Minimizing Bond Splits Between Rubber Extrusion and Mold Material in Vehicle Glass Run System

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Abstract

Initially there is a 16% scrap rate being seen at the customer plant of glass runs due to splits seen at the bonded location between extrusion and mold. Using the DMAIC phases of six sigma the project team defined the problem using a project charter, SIPOC, and VOC. It was decided on using a sample set from the three different operators on each shift in the production plant to effectively measure a small overall data set to see at what compression percentage between the mold cavity and measured extrusion thickness are we seeing good parts or bad parts. Analyzing the data it was found that from 0%-5% compression we are seeing no bad parts produced that lead to splits on vehicles. In a compression range from 5%-10% there is a one third chance of seeing a split on parts where this range falls in the split risk category and anything above a 10% compression there a split likely to occur where every single part measured in this zone failed on installation. Using the data and the generous tolerance currently used for extrusion of +/-0.75mm we decided to implement a smaller tolerance zone at +/-0.25mm to see if we could obtain an improvement in the percentage of scrap. Decreasing the tolerance has increased the amount of time to meet print for extrusion by 15 minutes for line start up but has not increased any scrap once the line is tuned and running for the shift. The 15-minute delay is not leading to any shortcoming on part production so there is no loss of revenue in using this additional time to fine tune the profile. After implementing the tolerance change a control follow up was conducted to see if we made an improvement in the sigma level. We managed to go from approximately a 16% scrap rate to 5% scrap rate meeting the customer expectations for the VOC and ultimately improving the sigma level from 2.48 to 3.18.

Keywords
Define, Measure, Analyze, Improve, Control

1. Introduction

Currently there is an issue with extrusion to molding leading to splits being seen during installation in vehicles for glass run static seal parts. This has triggered a six-sigma project to be conducted to help solve the problem and implement a solution that will work in the long term for the remainder of the project life cycle and even potentially transfer over into future projects. The project team will utilize six-sigma Define Measure Analyze Improve and Control (DMAIC) phases to work through the process. Within each phase a specific set of tools will help guide the team towards the end goal. The define phase will consist of using a project charter, project timeline and plan, SIPOC and VOC to initially define the project and layout all initial information needed to proceed with a plan to measure data. In the measure phase we will lay out the plan to collect qualitative data in a way that will inhibit potential responses to solve various potential causes of problems. During the analyze phase the team will look at the data by using specific charts and diagrams within Minitab to effectively interpret the data to translate into specific identification of needs to feed the improve phase. Additionally, a fishbone diagram will be utilized concurrently to identify potential root causes and ultimately identify the actual cause leading to the current failure we are seeing in assembly. The improve phase will look at comparing the data and creating an implementation plan for the identified cause with the solution that may solve it. From there we will transition to the control phase to re-measure sample sets of data like previously used in the measure phase to evaluate if our response and solution to the problem has efficiently increased our sigma level. Through this plan we hope to not only solve the problem but also provide a better fit for our products to match the voice of the customer.

2. Literature Review

The optimization that we are looking for deals with reviewing the tolerances in the injection molding process for good and bad parts. As such we have reviewed in depth what we are looking for in tolerancing to further understand the topic. This allowed us to better grasp the initial root cause and further expand to other issues that may be related to provide more complete optimization results. Additional literature reviews were completed for DMAIC methodology and associated tools to expand on what is covered in each portion of the Six Sigma process and what tools we will use to help guide us through each step of the process. The following subsections are the literature reviews for the basis of the Six Sigma project in tolerancing, DMAIC methodology, and DMAIC tools to be applied to our project.

