**Implementation of Six Sigma for Process Improvement in Manufacturing Industry Sector**

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ISE 250: Leading the Six Sigma Improvement Project

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# Contents

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## 1. Abstract

The project goes through the use of Six Sigma in manufacturing to improve quality management and operational efficiency. To address major quality and process inefficiencies in the tire, steel bar, rubber glove, and steel bar manufacturing, the group employs the DMAIC (Define, Measure, Analyze, Improve, Control) framework. Each case study shows possible cost savings and defect reductions as they highlight customized strategies such as factorial design experiments and modified operating procedures for less waste production and reduced errors among other operational changes. This project stresses that Six Sigma methodologies play a critical role in significant improvements within the manufacturing processes.

## 2. Introduction

In this work, the Six Sigma DMAIC method has been operated and worked in order to solve inefficiencies problems and change quality in manufacturing industry. The project addresses the process of making steel rods, tires, and rubber gloves using the DMAIC , namely Defining, Measuring the Analyzing, Improving and Controlling, to have the processes analysed and improved accordingly.

The project demonstrate the unique style for the purpose of reducing wastes and the problems like defects with the factory approaches and experimental designs that have been modified. The application of such techniques onto different case studies achieves for noticeable cost saving with marked decrease in defect impacting, therefore contributing to the significance of Six Sigma methodologies as the key of directing for great improvement within manufacturing procedures.

The DMAIC implementation in each case study that outlines the step-by-step process is not only effective in solving various manufacturing problems, but also serves as a standard of operational excellence amongst the industry performers. The aim and objective of this project is to show how Six Sigma's tools and system reduces the operational inefficiency; enhance production performance; lowers cost; thus, apart from achieving the great economic gains and more satisfied customers; it will help the company to be more effective and profitable.

## 3. Literature review

The importance of an excellent quality management system cannot be underestimated in the current manufacturing industry. Companies are now implementing Six Sigma-type methods in relation to their production processes to reach as close to perfection as possible. This project introduces the application of the Six Sigma methodology across three distinct manufacturing sectors: steel rods, tires, and rubber gloves. Every department entails different problems that may hinder productivity and attainment of quality standards. Addressing these challenges is the main purpose of the DMAIC methodology (Define, Measure, Analyze, Improve, Control) implementation. This will not only increase the efficiency of operations but also reduce waste.

The first case study deals with production of steel bars where wastage and the high cost of imperfect products are the main issues. The second case investigates the works of tire manufacturing such as the bead splice variability that usually cause customer dissatisfaction. The next case highlights the manufacture of rubber gloves, pinpointing leak and contamination incidence as certain parameters that affect final product integrity. With every given problem, the DMAIC framework offers a solution, which guarantees that the result is not only effective but also sustainable. This controlled approach permits a detailed assessment of the modifications in each step, from raw material handling up to through to the final product testing.

To sum up, the project is undertaken to showcase the usefulness of Six Sigma in the elimination of the operational inefficiencies, the increase of production performance and the reduction of costs. Through carefully implementing the Six Sigma approach in the individual cases, the project goes beyond its mandate of helping with specific manufacturing issues by also establishing a standard of excellence for the industry. It is clear that systemic process improvements lead to the achievement of high economic gains and customer satisfaction with the assistance of the manufacturing industry.

## 4. Case studies

### 4.1. Six sigma in Tire manufacturing industry

#### *4.1.1. Objective*

The use of the implementation of Six Sigma DMAIC, intrinsic in a tire production company in reference to the bead splice operation, illuminates a very efficient way of improving. This investigation has supported that Six Sigma mechanisms can greatly contribute to reducing discrepancies of the process, the wastage, and the improvement of quality standards in the tire manufacturing sector. The implementation of the DMAIC phases of the problem-solving method--Define, Measure, Analyze, Improve, and Control--into the process is essential for the detection and resolution of the core issues of the bead splice disparities. This ensures that the status of PCP Indices will go up and consumer satisfaction will also be increased (Gupta et al., 2017).

**Methodology**

Using methodology in this study DMAIC six-sigma was used to eliminate the long-term process capability of bead splice. As the DMAIC methodology progressed in every one of its stages, qualitative and quantitative techniques were being used at the same time. The steps of the DMAIC process followed in this study are outlined as follows: The steps of the DMAIC process followed in this study are outlined as follows:

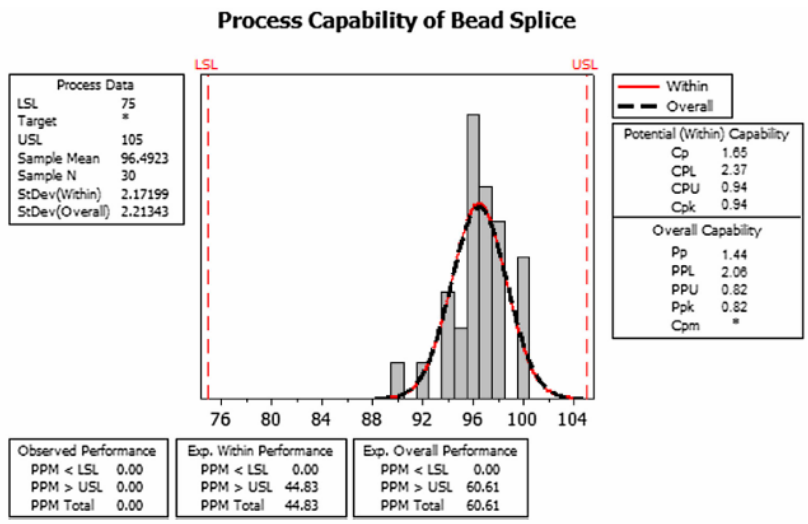
### *4.1.2. Define*

The first step of the project was to set goals for improving the process as it was, being primarily based on the customers' perspective, which was gathered through the surveys (VOC). Defect reduction and operation throughput stability are essential goals of this strategy which aims to achieve them by optimizing the production process itself. In a nutshell, the targeted problem is shown to be the one that arose from CSV analysis of the VOC data, which indicates client-related concerns about production of waste material a result of problems in bead splice process, which are described in details in Table-1. (Gupta et al., 2017).

### *4.1.3 Measure*

The main objective of the project performance measurement phase was to be able to measure the operation efficiency of the system. The paper chose A (Process Capability Index) Cpk as an assessment index. Initially, our screening tests were conducted on screener variables, which were later plotted using Minitab16 software as shown in figure 1. Recognizing the preliminary step here was the normal test of data presented in the form of the normal distribution curve that can be seen in Figure 1. The factor of normal density function check was followed by the Cpk value calculation. If the table number 2 is used to get the Cpk value, it will be clear that this is the indicator of the current process performance. The operations have been useful in estimating the initial state of the system, which currently gives us the grounds for enhancing and optimizing the system. Based on the second graphic, the CpK value is zero. Notice 94. This discerns the operation activity loss of efficiency hence one may be under the set parameters for the specified limits. The histogram of the process is built, while the indices of its sufficiency such as Cpk and Ppk – both less than 1—are also found, and it is discovered that the proficiency of the process has been poor. Well, this example proves that no level of the public office is exempt from the disorder. 83 ppm of iron may tend to breach the lower limit (LL), whereas 60 ppm creates the part which is beyond the shorter specification limit (LSL). A highly sensitive indicator will be at the level of 61 parts per million and so, it makes sense to measure the quality at this point only. (Gupta et al., 2017)

**Fig. 2** Process capability diagram of bead splice: before improvement




### *4.1.4 Analyze*

In this phase, the data were carefully evaluated and control diagrams were created accordingly. As shown in Figure 3, the X-Bar and R-Chart show that although some data points are below the lower control limit, the process remains statistically stable. The Ishikawa diagram, shown in Figure 4, was used to determine the main causes of the problem. The results are as follows: - The initial problem identified was the bead splice setting, which was too high due to the slip of the bead tape from the swivel. This problem stems from the wear and tear of the gripper key. - A second problem was found in the variability of the progressive environment, which was linked to different levels of skill among workers. This inconsistency stems from the absence of standardized installation instructions. - The third identified question relates to the frequency of adjustments required for sensor settings, as changes in the old diameter required regular adjustments. The lack of guidelines has hampered these necessary adjustments. - Finally, it was pointed out that the workers did not use the measuring tape as required. These analyses highlight the complexity and variability inherent in the process, underlining the need to understand the challenges at a high level of complexity and to be more coherent in the application of solutions in order to ensure maximum relevance and coherence in addressing the underlying problems.

