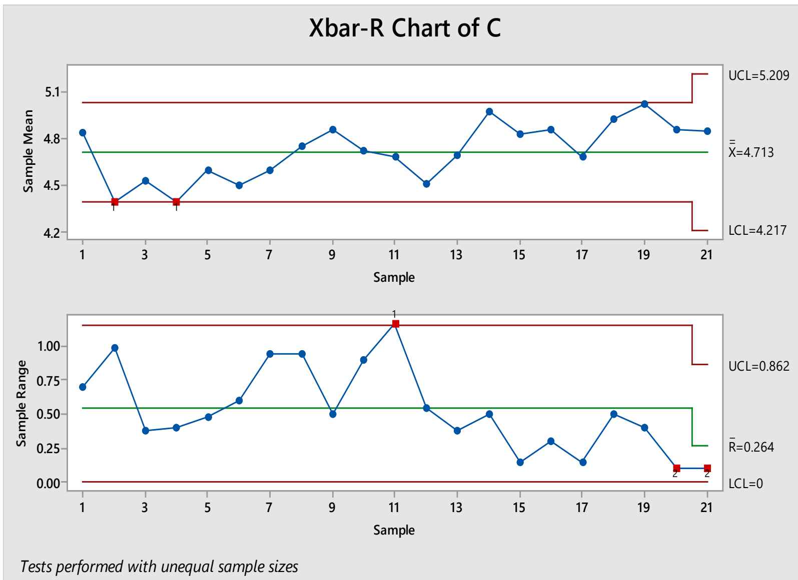

Figure 11: X-bar R chart for point c on 200mm pipe

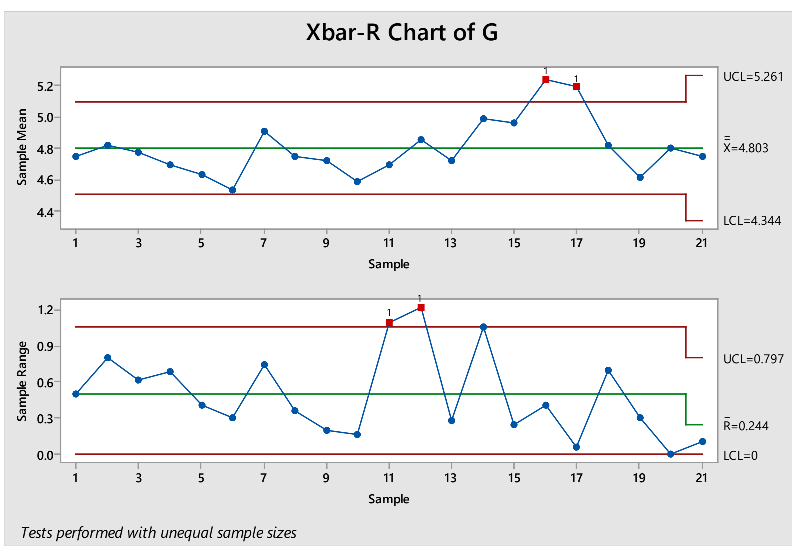

Figure 12: X-bar R chart for point g on 200mm pipe

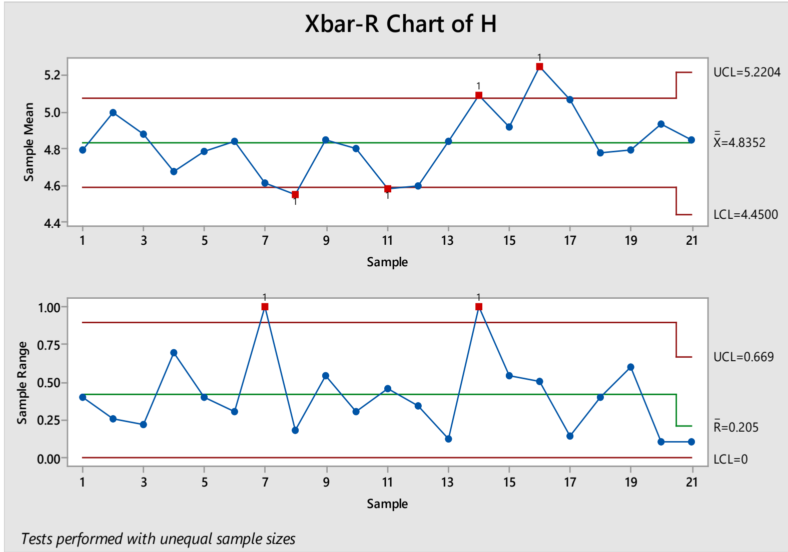

Figure 13: X-bar R chart for point h on 200mm pipe

3.4 Improve:

In this phase we iterated the Xbar and Xbar-R charts several times for the 200mm pipe to remove all the defective points that were caused by the settings of torque and feeder speed levels in order to finalize the control limits of phase I and these graphs after improvements are shown below.