2.1 Tolerance Overview

To further understand the initial potential problem, we needed to further understand exactly what is tolerancing is and what all may affect any issues with meeting dimensional expectations. Andreas Velling provides a good foundational understanding of what a mechanical engineering tolerance is and what it includes. He mentioned that "Engineering tolerance is the permissible variation in measurements deriving from the base measurement. A tolerance range sets the manufacturer a boundary for deviation" (Velling 2020). With this basic understanding of tolerancing we needed to look more in depth to what may have influence on tolerances for part deviations made of rubber. Reviewing publications and manuals we stumbled across a rubber manufacturing handbook that delved deep into tolerancing issues and the causes behind them to better prepare for additional root cause analysis for our project. The first issue that influences tolerances is shrinkage. "Shrinkage is defined as the difference between corresponding linear dimensions of the mold and of the molded part, both measurements being made at room temperature. All rubber materials exhibit some amount of shrinkage after molding when the part cools" (RMA 2005). The differences in the designed part and the designed mold could affect tolerances during cooling of the injection rubber. This leads us into the next issue with tolerancing being the mold design. "Molds can be designed and built to varying degrees of precision, but not at the same cost. With any type of mold, the mold builder must have some tolerance, and therefore, each cavity will have some variance from the others" (RMA 2005). The mold design precision has a direct correlation to cost. If you want to have a tighter tolerance on the design to mold, then the cost may be driven up for the mold itself. If there is long term life of a program and scrap rate reduction is important or customer satisfaction is crucial, then additional capital costs should be considered to maintain a tighter tolerance to extruded rubber parts. Another issue for tolerancing is the trim and finish from the rubber extrusion post extruded and prior to molding. "The objectives of trimming and finishing operations are to remove rubber material -- such as flash, which is not a part of the finished product. Often this is possible without affecting important dimensions, but in other instances, some material is removed from the part itself. Where thin lips or projections occur at a mold parting line, mechanical trimming may actually control the finished dimension" (RMA 2005). As stated, this may or may not be an issue but important none the less for the purposes of this project to keep in mind during the Six Sigma process. The last two issues deal with the material itself and characteristics that are associated with rubber. The flexibility of the material can be an issue for the operators operating the molding portion of the part process. "Because rubber is a flexible material, its shape can be affected by temperature. Distortion can occur when the part is removed from the mold or when it is packed for shipment. This distortion makes it difficult to measure the parts properly. Some of the distortion can be minimized by storing the part as unstressed as possible for 24 hours at room temperature" (RMA 2005). Along with flexibility of the material there is also the material makeup and capabilities of the plant for part handling after parts are produced. Depending on temperature and humidity during storing and shipping of parts there may be some tolerancing issues that are unseen until parts arrive at the customer. "Temperature: Rubber, like other materials, changes in dimension with changes in temperature. Humidity: Some rubber materials absorb moisture. Hence the dimensions are affected by the amount of moisture in the product" (RMA 2005).

2.2 DMAIC Methodology Overview

The DMAIC methodology used is to ensure that the root cause of the variations witnessed are identified, and improvements instituted to ensure future productions are within the required dimensions. The first step is to define what the problem is. In this case, the problem is the variations seen in rubber production, which results in production of bad parts. In defining, the voice of the customer is critical. The next step is to measure the level of variations witnessed. This is a data collection procedure, which aims at creating baseline metrics that will be used to make comparison as to whether any improvement has been made. Next is to analyze the nature of the problem. In this phase, analysis tools must be used, such as fishbone diagrams that are used in identifying the root cause of the injection variation. Then, the improvement phase aims at utilizing the information obtained from the analysis phase to ensure that going forward, the injection system will minimize on the production of bad parts of rubber. "In improving, testing solutions using the plan-do-check-act cycle (PDCA) helps in ascertaining whether the solutions are effective and feasible" (Sokovic, Pavletic & Pipan, 2010). Finally, controlling to ensure the changes are embedded and sustainability is guaranteed for the future is necessary. A control chart is applied to gauge whether the improvements instituted are sustainable over a certain period of time.

2.3 DMAIC Applied Tools

The tools used in the DMAIC Six Sigma process include project charter, project timeline and plan, SIPOC and VOC in the defining process, fishbone diagrams, Minitab charts, P-chart analysis, and cause and effect diagrams in the analysis phase, and control charts in the control phase. The tools used in the define phase act as the 5 W's to provide the baseline or outline of the project. This will set the groundwork to visualize the and plan the project based on the process and voice of the customer. The next set of tools will be used in the analyze phase where we will take the data collected and transpose into quantifiable reports and charts utilizing Minitab. In this phase the cause and effect or fishbone diagram will be utilized. These allow us to work backwards to find root cause analysis and investigate other potential causes to the undesired effect. Pareto charts specifically indicate the frequency of defects of the rubber injection system, which highlights the number of defects being generated within a specific time. "Fishbone diagrams while highlight the exact reason why the defected occur the way they are" (Yurin et.al.2018). Control charts will then be used in the control phase to showcase the changes that happen over time, and whether the changes are sustainable.

3. Case Study

"In this paper, Lean and Six Sigma were applied to a Small and Medium-Sized Enterprise (SME), Company XYZ for plastic manufacturing in Kuwait, to reduce the variation in their injection molding process. Variation exists within any process and when this variation goes beyond certain limits, nonconforming parts are produced and the company will face increased percentage of waste, operational cost, and reduced customer's satisfaction. Many of the XYZ Company plastic fittings were rejected as they were defective or having defects such as internal surface marks, flash, and bubbles. Floor Traps 6x4x2 fittings accounted for the highest rejection rate in XYZ Company. Six Sigma DMAIC combined with the 5S were applied to tackle this problem. DMAIC is a general engineering design approach that can be applied for many production or service problems that need practical solutions. It is an acronym stands for Define, Measure, Analyze, Improve, and Control. Results show that by implementing Six Sigma combined with the 5S program, Company XYZ achieved an improvement in its Sigma Level and Defects rate (DPMO) which lead to significant cost savings and increased its competitiveness" (Alshammari et all)