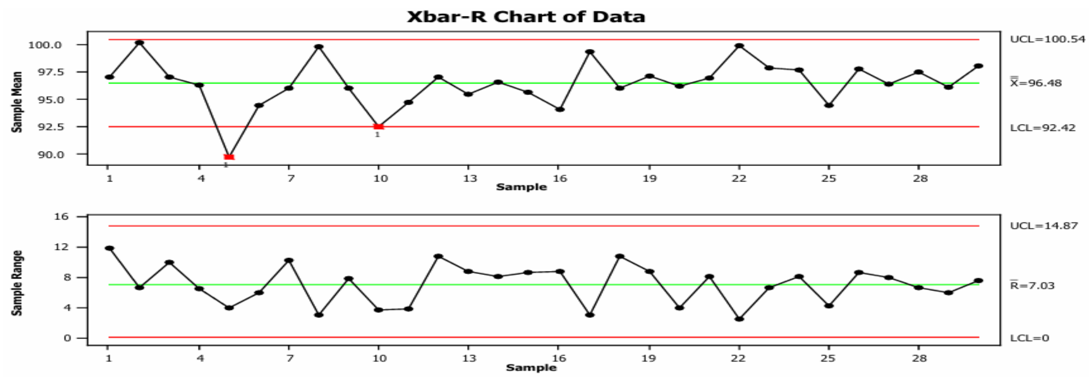



**Fig. 3** X- and R-bar chart of present data

In the XBar diagram, a data point is observed below the lower control limit, which may indicate a problem in the process at this particular time. However, the R diagram shows no points outside the control limits, which indicates that the process variability remains stable. The Ishikawa diagram used to analyze the potential causes of the "BEAD SPLICE VARIATION" puts this issue at the forefront, similar to the head of a fish. The main categories of root causes, highlighted as "bones" that converge from the central spine, focus primarily on human and machine factors.

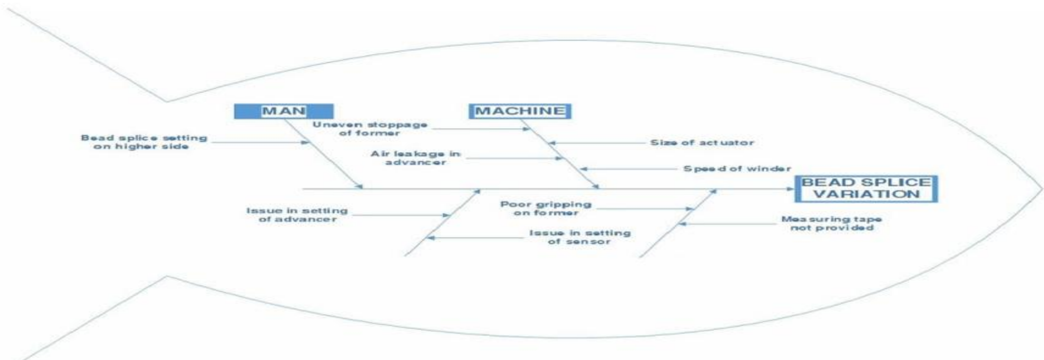
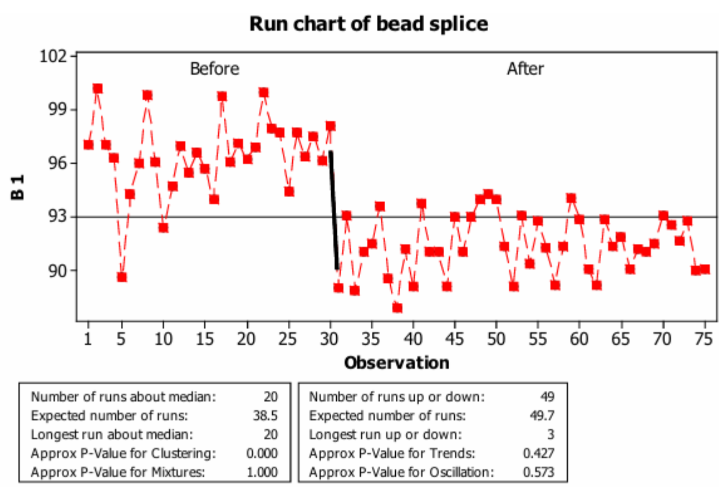



**Figure 4**: Ishikawa diagram

### *4.1.5 Improve*

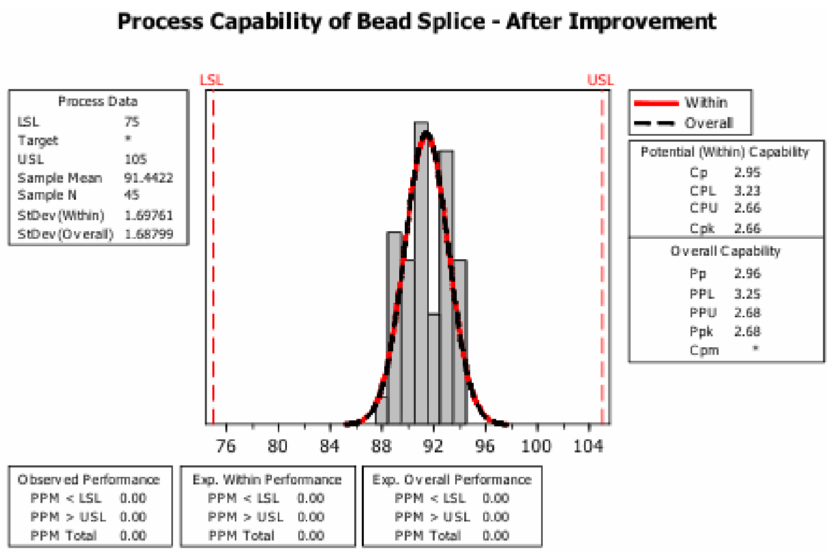
After identifying the underlying issues, corrective measures have been detailed in Table 3. The subsequent data collection after the implementation of these measures is represented in Table 4, while a comparative run chart showing the variation in the bead splice before and after these interventions is provided in Figure 5. This illustration confirms a significant reduction in process variability. Furthermore, the process capacity index was recalculated and showed an increased Cpk value of 2.66, as shown in Figure 6. This improvement emphasizes the capacity and effectiveness of the process (Gupta et al., 2017).

**Fig. 5** Run chart for bead splice



1. **Adjustments for High-Point Issues**
   - Inspect the bead splice after initial setup.
   - Adjust the advancer according to the specified guidelines to achieve the desired target value.
   - Align the proximity according to the recommended former diameter guidelines.
2. **Improvements for Low-Point Areas**
   - Ensure each line is equipped with a measuring tape.
   - Conduct regular follow-ups to maintain standards".

**Fig. 6** Process capability diagram of bead splice: after improvement




### *4.1.6 Control*

The Control phase in the DMAIC methodology aims to ensure that the process improvements achieved in the previous phases are sustained over the long term. This phase involves implementing control systems to monitor the process continually and respond quickly to any variations that might cause a decline in performance.

### *4.1.7 Critique*

The Six Sigma DMAIC methodology has served as a fundamental tool to improve production efficiency within the tire industry. Initially, the process capacity index (Cpk) of the existing system was calculated and found to be lower than the standard index of 1. This discovery has led to a detailed investigation of the main problem at hand: a fish shortage. In order to better understand the problem and its root causes, a cause-and-effect diagram was used. Further in-depth analysis revealed crucial insights into the functions of the operational system, which were subsequently addressed and resolved. The application of statistical techniques confirmed a positive Cpk value after the implementation of corrective measures. One of the most important results of this study is the significant potential to increase the process performance in tire production by adopting the DMAIC Six Sigma approach.

In addition, there are limited references to similar techniques in the existing literature, such as a study conducted by the Gupta team in India in 2012, which used cause and effect diagrams but did not explore complex production issues. Unlike this study, other research in 2013 focused exclusively on lean tools in an Indian radial tire manufacturing context without diving into the specific characteristics of the production process. However, this research focuses on the use of the Six Sigma DMAIC methodology to improve process performance. The main challenge addressed in this study was to increase production and productivity of the bead cutting process, which has seen a significant improvement in its process index. The DMAIC framework provides effective solutions to complex decision-making problems and defines appropriate techniques for achieving objectives based on control environment data.

Six Sigma not only serves as a measurement framework for products and processes but also as a driving force for operational excellence and continuous improvement, striving for the highest standards of quality and efficiency. The primary goal of employing Six Sigma tools is to achieve consistent and cost-effective performance that meets international quality standards. Successful implementation of Six Sigma projects requires substantial support in terms of business or technical skills, leadership endorsement, and robust quality systems. The recommendations from this case study have equipped the organization with effective strategies to address and rectify any issues.