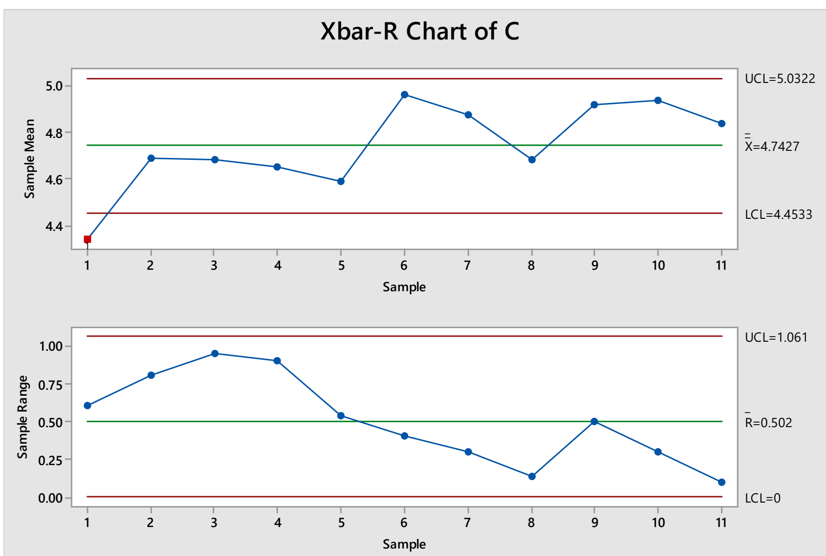

Figure 14: X-bar R chart for point c after improvements

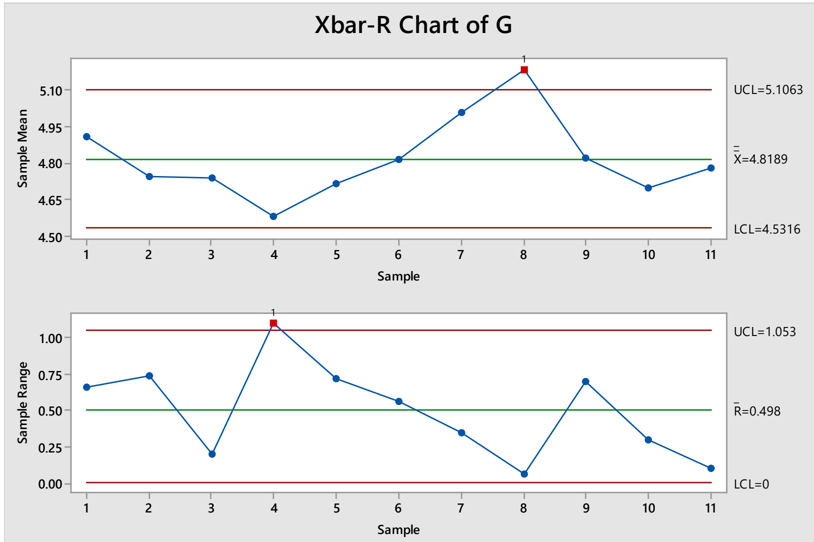

Figure 15: X-bar R chart for point g after improvements

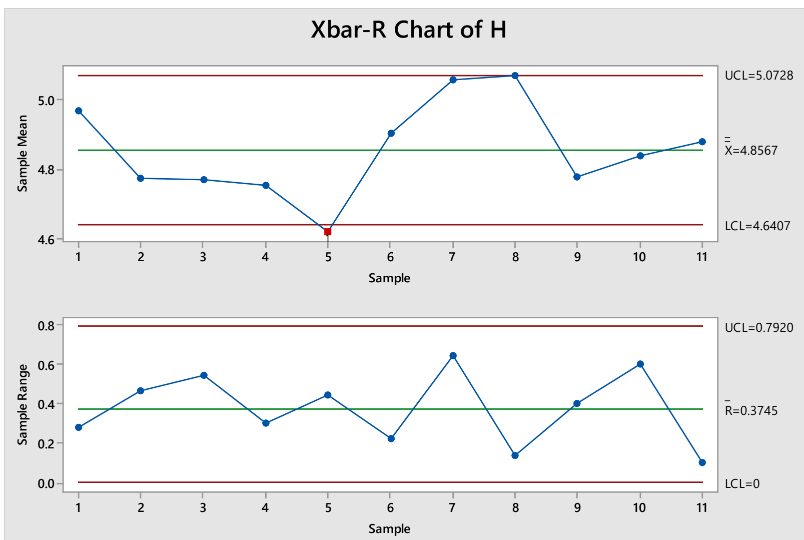

Figure 16: X-bar R chart for point h after improvements

After the iterations were made we finalized the upper and lower control limits as shown in figures 14, 15 and, 16, to be used for phase two. We found that all the out of control points were caused by the torque and feeder speed settings and after removing them we can see then nearly all the data points are within the control limits and the process is now in control. As a matter of fact, the one/two outliers that are seen in points c, g, and h are caused by chance and not due to the factors settings. Therefore, changing the optimal settings of torque from 59% up to 64% to 60% up to 62.5% is an effective solution.

Process Capability:

After improvements we recalculated the capability of the process and its index and found them to be 1.34 and 1.07 which means that the process is at an excellent state and is centered. In addition, the total defective parts per million has been reduced to 989 indicating that we succeeded in reducing the defects by 89.7%.