Looking at the case study above for a similar project involving injection molding the company was also seeing an increased number of defects during the molding process. In their project they utilized the same tools that will be expanded in the upcoming sections for each phase of the DMAIC process. Following the same process was key to guiding the approach to completing the project and in doing so the six-sigma level was similarly improved in the long run. The case study we analyzed allowed the team to gain imperative information for the outline and work processes needed to capture relevant information to be analyzed for the improvement and control processes. Finding such a similar project really helped to achieve positive results in our real-world problem.

Looking at another case study that reviewed molding compression in line with the injection molding process such as we are currently trying to investigate the case study mentions a good foundational explanation of the compression molding process. "Compression molding is the oldest and most common production technology in rubber industry. Compression molding is a cyclic molding process, in which vulcanization of rubber compound is performed by heat and pressure in a mold. During vulcanization, the rubber product also gets its final shape. The material in the pressing mold is molded by the pressure of the compression molding press at normal or increased temperature. The length of the compression molding cycle depends mainly on vulcanization kinetics and on the rubber compound heating. (An important influence on the duration of the heating is the thickness of the products walls.) One of the advantages of compression molding is its simplicity and the price of the mold. The internal tension is minimal as the material in the mold's cavity is only exposed to a short and multi-direction flow. There are no more problems related to the gating system. However, this technology also proves some disadvantages, e.g. more demanding preparation of raw products (batches). Also, it is prone to defects caused by insufficient breathing and humidity. On the moldings there are rather large molding flashes into mold parting surface. This method is not suitable for production of thick-walled parts or parts with longer flow. In case of pressing, these disadvantages indicate limited productivity of production." (Skrobak et all). This style of compression molding is seen in our process but an issue that we are facing is the over compression of an added extrusion introduced to the process. This may cause some additional investigation to look at the compression differences of the molding process coupled with the added compression if an extrusion is too thick or too thin when being molded to. It will be looked at further in the phases process throughout the project.

4. Define

The problem is in the splits that are evident at bonded locations between molds and extrusion. These splits have resulted in customer dissatisfaction. The scope of the improvement process will involve reviewing the extrusion process and tolerances to ensure that the current thickness of +/- 0.75 mm is revised downwards to +/- 0.25 mm. This will allow the company produce parts that are at most 10% compression into the mold. The process will take 1 month running from the 22nd of February to the 10th of April 2021. The project leaders are David Shepler and Ahmed Alnasser, who also were the data collectors and analyzers.

Problem Statement	Scope
There are splits evident at bonded locations between molds and extrusions once glass run channels are installed on vehicles. The extrusion and rubber injection molding process needs to be reviewed and improved to minimize the risk of splits leading to customer dissatisfaction.	Review the extrusion process and tolerances from 10X comparisons that are kept and moved on to the molding process. The mold cavity will be measured and compared with extrusion thicknesses with percent difference logged. This percentage will be used to see which parts split after being installed, are likely to split, or will see no splits to improve the extrusion tuning process for part tolerance to print that are then molded in secondary operations.
Business Case	**Team Members**
Extrusion and molding processes leading to defective parts are driving up scrap rates and driving dissatisfaction for the customer and end user. The process improvement plan will decrease scrap rates and defective parts that are being passed on to the customer during installation. Providing a better percentage of good parts will enhance customer satisfaction and drive future sales.	Project Lead: David Shepler Project Lead: Ahmed Alnasser Data Collection: David Shepler Data Analysis: Ahmed Alnasser
Objective Statement	**Timeline**
The objective of the project is to improve the current process by tracking the percent tolerance requirements needed to limit the likeliness of splits between the mold and the extrusion. We will look to decrease the overall defects seen on installed parts in conjunction with limiting scrap.	Define: 3/1/2021 Measure: 3/11/2021 Analyze: 3/22/2021 Improve: 3/31/2021 Control: 4/10/2021

Figure 1. Project Charter

In Figure 1 it is laid out indicating the problem statement, business care, scope, team members, and the timeline. The project charter details out all the specifics for background and what needs to be accomplished to use as a guide from point A to point B. This tool also allows the team to view the overall business case to help with envisioning how this will help the company once the task is completed. This is also used as an initial project timeline for hit times to meet project needs. In Figure 2 it displays the complete project timeline that is set to run from the 22nd of February to the 10th of April. This lays out the duration with any overlap that can be used to complete the individual phase tasks. These phase tasks can be further broken down but due to the size of our team it was chosen to keep the project timeline simplified.