## 4.2. A Six Sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process

### *4.2.1 Objective*

The project focuses on improving the quality control in rubber glove manufacturing industry using six sigma techniques. Our goal is to reduce defects from 195095 per million to 100000 per million, so that customer satisfaction will increase. The "DMAIC" methodology is used to improve the important aspects of manufacturing process. We are intending to raise our six-sigma level from 2.4 to more than 3.

### *4.2.2. Define*

In the Define phase, we created a team with a product manager, a quality assurance expert, and the project lead took part in. The focus of the team was on helping the project ensure that it can achieve its goals on quality and efficiency. The team is directed to concentrate on medium-sized rubber gloves production, with more customer defects and customer returns issues being their prime concern. The team concentrated on (dipping and leaching) production where most defects are seen (Jirasukprasert et al., 2014).

Feedback from customers and market analysis serve as a kind of data that helps the understanding of customer needs. These responses will serve as a guideline for the purposes of setting goals where they demonstrate the paramount role that quality improvement and client satisfaction play in the glove manufacturing process (Jirasukprasert et al., 2014).

To be successful, we acquired executive sponsorship and support. Moreover, the management was given a thoroughly elaborated value proposition that included the cost implication of defect reduction such as material cost savings and rework cost. This effort was referred to as consequential undertaking to raise operational efficiency and client trust (Jirasukprasert et al., 2014).

A project charter was specifically written and signed by all parties to capture the project features such as scope, objectives, and the timelines with such an aim of ensuring all stake holders understood these issues clearly. It acted as the benchmark for the project duration, bringing together the project team and the other organizational units to make them strong (Jirasukprasert et al., 2014).

#### *4.2.3. Measure*

In Measure step of the DMAIC methodology the team already have got a proven system to quantify the current defective situation in rubber gloves production. The top variables gauge to show the advances of the improvements activities that have been done will be the defect reduction after the identification of the major defects (Jirasukprasert et al., 2014).

Data gathering had been done over time in order to measure the first accepted levels of gloves. The errors were typically separated into three categories, which included 'leaking', 'dirty', and 'miscellaneous' types. ‘Leaking’ gloves that in turn were the result of either water or air leak tests were set down as the highest level of defect with the highest proportion of total defects in them. Two categories included are 'dished' gloves and 'miscellaneous' gloves.  The 'dished' gloves refer to gloves with visible stains or foreign matter, and the others are misshapen or sticky gloves (Jirasukprasert et al., 2014).

The process capability has been assessed utilizing the Defects per Million Opportunities (DPMO) and the process Sigma level. The data from historical reports showed that the leaking was the main problem which arose time and time again and badly affected the quality assurance process (Jirasukprasert et al., 2014).

We have conducted a Pareto analytics to identify leaks of the biggest contributor to the inefficiency, which confirmed the need for an immediate cure of the leaking category. As described by the method above, the team identified the most important corrective actions needed to compensate for quality issue deteriorators first (Jirasukprasert et al., 2014).

We were also able to extract the necessary data from the measurements for setting up a baseline which would enable us to make comparisons later when we would put the improvement strategies into effect. What is more, this benchmarking enabled us to prove the non-competitive status of our organization because of the weighted problem of defects it faced that requires comprehensive and urgent action to solve the issue within the Six Sigma project (Jirasukprasert et al., 2014).

**Table 1**

Defect Summary before Improvement

| Type of defects | Number of defects | Percentage of defects |
|---|---|---|
| Leaking | 4495 | 19.51 |
| Miscellaneous | 1686 | 7.32 |
| Dirty | 788 | 3.42 |
| Total | 6969 | 30.25 |

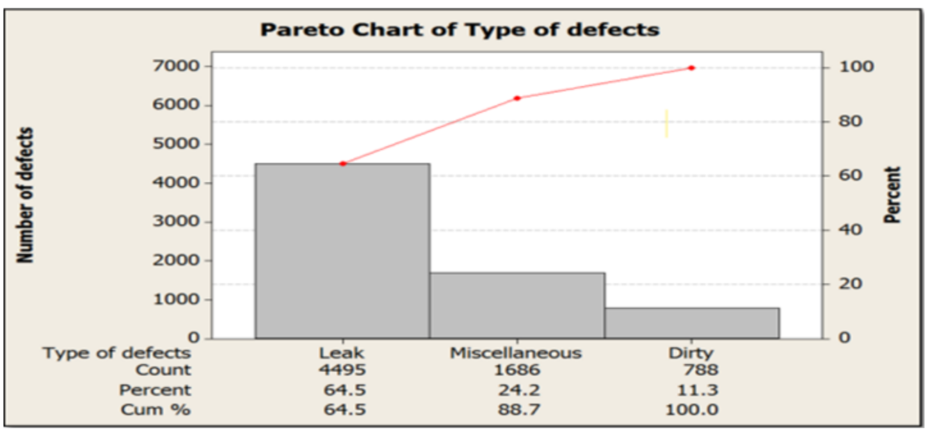
**Table 2**

Manufacturing process of Gloves with current and expected states

| Major type of defects | Number of the major defect (units) | | Quality levels (DPMO) | | Sigma levels | | Loss ($) | |
|---|---|---|---|---|---|---|---|---|
| | C* | E* | C* | E* | C* | E* | C* | E* |
| Leaking gloves | 4,495 | 2,248 | 195,095 | 97,569 | 2.4 | 2.8 | $16,000 | - |

**Figure 1**

Type of defects in Pareto chart




### *4.2.4. Analyze*

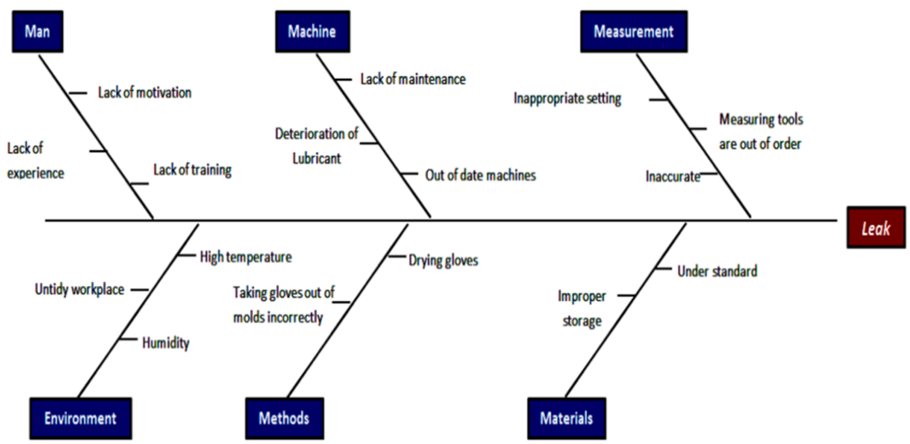
As a part of the DMAIC methodology analysis stage of this particular project, the team was trying to find out all the data gathered during the Measure phase to find out the main root causes of defects in manufacturing sub-processes that produce rubber gloves. With the help of a flowchart, the team could literally see the whole process and these stages, where defects were most likely to happen, or even simply the quality level of the final product, could be shown (Jirasukprasert et al., 2014).

The team engaged through meetings to collate possible explanations of the defects. These were based on the individuals' hands-on experiences and exploration of the entire process. Participating in these sessions, the teamwork was enhanced as members had a forum to hold uninterrupted discussions while freely proposing and debating the different things that could have led to the defects (Jirasukprasert et al., 2014).

In order to stratify, particularly, the instances of possible causes, a cause and effect chart, which is also called as Ishikawa or fishbone diagram, has been made. A schematic of this visual appearance aids in grouping the causes into man-machines, men-materials, methods, measurement, and environmental factors classes which commonly taken into consideration when proposing an improvement (Jirasukprasert et al., 2014).