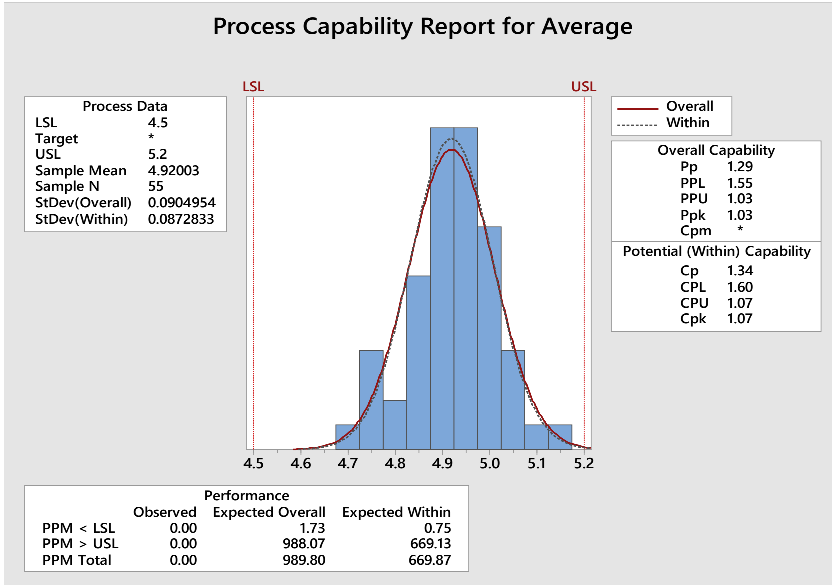

Figure 17: Process Capability report after improvements

Out of Control Action Plan:

After finalizing the control limits for both pipes, they can be used now to monitor the process and check to see if an out of control point is detected. If a defective point is detected then the Out of Control Action Plan shown in figure 18, below can be used. If an out of control signal is seen then the data must be checked whether it was entered correctly or not, then if it was entered correctly the failure test should be checked. From their onwards specific actions must be taken for the average test failure and for the range test failure. If the average test failed, then the torque and feeder speed levels should be checked and if they were not set to their correct levels then they should check whether this is the third adjustment or not. If it is, then the process engineer should be contacted, otherwise, the factor levels should be set to their optimal levels. However, if the range test failed, then the defective points out of the control limits should be checked for their causes and if they were caused by torque and feeder speed then by setting these factor levels back to their optimal settings the problem can be fixed.