Figure 3 shows the detailed supplier, input, process, output, and customer diagram (SIPOC) which shows the steps involved in the overall scheme of things from the initial input to the end output. This helped to further visualize each step of the process to see what all goes into the overall production of the part that needs to be evaluated. This can be coupled later with helping to fill out the fishbone or cause and effects diagram to guide the team to potential problems and solutions to the process.

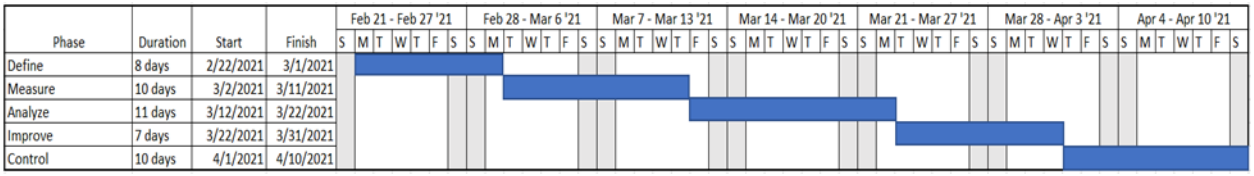

Figure 2. Project Timeline

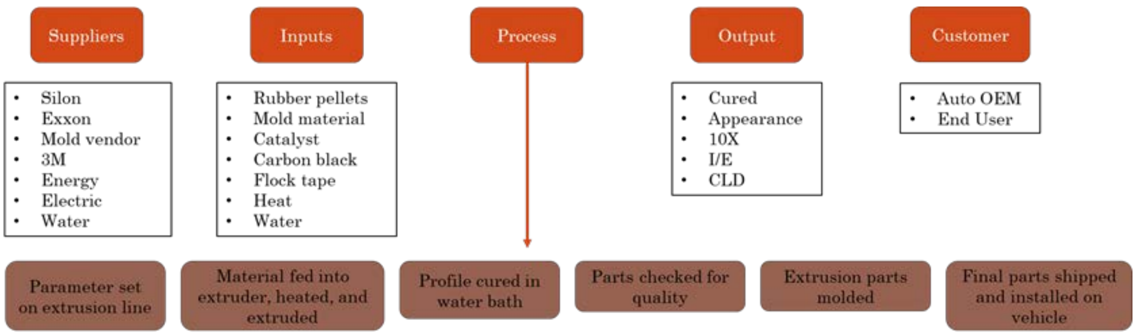

Figure 3. SIPOC

Date	Shift	Mold Cavity Lip Thickness (mm	Actual Lip Thickness (mm)	% Difference	Split Seen on Insta
3/2/2021	1st	1.8125	1.9526	7.175	X
3/2/2021	1st	1.8125	1.9122	5.214	
3/2/2021	1st	1.8125	1.8954	4.374	
3/2/2021	1st	1.8125	1.7995	-0.722	
3/2/2021	1st	1.8125	1.7524	-3.430	
3/2/2021	1st	1.8125	1.8142	0.094	
3/2/2021	1st	1.8125	1.9054	4.876	
3/2/2021	1st	1.8125	1.8624	2.679	
3/2/2021	1st	1.8125	1.7641	-2.744	
3/2/2021	1st	1.8125	1.8692	3.033	
3/2/2021	1st	1.8125	1.9412	6.630	
3/2/2021	1st	1.8125	1.9005	4.630	
3/2/2021	1st	1.8125	1.8624	2.679	
3/2/2021	1st	1.8125	1.8199	0.407	
3/2/2021	1st	1.8125	1.7528	-3.406	
3/2/2021	1st	1.8125	1.7993	-0.734	
3/2/2021	1st	1.8125	1.8647	2.799	
3/2/2021	1st	1.8125	1.9296	6.069	
3/2/2021	1st	1.8125	1.9018	4.696	
3/2/2021	1st	1.8125	1.8564	2.365	

Figure 4. Data Collection Example

5. Measure

With the problem being the splits that are evident at the bonded locations, the data has to be collected to ascertain the amount of variations being witnessed within a specified duration of time. Data collected include the thickness, compression, and the percentage probability of splitting against compression. For every between 5-10% compression, there is a 30% chance of splitting forming a bad part. For under 5% compression, there is a 0% chance of splitting and forming bad parts. Therefore, it would be prudent to ensure that the compression process be done in accordance with the data on splitting. A 5% compression should be mooted to ensure effective splitting process. In Figure 4 it is displayed an example data set pulled from the 1200 data points that were collected before and after implementing a change. The date was logged by the operator, the shift that the information was collected from, the mold thickness, the actual extrusion thickness, the percent difference, and if based on the thickness difference there was a split on installation on the door buck.