**Figure 2**

Fishbone Diagram related to leaking glove process



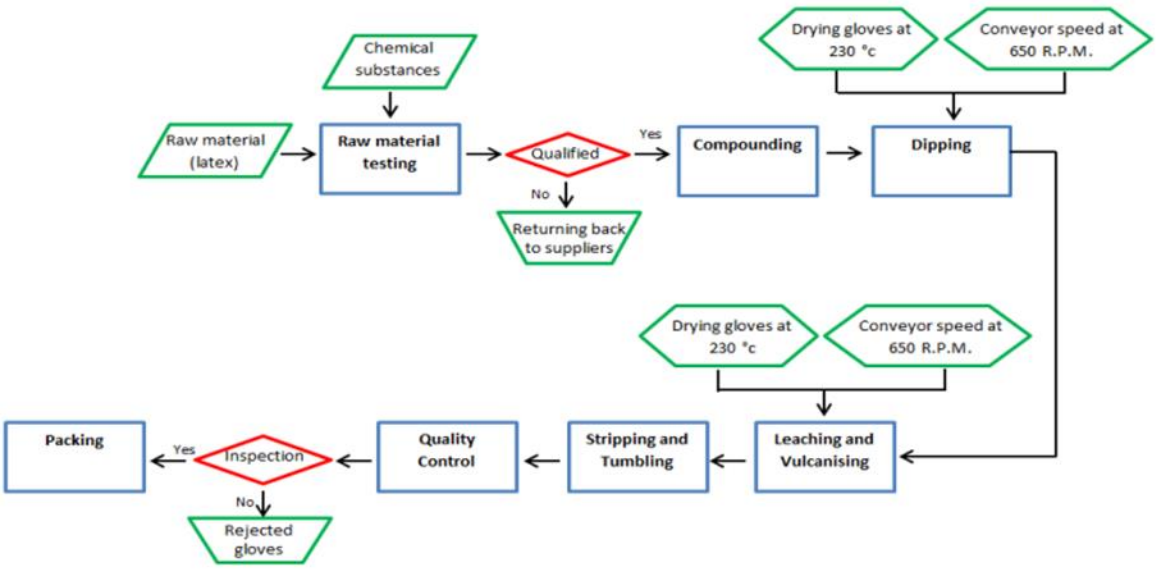

By thorough analysis, the team figured out that certain process factors, especially those factors of the oven's temperature and the conveyor's speed during the curing time, had been directly correlated with the defect modes. Due to these findings, the correlation was considered very significant with the possibility of these variables becoming unavoidable causes of faults and as a result improvement measures should be directed to these areas (Jirasukprasert et al., 2014).

Valuable insights obtained will be a powerful guide as to how the subsequent steps in the DMAIC roadmap will be taken, with the focus at this stage being the discovery of and implementing the solutions of the roots causes and most likely some intensive work will be done to improve the oven's temperature and the speed of the convection, to reduce the incidence of defects. This analysis was the basis to transition the project into the Improve phase where these findings will start to be tested and applied as new data begins to emerge. (Jirasukprasert et al., 2014)

The Improve phase used DOE methodology to subject the process variables, which had been outlined in the Analyze phase - that is, oven temperature of the gloves and conveyor speed - to testing with respect to defects. This method of trending statistical data was selected to confirm the assumed correlations, and then these vital parameters were set to the lowest level to eliminate defects (Jirasukprasert et al., 2014).

**Figure 3**

Process flowchart of glove manufacturing




### *4.2.5. Improve*

The DOE was structured to manipulate the oven temperature and conveyor speed across multiple levels, allowing the team to observe the effects on defect rates. Four temperature settings (220°C, 225°C, 230°C, 235°C) and four conveyor speeds (600, 650, 700, 750 RPM) were tested in a controlled experiment to isolate their impacts. Each combination of settings was replicated to ensure the reliability of results, considering the natural variability in production (Jirasukprasert et al., 2014).

Analysis of the experimental data was performed using a two-way Analysis of Variance (ANOVA), a technique that enabled the team to compare the effects of different settings statistically. This analysis confirmed significant interactions between the temperature and speed on the defect rates, providing a clear evidence base for optimizing these variables (Jirasukprasert et al., 2014).

Taking into account the outcome, the ideal conditions were determined as being 230°C for the oven temperature and 650 RPM for the rate of the conveyor. As the most effective for the highest output of quality and compared to the other states, those conditions were recommended to be used on a standard basis throughout production (Jirasukprasert et al., 2014).

Further trials introduced these settings in the real production circle, and it has proven to be a good move. The trials showed that the defect rate was reduced significantly, by a figure of fifty percent, quite a low quantity of wrong gloves. Besides that, it came to the result not only reaching but demonstrating a much higher improvement, which essentially increased the Sigma level of the process to 3. 4 to 2. 9 (Jirasukprasert et al., 2014).

In this phase, we were able to show that DMAIC is the right example of a structured approach toward using data for process improvement. What the DOE had established through empirical evidence, became the core of adjustments made to the oven temperature and conveyor speed. The result was immediate as rubber gloves were made that outperformed older quality standards (Jirasukprasert et al., 2014).

**Table 3**

Design structure of Experiment

| Temperature (°c) | Order | Conveyors speed (R.P.M.) | | | | Number of defects (Units) |
|---|---|---|---|---|---|---|
| | | 600 | 650 | 700 | 750 | |
| 220 | 1 | 278 | 189 | 156 | 147 | 2682 |
| | 2 | 244 | 154 | 193 | 108 | |
| | 3 | 253 | 173 | 129 | 83 | |
| | 4 | 214 | 147 | 101 | 113 | |
| 225 | 1 | 212 | 120 | 101 | 78 | 1780 |
| | 2 | 152 | 85 | 62 | 28 | |
| | 3 | 200 | 71 | 94 | 71 | |
| | 4 | 166 | 106 | 83 | 152 | |
| 230 | 1 | 189 | 41 | 78 | 232 | 2105 |
| | 2 | 150 | 60 | 127 | 173 | |
| | 3 | 168 | 74 | 133 | 193 | |
| | 4 | 147 | 44 | 94 | 202 | |
| 235 | 1 | 78 | 97 | 242 | 299 | 2742 |
| | 2 | 127 | 85 | 205 | 292 | |
| | 3 | 87 | 147 | 170 | 219 | |
| | 4 | 94 | 99 | 223 | 278 | |
| Number of defects (Units) | | 2758 | 1691 | 2192 | 2668 | 18616 |

**Figure 4**

Number of Leaking glove defects correlation with conveyors speed and oven's temperature – Line chart

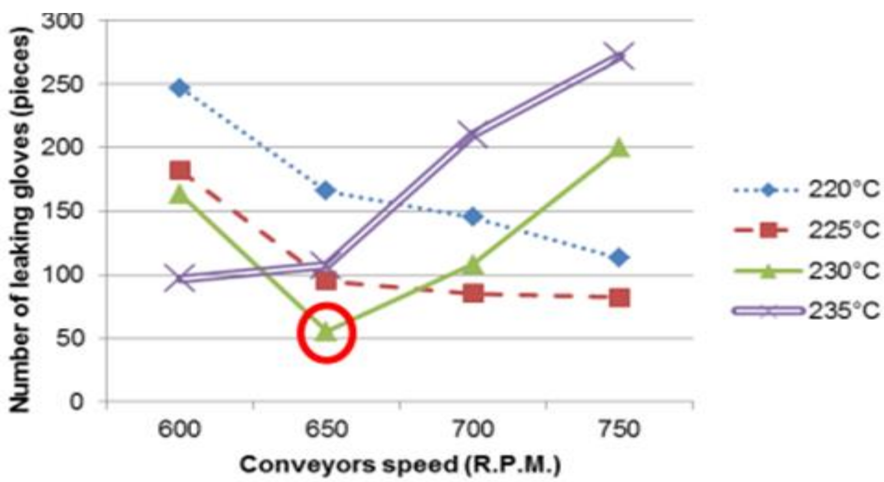


**Figure 5**

Number of Leaking gloves defects correlation with conveyors speed and oven's temperature –Boxplot chart

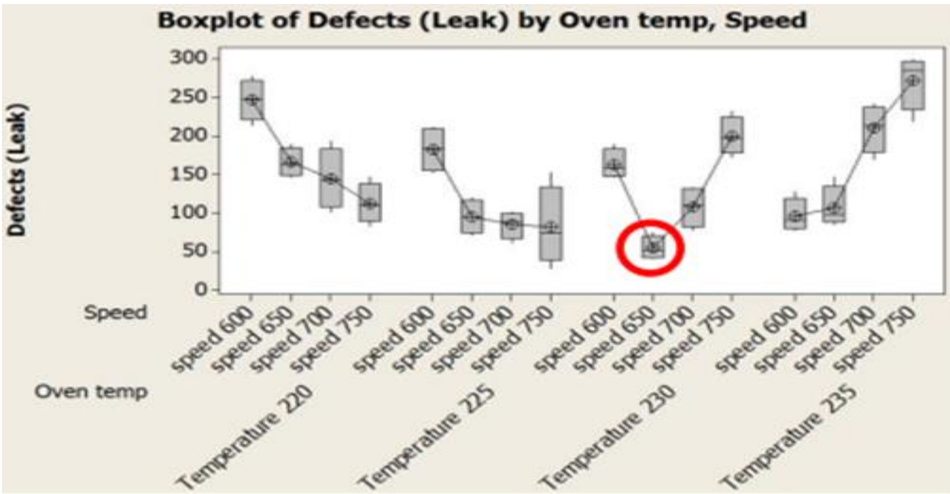



**Table 4**

Percentage of defects between before and after the improvement

| Type of defects | % of defects Before the improvement | % of defects After the improvement |
|---|---|---|
| Leak | 19.51 | 8.38 |
| Miscellaneous | 7.32 | 3.88 |
| Dirty | 3.42 | 2.44 |
| Total | 30.25 | 14.70 |

### *4.2.6. Control*

At the Control stage of DMAIC, the attention switches to the maintaining of the improvements that had been achieved by the project. In addition to limiting the production variability, the standard baking times and belt conveyor running speed must be incorporated into the baking operations to maintain the ovens` consistency. Control charts are a quality control tool for the continuous process monitoring of the production loop by detecting the divergences, which in the end result in elevated defects. These charts show the standing apart of the process normal range from the variation outside, so with that highlight, immediate correction can be made. By tracking defect rates and process variability over time, for instance, the company is constantly assured that the quality improvements from the DMAIC are not lost to regression and prevent any gain reduction that is induced by the process improvements (Jirasukprasert et al., 2014).