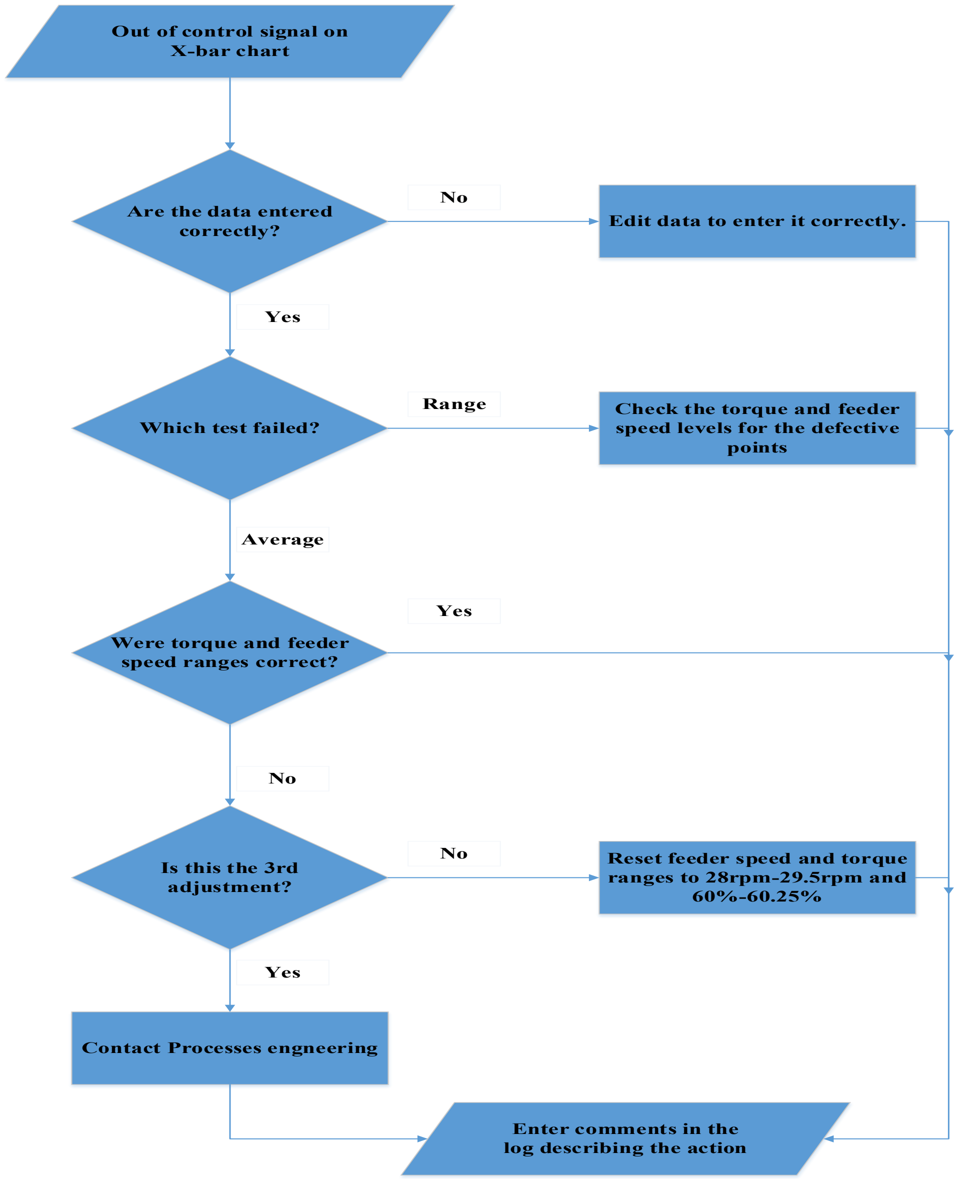

Figure 18: Out of Control Action plan

4. Results and Analysis

After careful observations, we found that pipes were defective due to less wall thickness and to find the cause of this we used response surface methodology to test specific factors significance on the eight points of the pipe's wall thickness. The results we gained from the response surface methodology provided us with the specific points that were being affected by both feeder speed, torque and their interaction. Then contour plots were constructed for these specific points to find the optimal settings of feeder speed and torque. Furthermore, control charts were established to see which points were out of control and to check whether the torque and feeder speed are out of the optimal settings or not. We found out that the torque and feeder speed ranges were too broad and this was the major cause of the defective pipes. In addition, we analyzed the capability of the process and understood that it was not working efficiently and was not centered but was producing on average less than the lower specification limit of the customer. Furthermore, the defective data points on the X-bar and X-bar R charts that were out of the optimal settings were removed and the ones within the optimal settings, were considered to be out of control because of natural causes and is kept in the readings. This step was done several times until the out of control points were all due to natural causes and the graphs were constructed again to show that now the process is in control. Moreover, the capability analysis was recalculated and showed an increase in the capability index indicating a centered process able to meet customer's satisfaction. Also, the number of defective parts per million decreased significantly from 9657 to 989 showing that the system improved by 89% and is producing less defective pipes. So, we learned that to not produce defective pipes the torque and feeder speed levels should be maintained within their optimal settings.

5. Conclusion

To conclude, we used six sigma methodology on a pipe production line in a plastic manufacturing company and we found that the problem they are facing is having 2.02% defective pipes per month. After conducting the phases of DMAIC we understood that the torque and feeder speed levels were causing the pipes to have less wall thickness and in return causing them to be defective. Therefore, we used Minitab to draw contour plots and were able to find the optimal settings for the torque and feeder speed level which when used provides us with an in control process plotted on an X bar-R chart. Hence, 89% improvements were achieved by providing the optimal settings of both factors.