6. Analyze

On analyzing the data given, the cause effect diagram illustrates what aspects of the manufacturing process are responsible for the variations being witnessed. What is apparent is the variations are as a result of shrinkage, mold designs, trim and finish after extrusion, rubber characteristics amongst others. The histogram of measurement gives a normal curve of error, with the frequency of variation in measurement showcasing the disparity in different injection systems. Shrinkage is a normal occurrence in manufacturing rubber and should be put into consideration when designing molds to accommodate the size that will be lost as a result of shrinkage.

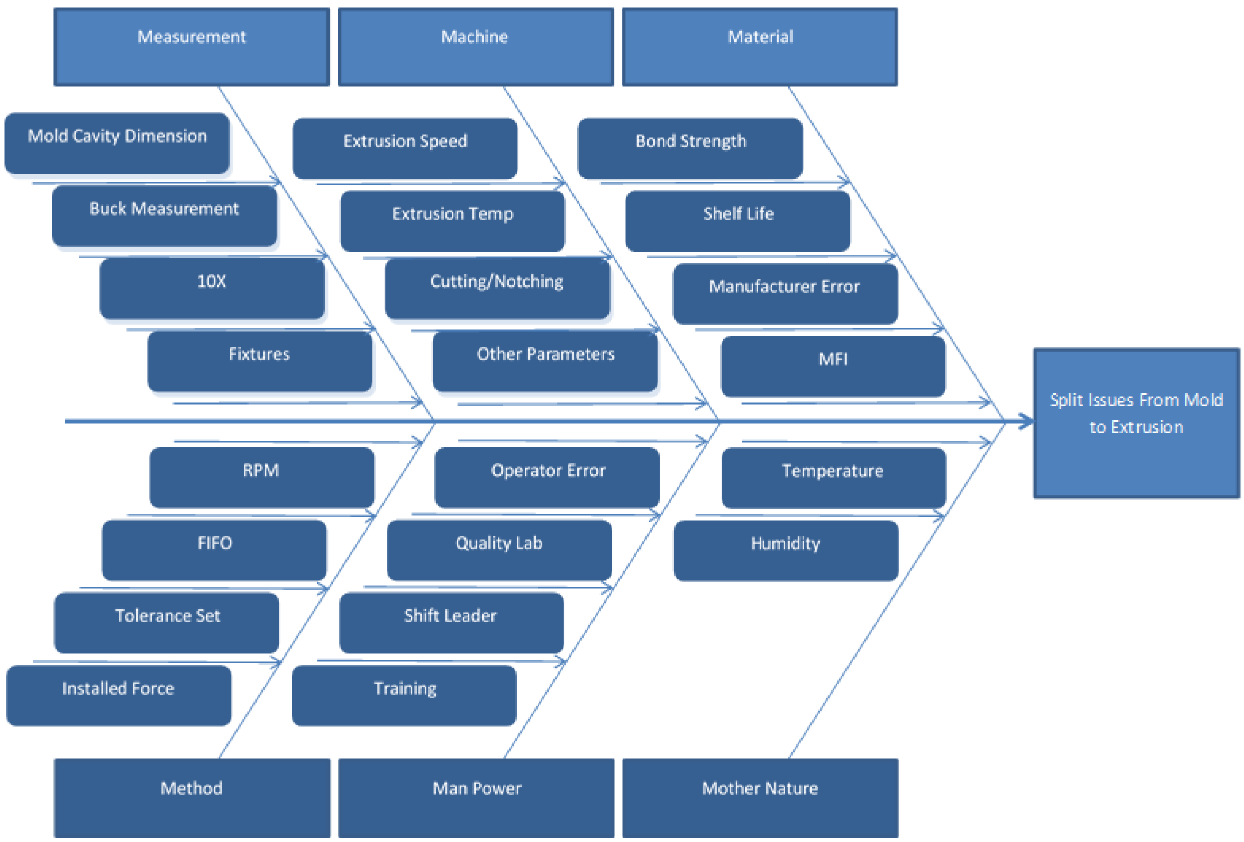

Figure 5. Fishbone Diagram

Figure 5 is shown indicating the likely causes of splitting issues from mold to extrusion, such as temperature, humidity, quality lab, operation error, and shift leader. These are broken down in to the six main areas of the standard fishbone diagram for man, machine, method, measurement, material, and mother nature. This diagram was used to identify all potential problems that could be causing the splits seen on installation. As a team it is imperative to view all potential problems and go through each to verify or eliminate from the overall hierarchy of the problem scheme to really boil down to a few main potential problems to further investigate. From this it was determined that the method needed to be investigated further to identify the true root cause of the problem which ultimately is the compression of the extrusion in the mold where the material will expand after molding leading to splits at certain percentage zones of compression.