**Figure 6**

Before and After state of conducting Six Sigma projects in the glove manufacturing process

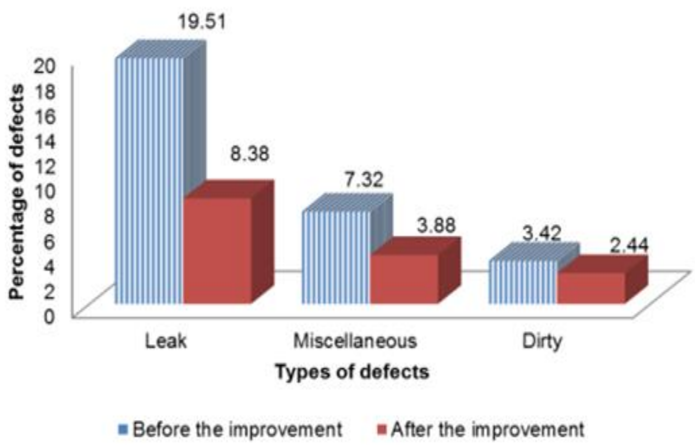



**Table 5**

Final summary of the result

| Major types of defects | Quality levels (DPMO) | | | Sigma level (Sigma) | | |
|---|---|---|---|---|---|---|
| | Before the improvement | Expected | After the improvement | Before the improvement | Expected | After the improvement |
| Leaking gloves | 195,095 | 97,569 | 83,750 | 2.4 | 2.8 | 2.9 |

***4.2.7. Critiques***

The DMAIC process shed a lot of light on how the manufacture of rubber gloves is carried out, given this example, but there are various areas in which the paper could have done a bit better to make it easier for readers to follow and learn from, and to make the study clearer overall. For instance, the entire problem definition stage could have been written succinctly using a process like ‘5 Whys’. Furthermore, it would have been good to provide additional context on what the implications are for the industry at large – what is at stake with this project in terms of competitiveness within the field.

Although there seemed to be some process of goal setting, it was not clear what would be the timelines and benchmarks for tracking progress and building momentum for improvement efforts. With the emphasis on process with less exploration of each phase in detail, details that could have been valuable were not analyzed.

Additionally, and arguably most importantly, not adequately addressing the limits and boundaries of the findings means forsaking the chance to explore why (or why not) the conclusions are transferable to other industries or to the rubber glove industry, thereby muting the extent to which the findings may be extrapolated beyond those of their current scope.

Overall, the case study expresses how Six Sigma and DMAIC can be implemented to reduce defects. It could be improved if it concentrates more on these things as it will make it more useful and relevant to an audience.

**4.3. Optimization of Steel Bar Manufacturing Process Using Six Sigma**

***4.3.1 Objective***

In this case study (Neem Khawar, Ullah Misbah, Tariq Adnan, Masood Shahid, Akhtar Rashid, Hussain Iftikar) conducted a six-sigma improvement project in a steel bar manufacturing industry. The objective of the project is to reduce the scrap rate by improving the six-sigma level of manufacturing process by enhancing yield, reducing process variation and defects per million opportunities.

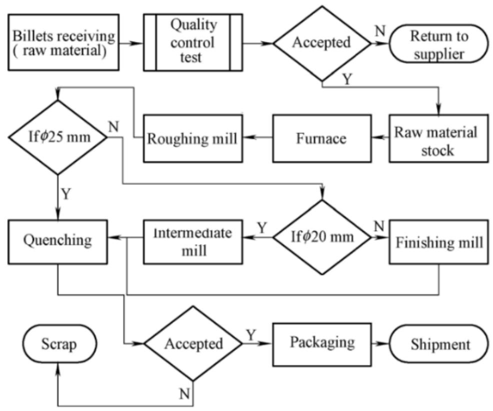
***4.3.2. Define***

The main customers' needs are collected via the interviews with core units - the quality manager and the production department in the steel bar manufacturing industry. The production problem was narrowed down to the aspect of production loss in yield as the main problem. Clearly, the authors of the case study are pursuing two outcomes – increased yield and less scrap. CTQ consists of a variety of characteristics for the product in question such as Ultimate tensile strength, Yield Strength, and mass per length. The selected product to be manufactured for this project is TMT bar for Grade 60 steel that comes in three different diameters: 15mm, 20mm, and 25mm. One of the reasons behind writers' interest in this topic is to increase compensability by picking and ruling out key factors of the process. Factors and settings are evolved based on DMAIC six-sigma approach to find the best possible solutions. our product’s process map is depicted with Figure 1 (Figure 1 below) for the selected manufacturing facility. Before manufacturing, the plant is receiving the raw materials, then checking for quality in terms of chemical composition, and then approved ones are put in the storage and used in accordance with production schedule. In the end the matter is heated up to 1200°C then the heated bills will go to the rough mill, then the 25mm of the billets will begin to quench; after that, the 20mm of the billets will be handed over to the intermediate mill and the last one, the 15mm of the billets will be used in the finishing mill. These bars, further along this course of action, are quenched with 2MPa pressure and the cooling process is carried out in open air. An end check is done, which includes tests for shear modulus, yield strength and Area weight per length with no defects found.

Defective bars (scraps) are sent to the scrap yard, but successful ones are immediately sent to a finished goods yard (Naeem et al., 2016).

**Figure 1**

The steel bar production map of the company




### *4.3.3. Measure*

The required data is collected from the quality department and will be used to measure "Critical to Quality". These data include ultimate tensile strength, yield strength and mass per product according to their sizes. The process performance is examined using the data focusing on capability, process mean, defects per million and six sigma level. The design specifications for the grade 60 steel bar are mentioned in Table 1. The products which are manufactured under this process must meet these specifications (Naeem et al., 2016).

**Table 1**

Design Specifications for grade 60 steel bar

| | |
|---|---|
| Yield Strength = 60 KSI | |
| Ultimate Tensile Strength = 90 KSI | |
| **Diameter of the Steel Bar** | **Mass Per Length (gm m$^{-1}$)** |
| 15mm | 452 |
| 20mm | 707 |
| 25mm | 1140 |

The control charts are used to verify whether the manufacturing process matches the required design standards. The control charts for the 15mm steel bar are shown in Figure 2 as an example. The LSL for 15mm steel bar is 452 gm/m and the process mean is 471.57 gm/m. The lower and upper control limits for the process are 458.00 gm/m and 485.15 gm/m respectively. The process is in control. The control charts for remaining "Control to Quality" are made and their parameters are calculated. The collected data is given in table 2. The process performance is good because the average values and lower limits of the control charts for all main quality characteristics are higher than the minimum required levels. Standard deviation values and UCL-R bar are greatest for 25mm steel bar. The standard deviation of "Critical to Quality" increases from 15mm steel bar to 25mm steel bar. The performance of the steel bar manufacturing process is measured by process capability study. Process performance index, process capability index and defects per million outputs are calculated. The six-sigma level of the current process of the study is stated in table 3. To produce steel bars measuring less than 15 mm, the Cpk and Ppk are 0.72 and 0.71, respectively, in grams per meter, and the DPMO, as illustrated in Fig. 3, is 16158. In a similar manner, the remaining CTQs' process capabilities are analyzed, and their values are determined. For steel bars that are 20 mm and 25 mm, the values of Cpk and Ppk are computed as (0.64, 0.665) and (0.84, 0.85) (Naeem et al., 2016).