Acknowledgement

We would like to express our gratitude to our professor Dr.Ufuk Kula who guided us throughout the project and helped us in completing it. We would also like to thank Eng. Mohammed Kanso, the manager of National Industries Company for being cooperative in providing us with all the necessary data and answers that we needed. Finally, we owe it to each other as a group as each and everyone of us put as much effort as the other to accomplish the projects goals.

References

Abbes, N., Sejri, N., Chaabouni, Y., &Cheikhrouhou, M. (2018). Application of Six Sigma in Clothing SMEs: A case study. *IOP Conference Series: Materials Science And Engineering*, *460*, 012009. doi: 10.1088/1757-899x/460/1/012009.

Amri, H. Kaizen-Six Sigma To Improve Pipeline Project Performance Base On Balance Score Card Framework. *The 4Th International Conference On Technology And Operations Management*, *4*(1).

Choomlucksana, J., Ongsaranakorn, M., &Suksabai, P. (2015). Improving the Productivity of Sheet Metal Stamping Subassembly Area Using the Application of Lean Manufacturing Principles. Procedia Manufacturing, 2, 102-107. doi: 10.1016/j.promfg.2015.07.090

Gupta, V., Jain, R., Meena, M., &Dangayach, G. (2017). Six-sigma application in tire-manufacturing company: a case study. *Journal Of Industrial Engineering International*, *14*(3), 511-520. doi: 10.1007/s40092-017-0234-6.

John, B. (2018). Reduction of Rework in Bearing End Plate Using Six Sigma Methodology: A Case Study. Journal of Applied Research on Industrial Engineering, 5(1), 1-17. Retrieved March 9, 2019.

Kucuk, M., &Orbak, A. Y. (2011). Six sigma approach for the reduction of transportation costs of a pipe manufacturing company. *2011 IEEE International Conference on Quality and Reliability*. doi.org/10.1109/icqr.2011.6031598.

Ozgur C. (2012). IMPLEMENTING LEAN SIX SIGMA: A CASE STUDY IN CONCRETE PANEL PRODUCTION. 2-11. Retrieved March 10, 2019.

Prabu, K., Makesh, J., Raj, K., Devadasan, S., &Murugesh, R. (2013). Six Sigma implementation through DMAIC: a case study. *International Journal Of Process Management And Benchmarking*, *3*(3), 386. doi: 10.1504/ijpmb.2013.058162.

Raman, R., &Basavaraj, Y. (2019). Defect reduction in a capacitor manufacturing process through Six Sigma concept: A case study. *Management Science Letters*, 253-260. doi: 10.5267/j.msl.2018.11.014.

Ur Rehman, H., Asif, M., AamirSaeed, M., Asim Akbar, M., &UsmanAwan, M. (2012). Application of Six Sigma at cell site construction: a case study. Asian Journal On Quality, 13(3), 212-233. doi: 10.1108/15982681211287775