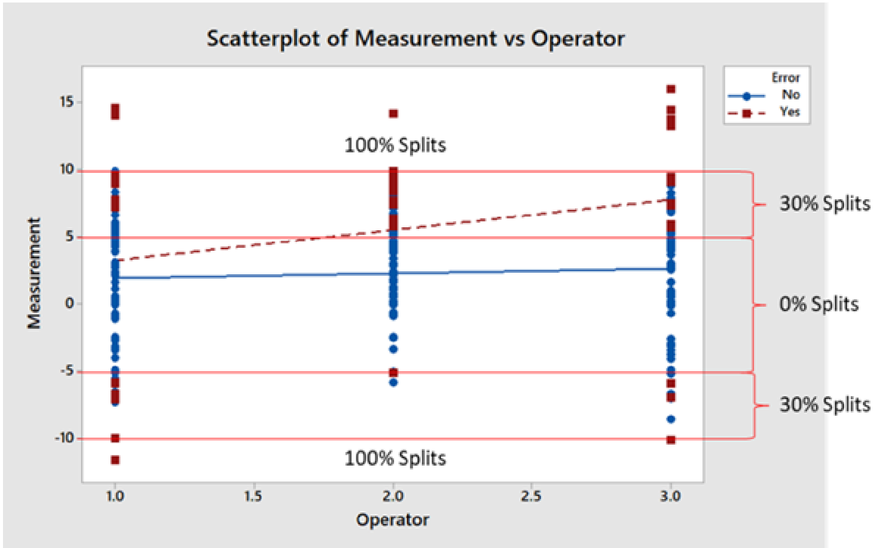

Figure 6. Scatterplot by Measurement vs Operator

Figure 6 shows the overall error and good parts highlighted by red and blue marks respectively. This is further broken down after analyzing to show the main areas where there is no split, a split possible, and a split risk. Any measurement that was taken at 5% compression or less there were no splits seen at all regardless of operator or shift. From compression zones of 5% to 10% there was a 30% chance that a part would split on installation. This is varied and not specific so we could not tailor the compression zones any further. Finally, there was a guaranteed split to be seen if the compression amount was greater that 10%. These three zones are clearly visible tracking the overall data points gathered from the 3 different operators at multiple random points in their respective shifts.

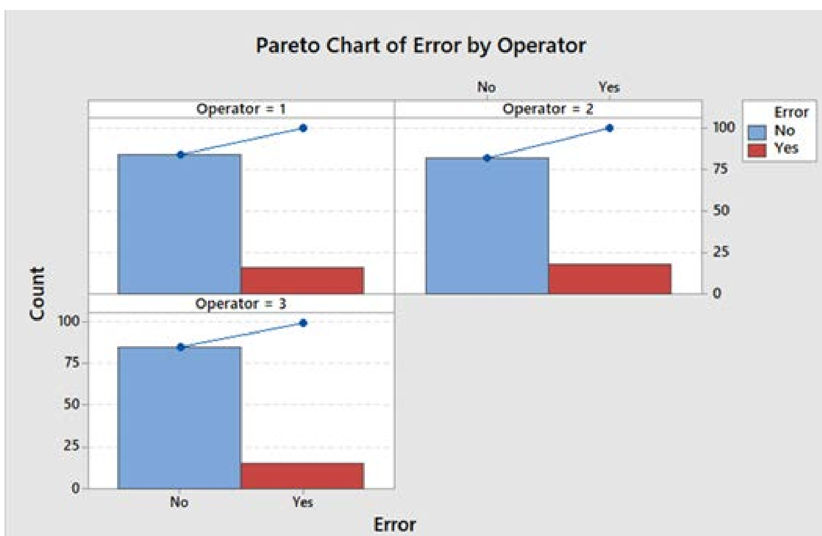

Figure 7. Errors by Operator

Breaking down the data further by the different operators in Figure 7 allowed us to verify that there were no unseen circumstances that specific operators were causing additional splits to be seen on installation. Each operator despite the time of day was seeing about a 20% rate of bad parts being produced despite random sample sets of data collection.