**Table 2**

Control chart results of CTQ.

| **CTQ Parameters** | **Mass per Length (g $m^{-1}$)** | | | **Yield Strength** | **Ultimate Tensile Strength** |
|---|---|---|---|---|---|
| | Ø15mm | Ø20mm | Ø25mm | | |
| Lower Specification Limit | 452 | 707 | 1140 | 60 KSI | 90 KSI |
| Mean | 472 | 739 | 1196 | 68 KSI | 98 KSI |
| Lower Control Limit (x-bar) | 458 | 704 | 1163 | 61 KSI | 92 KSI |
| Upper Control Limit (x-bar) | 485 | 775 | 1223 | 75 KSI | 105 KSI |
| Upper Control Limit (R bar) | 42 | 62 | 104 | 17 KSI | 21 KSI |
| Standard Deviation | 9.1 | 16.7 | 22.2 | 3.8 KSI | 4.4 KSI |

**Table 3**

Measurement Phase Summery

| **CTQ Parameters** | **Mass Per Length (g $m^{-1}$)** | | | **Yield Strength** | **Ultimate Tensile Strength** |
|---|---|---|---|---|---|
| | **Ø15mm** | **Ø20mm** | **Ø25mm** | | |
| Process capability index (Cpk) | 0.72 | 0.64 | 0.85 | 0.70 KSI | 0.63 KSI |
| Process Capability Index (Ppk) | 0.71 | 0.65 | 0.84 | 0.71 KSI | 0.63 KSI |
| Defects per million Opportunities (DPMO) | 16158 | 26433 | 5661 | 16189 | 29507 |
| Per million opportunities (PMO) | $10^6$ | $10^6$ | $10^6$ | $10^6$ | $10^6$ |
| Process Yield | 98.121% | | | | |
| Sigma Level | 3.579 | | | | |

The findings of the test phase are highlighted in the table below in Table 3. A table depicts the following process means, the upper and lower bounds of that process, and process capability index Cpk, Ppk, and Dpmo. The results are employed to calculate the company's internal six-sigma baseline, which is a measure of the current process quality along with possibilities for its enhancement. The processed six-sigma level is determined to be 3.579. For the weight per unit length of the steel bar 25 mm in diameter, the highest values both of the Process Capability Index and the Process Performance Index, are recorded. 85 and 0. 84, respectively. Currently, the DPMO of the critical quality characteristic of Ultimate Tensile Strength is reported as 29,507 and that is higher to the DPMO for other quality characteristics. The objective of this research is to work towards an enhancement of the sigma level by doing the necessary to identify the main factors that have been examined during the Analysis phase of the DMAIC cycle (Naeem et al., 2016).

**Figure 2**

Control Chart for Mass per length of 15mm steel Bar.

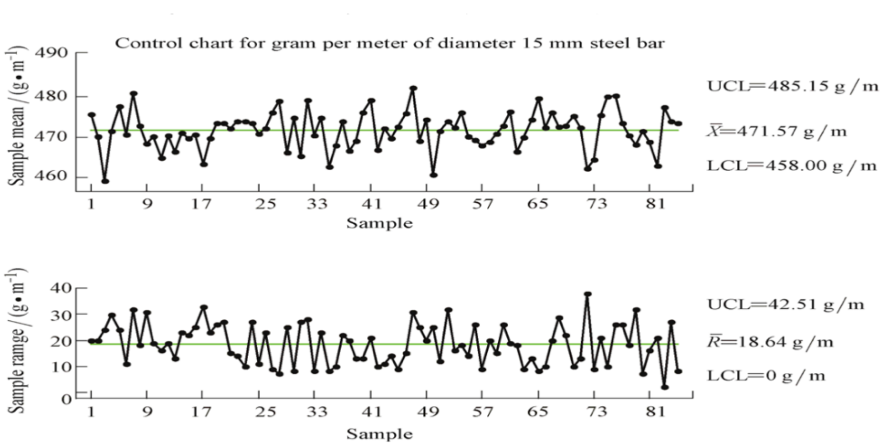
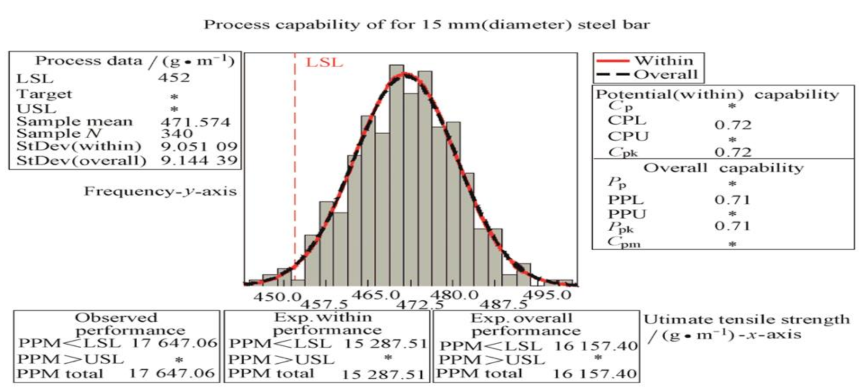



**Figure 3**

Process capability of 15 mm steel bar.




### *4.3.4. Analyze*

The analysis phase is used to figure out the factors causing products to fail quickly. After identifying these factors, the process can be adjusted to reduce the number of rejected items and increase efficiency. To achieve these a thorough analysis is conducted using methods pareto charts, plots to study effects, factorial design experiments and regression modelling. The pareto analysis is conducted using the scrap data collected from quality engineering department and these results are listed in table 4 and figure 5, these includes fluctuations in temperature, variation in input metal composition, water pressure during quenching process and the life span of cutting blades. These are the main factors which account for 92% of the total scrap (Naeem et al., 2016).

**Table 4**

Pareto analysis of Scrap

| Factor | Contribution | Scrap | Cumulative |
| --- | --- | --- | --- |
| Temperature | 0.39% | 21060 Kgs | 0.39% |
| Material Composition | 0.28% | 15120 Kgs | 0.67% |
| Cutting blades | 0.15% | 8100 Kgs | 0.82% |
| Pressure | 0.10% | 5400 Kgs | 0.92% |
| Other Factors | 0.08% | 4320 Kgs | 1.00% |
| Total | 1.00% | 54000 Kgs | |

To verify the results obtained from pareto analysis are verified using factorial design experiments. The low and high setting for these factors is identified by consulting with quality and production experts after reviewing the overall process. The specific setting for each factor is listed in table 5. A detailed factorial design experiment with four variables is conducted across sixteen individual tests, each processing 268 tons of steel. In these tests, each variable is adjusted between predefined low and high settings, it is mentioned as (-1) and (1). The scrap output is measured and recorded. The collected data and the statistical significance (P-values) of each variable are listed in Tables 6 and 7. By keeping all the variables at their low setting 5.32 tons of scrap were produced from 268 tons. The analysis shows that three of the variables (A, B, and C) significantly affect scrap rates, as their P-values are below the threshold of 0.05, indicating strong effects. The fourth variable D does not show a significant effect on scrap rates. The significant factors are displayed in figure 5. The normal pleats show the effects of factors A, B, and C in red which indicates that they are deviating from the normal effect line. In addition to that, the Pareto chart in Figure 6 confirms the importance of these factors (Naeem et al., 2016).

**Table 5**

Process input factors along with respective levels.

| Level | Material | Temperature | Cutting Blades | Water Pressure |
|---|---|---|---|---|
| Low (-1) | 0.35 | 900°C | 1000 h/C | 1 MPa |
| High (1) | 0.75 | 1070°C | 100 h/C | 1.2 MPa |

**Table 6**

Full factorial design experiment

| Sr/No | Material (A) | Temperature(B) | Cutting Blades(C) | Pressure (D) | Scrap/t |
|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 5.32 |
| 2 | 1 | -1 | -1 | -1 | 4.00 |
| 3 | -1 | 1 | -1 | -1 | 3.85 |
| 4 | 1 | 1 | -1 | -1 | 3.00 |
| 5 | -1 | -1 | 1 | -1 | 4.24 |
| 6 | 1 | -1 | 1 | -1 | 3.38 |
| 7 | -1 | 1 | 1 | -1 | 3.12 |
| 8 | 1 | 1 | 1 | -1 | 2.72 |
| 9 | -1 | -1 | -1 | 1 | 4.85 |
| 10 | 1 | -1 | -1 | 1 | 3.98 |
| 11 | -1 | 1 | -1 | 1 | 3.29 |
| 12 | 1 | 1 | -1 | 1 | 2.92 |
| 13 | -1 | -1 | 1 | 1 | 4.18 |
| 14 | 1 | -1 | 1 | 1 | 3.20 |
| 15 | -1 | 1 | 1 | 1 | 3.04 |
| 16 | 1 | 1 | 1 | 1 | 2.02 |

**Table 7**

| **Source** | **P-Statistics** | **Conclusion** |
|---|---|---|
| Main Effects | 0.000 | **Significant** |
| Material (A) | 0.000 | **Significant** |
| Temperature (B) | 0.000 | **Significant** |
| Cutting Blades (C) | 0.001 | **Significant** |
| Pressure (D) | 0.055 | **Non-Significant** |
| 2-Way Interactions | 0.626 | **Non-Significant** |

The interaction plots, main plots, cube plots, surface response plots, contour plots are used to know how changes in the levels of several factors affect the rejected amount. The observations are, when factor level increases from low to high the scrap decreases and there is no interaction between the factors, as indicated by the lack of crossing lines in the interaction plots and the consistent parallel lines. Specifically, factors A, BB and C show decrease in rejection with increasing levels, as shown by steeper slops in the main plots, where D does not show significant change as shown in figure 7. No interactions between the factors observed as shown in figure 8(Naeem et al., 2016).