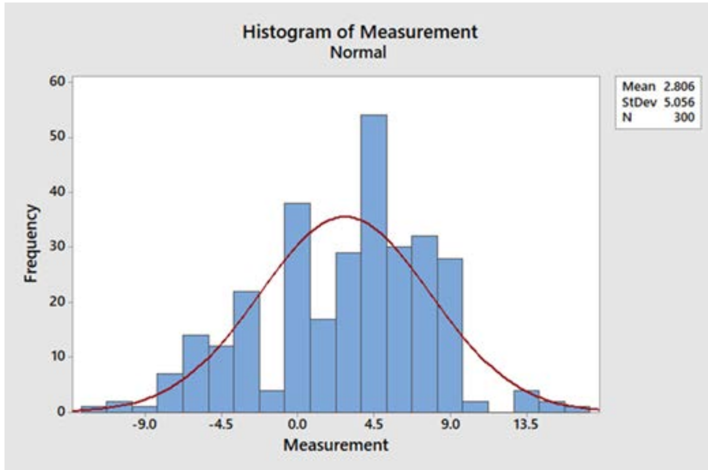

Figure 8. Histogram of Measurements

Looking at the data from a different perspective can be seen in Figure 8. This was used to indicate a normal curve of the different measurement expected from the rubber produced. A vast majority being within the normal range of measurement shows that the parts are typically being produced on the higher end of the compression spectrum with very little that seem to spread outside the normal range. Though this follows the typical production variations the number of those in the outer most regions of the bell curve are problematic when it comes to the number of those that are failing at the customer assembly plant.

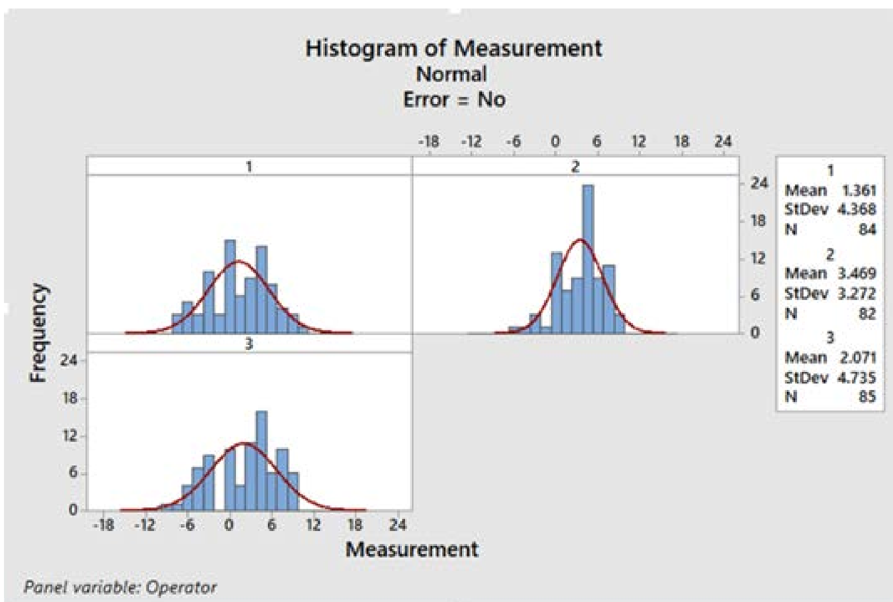

Figure 9. Histogram of Errors

Further breaking down the histogram from Figure 8 it was looked at the histogram for those parts that were failures or errors in Figure 9 and those parts that were good or normal in Figure 10. Looking at these more dialed in histograms was used to view the standard deviations of each good or bad part by operator. The good parts seemed to fit standard across the board for the variation seen by operator but the bad parts operator 2 seemed to be more dialed in for variation seen. This will be evaluated further for the control phase to gather the operators to view the process each follow for tolerancing to see if they can group together to try to come up with a standard operating procedure for line start up and operation to dial in the tolerance and start producing more good parts across the board.

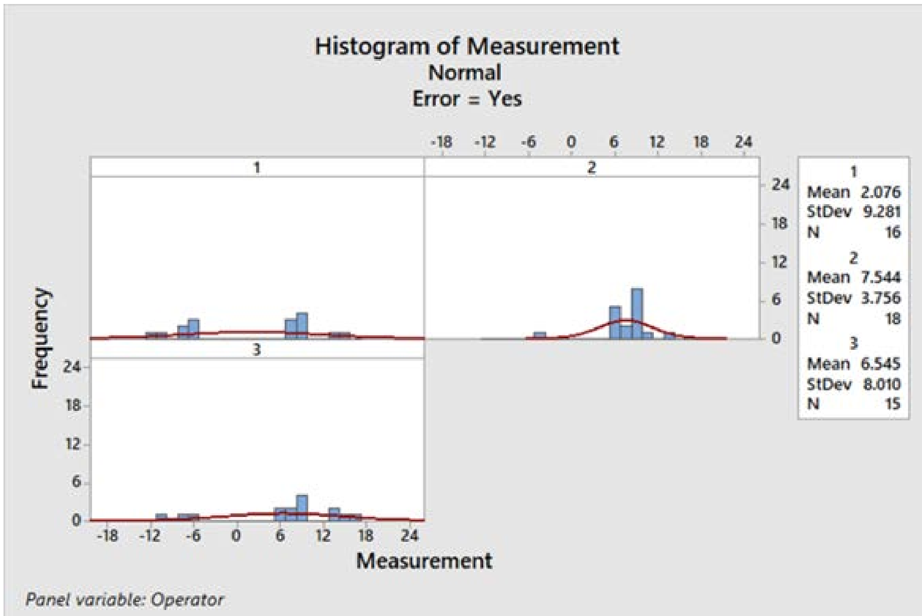

Figure 10. Histogram of Good Parts

7. Improve

The best way of dealing with the variations in the rubber parts being produced will be to invest in the mold designs being used to ensure that the variations are as a minimal as possible. The prizes of mold designs are directly related to the quality of these molds, and more finances will have to be directed towards these molds. Implementation plan will involve setting funds in the next fiscal year for the improvement process, which will best be done in 2 phases to ensure ease of transition. With standard mold designs that are of high quality, the production of rubber that meets the expectations and with minimal variations will be achieved. The molds have to be revised frequently to guarantee continuity.

Data Snapshot (Before Adjustment)				
Compression	**0-5%**	**5-10%**	**10% and up**	**Total**
Errors	0 of 159	40 of 132	9 of 9	49/300
Percentage	0%	30.30%	100%	16.33%
Defects Per Million			**Sigma Level**	
163,333			2.48	

Figure 11. Data Snapshot Before

Figure 11 shows the data snapshot before any adjustments to the line were made. This includes the range of bad parts seen by compression ranges identified in the analysis phase. Since the sample set was a smaller than one million data collection points the overall percent of bad parts form the sample set was used as a foundation for analysis for a million parts and the number of defects that would be comparably seen. This sigma level equates to roughly 2.48.

In Figure 12 it shows the same data table for the same amount of measured data points after an improvement was made to tolerancing of the extrusion and dialing that in a little further through standardizing across the board for all operators. There were still some minor variations seen when the line varies from the startup procedure, but they were fewer and farther between. The number of defects per million was decreased which ultimately improved the sigma level to 3.18. This improvement was smaller than anticipated but an improvement none the less.

Data Snapshot (After Adjustment)				
Compression	0-5%	5-10%	10% and up	Total
Errors	0 of 217	224of 82	1 of 1	14/300
Percentage	0%	29.26%	100%	4.66%

Defects Per Million	Sigma Level
46,666	3.18

Figure 12. Data Snapshot After

8. Control

To ensure that the improvements are sustainable, the mold designs will have to reviewed first to ensure that the variations are markedly reduced. Once that is checked, it is critical to ensure that the fiscal responsibility of the company is directed towards ensuring that the results can be sustained. Purchase of the mold designs has to be procured within a specific duration of time and must not be left to overstay their use. Replacing them is pertinent towards ensuring sustainability. For this to happen, then the company has to empower the technicians working to ensure that the molds are frequently renewed. Empowering them will involve equipping them with the requisite finances within their dockets.

In this final phase in order to control the process improvements we had to make sure the line operators were on board in standardizing the line start up procedures to a by the book process in steps. The initial line startup needs to see a 10X section to print within the new tolerance before parts can be collected for follow up operations and ultimately being shipped to the customer. Additional sections need to be cut and measured every 30 minutes to ensure variation changes in the extrusion have altered the tolerance outside of the new range dimensioning. In doing this it will be easier to control the process to maintain the project goals.

9. Conclusion

After reviewing the project following the DMAIC phase process the team was able to analyze the data completely and efficiently to identify three range of compression where the was no risk, split risk, or split likely to be seen. It was found that from 0%-5% compression we are seeing no bad parts produced that lead to splits on vehicles. In a compression range from 5%-10% there is a one third chance of seeing a split on parts where this range falls in the split risk category and anything above a 10% compression there a split likely to occur where every single part measured in this zone failed on installation. Using the data and the generous tolerance currently used for extrusion of +/-0.75mm we decided to implement a smaller tolerance zone at +/-0.25mm to see if we could obtain an improvement in the percentage of scrap. Decreasing the tolerance has increased the amount of time to meet print for extrusion by 15 minutes for line start up but has not increased any scrap once the line is tuned and running for the shift. The 15-minute delay is not leading to any shortcoming on part production so there is no loss of revenue in using this additional time to fine tune the profile. After implementing the tolerance change a control follow up was conducted to see if we made an improvement in the sigma level. We managed to go from approximately a 16% scrap rate to 5% scrap rate meeting the customer expectations for the VOC and ultimately improving the sigma level from 2.48 to 3.18.

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Biographies

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