The comparison between surface plots for factors A, C and rejection in the straight-line surface shows that there is no interaction between these factors shown in figure 9. The cube plots for the factor A, B, C, D are shown in figure 10, demonstrates that scrap is higher when all the factors are at their lowest level (5.23 tons) and lowest when all the factors are at their highest level (2.02 tons). Similarly, the contour plot factors “A vs B and A vs C” shows reduction when increasing the level of these factors. Now it is clear we need to develop a regression model based on a factorial design experiment. The factorial design shows that the factors of material, temperature, and cutting blades A, B, and C are significant, and the effects are assessed in the regression model shown in equation one. The coefficients indicate that the increasing levels of material composition, temperature, and cutting blade quality and decrease scrap by 0.411%, 0.568%, 0.327%, respectively. This analysis shows that these factors are crucial for reducing waste and improving yield in steel bar production. By maintaining these variables at prominent levels, the process can achieve maximum efficiency with minimal scrap (Naeem et al., 2016).

Scrap = 3.62 - 0.417(A) - 0.574(B) - 0.332(C) - 0.134(D) 1)

**Figure 4**

Pareto chart for Scrap percentage

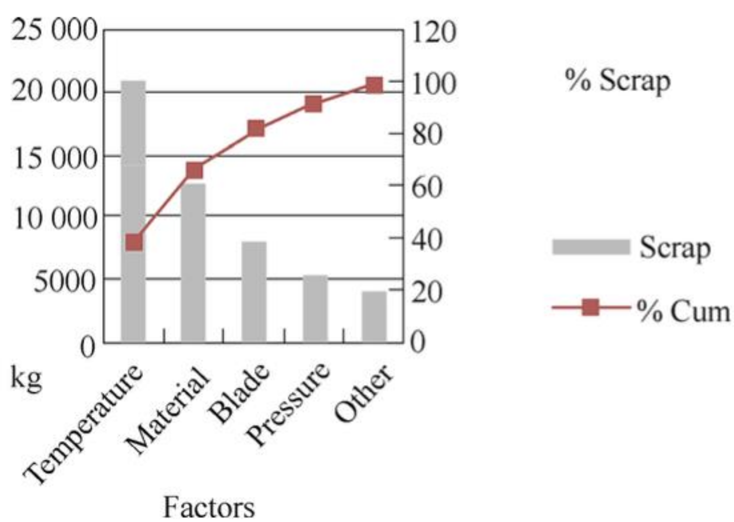


**Figure 5**

Normal plot of the factor effects

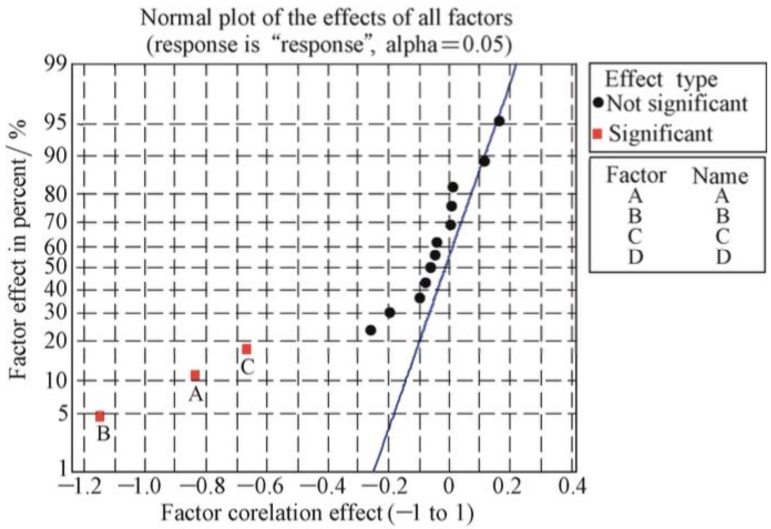



**Figure 6**

Pareto chart for the scandalized effect

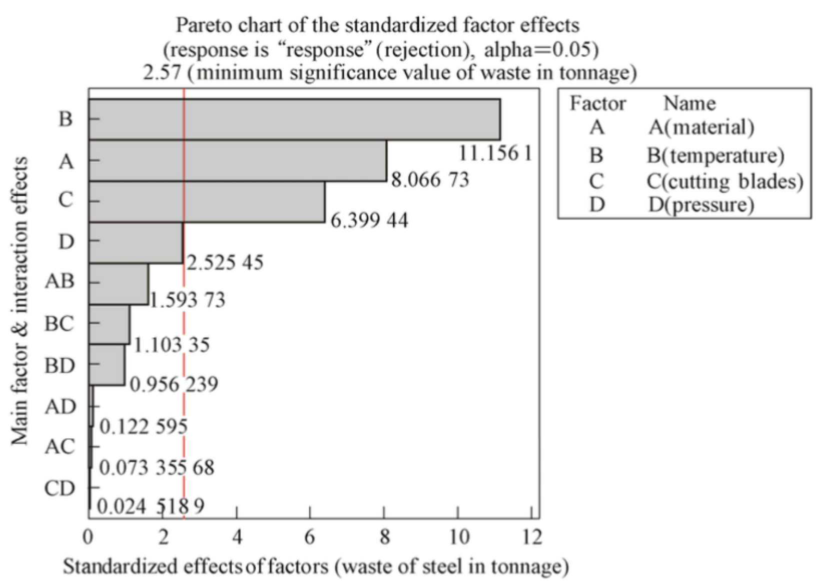



Fig. 6. Pareto chart for the standardized effects

**Figure 7**

Main effect response plot

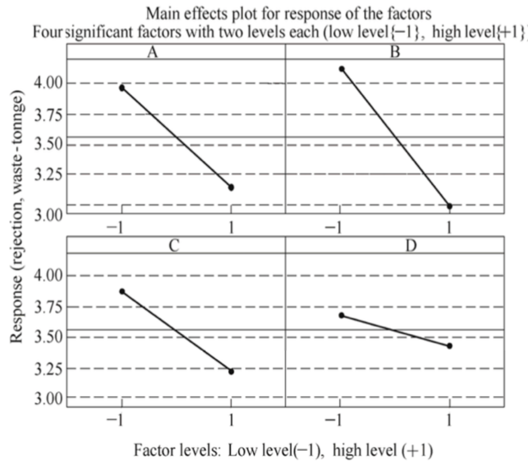



**Figure 8**

Interaction plot for Significant factors

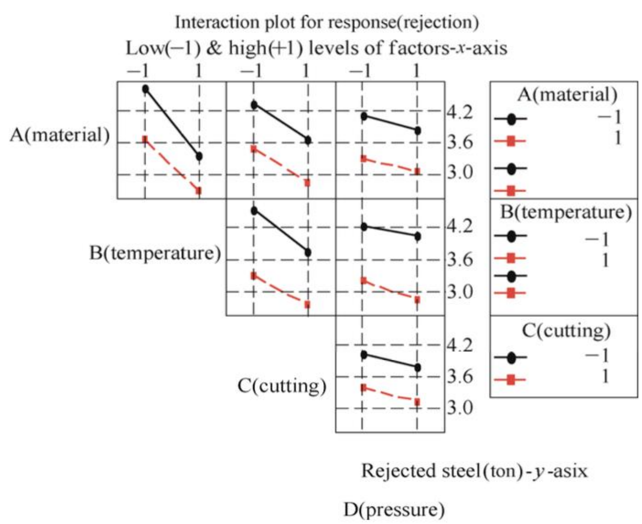


**Figure 9**

Surface plot for the factors A and C

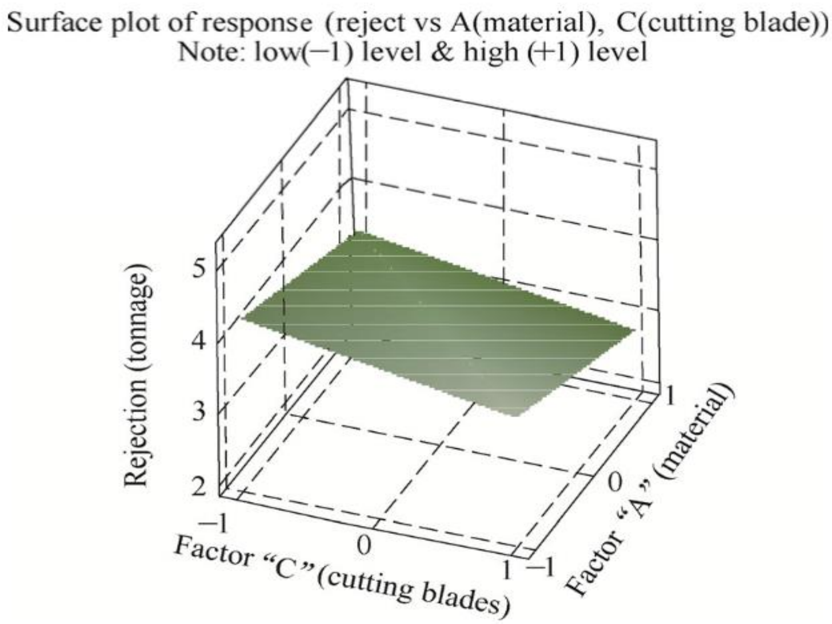
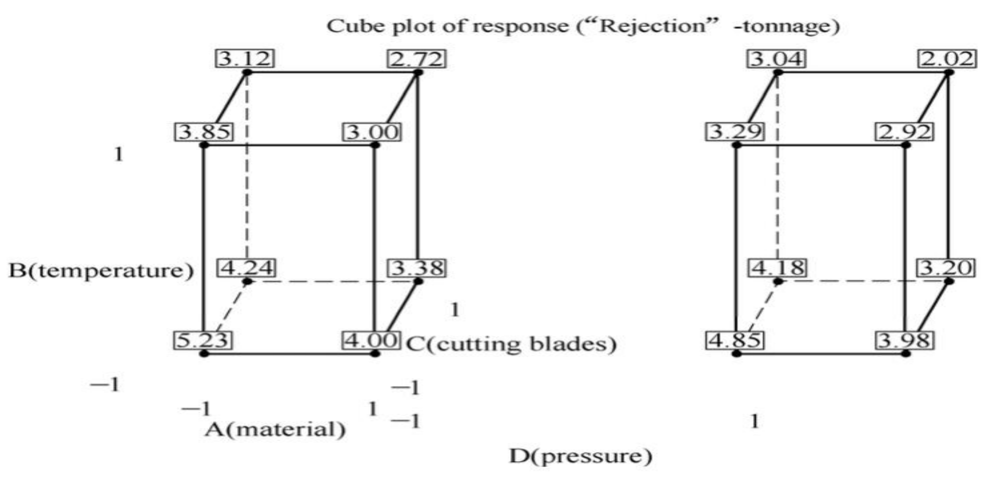



**Figure 10**

Cube plot for the response of Significant Factors



#### *4.3.5. Improve*

The steel bar manufacturing company implements the findings obtained during the Analyze phase during improvement phase. The key factors found are material with the composition of 0.75% of manganese, cutting blades used for hundred hours and the melting temperature is 1070°C. The factory operating at these parameters is calculated and outcomes are measured and listed in table 8 (Naeem et al., 2016).

**Table 8**

Control chart results of CTQ(KPOV)

| **CTQ Parameters** | **Mass per Length (g $m^{-1}$)** | | | **Yield Strength** | **Ultimate Tensile Strength** |
|---|---|---|---|---|---|
| | Ø15mm | Ø20mm | Ø25mm | | |
| Lower Specification Limit | 452 | 707 | 1140 | 60 KSI | 90 KSI |
| Mean | 474 | 746 | 1197 | 69 KSI | 99 KSI |
| Lower Control Limit (x-bar) | 462 | 715 | 1168 | 64 KSI | 93 KSI |
| Upper Control Limit (x-bar) | 486 | 779 | 1227 | 74 KSI | 105 KSI |
| Upper Control Limit (R bar) | 38 | 56 | 94 | 15 KSI | 20 KSI |
| Standard Deviation | 8.3 | 14.9 | 20.8 | 3.1 KSI | 4.3 KSI |

During the process, the mean and lower control limit passed limits of a minimum value that is a defined specification of the product, which else confirms that the process is in control. The workability of this method has been improved and the standard deviation of it is smaller for random plant settings than it is for the new improved method. The mean, Cpk, Ppk and DPMO data for initial were annotated in the table 8 Moreover, in table 9, the same set of data discloses values of DPMO, process yield, and six sigma levels after the improvements. CTQ features - yield strength - and ultimate tensile strength - are 1,909 and 17,206 respectively. The values of the tensile strength under elongation are lower than the original measurements at 29,507 for UTS and 16,189 for YS as expected from table 4. The total amount of discarded goods as a result of the initiative was cut, while also the sigma-level and process yield were enhanced. The 6sigma quality level increased to 3. 579 to 4. 007(Naeem et al., 2016).

**Table 9**

Summarized results of improvement phase.

| CTQ Parameters | Mass Per Length (g $m^{-1}$) | | | Yield Strength | Ultimate Tensile Strength |
|---|---|---|---|---|---|
| | Ø15mm | Ø20mm | Ø25mm | | |
| Process capability index (Cpk) | 0.72 | 0.87 | 0.96 | 0.94 KSI | 0.72 KSI |
| Process Capability Index (Ppk) | 0.87 | 0.89 | 0.92 | 0.96 KSI | 0.91 KSI |
| Defects per million Opportunities (DPMO) | 4574 | 3872 | 2851 | 1909 | 17206 |
| Per million opportunities (PMO) | $10^6$ | $10^6$ | $10^6$ | $10^6$ | $10^6$ |
| Process Yield | 99.39% | | | | |
| Sigma Level | 4.0073 | | | | |

***4.3.6. Control***

The results are communicated to the team and production departments are notified that they are operating in the updated conditions specified in table 10. Following these settings, the production system can achieve maximum output and improved performance. In addition, a sample Z test was carried out to improve the data to verify that the process means exceeded the product's lower specification limits. The test was carried out with a confidence interval of 95%, and the results are summarized in Table 11 (Naeem et al., 2016).

**Table 10**

Significant factors and optimum process level

| Level | Factor A (manganese) | Factor B (temperature) | Factor C (Cutting blades) |
|---|---|---|---|
| High | 0.75% | 1070°C | 100 h |

A one-sided tail test was conducted to see if the mean μ is greater than LSL. A p value smaller than 0.005 leads to the rejection of null hypothesis, which suggests that μ is not less than or equal to LSL. Then alternative hypothesis says that μ is greater than LSL is accepted. Therefore, it is confirmed that the mean values of the critical-to-quality points (KPOVs) are above the LSL, as required (Naeem et al., 2016).

**Table 11**

One sample Z test results

| CTQ Parameters | | Standard Deviation | Alternate Hypothesis | P- Value | Results |
|---|---|---|---|---|---|
| Mass Per length ($g\ m^{-1}$) | Ø15mm | 8.36 | μ>452 | 0 | Accept |
| | Ø20mm | 14.94 | μ>707 | 0 | Accept |
| | Ø25mm | 20.8 | μ>1140 | 0 | Accept |
| Yield Strength | | 3.144 | μ>60 | 0 | Accept |
| Ultimate Strength | | 4.311 | μ>90 | 0 | Accept |

***4.3.7. Critiques***

The six-sigma DMAIC methodology is applied systematically to develop the optimal production process for steel bar-casting, taking into consideration the most significant aspects such as material composition, temperature, and water pressure. Nevertheless, the research area can be extended to endow additional important variables in the study which might include cooling rates and the furnace's atmosphere. A two-level factorial design can be considered a strength, but implementations of even more sophisticated experimental designs like multi-level blocking, fractional factorial, or response surface methodology would help to better refine the optimization through the discovery of interactions at multiple levels. The study could possibly take additional advantage of advanced statistical methods like multivariate regression or machine learning processes that enable modeling with more precision of complex interactions. Consequences for the environment of the improved processes were omitted and could be serious, for being the very nature of the industry environment. Lastly, it is recommended to conduct the pilot tests with optimized findings to help sustain improvement and manage risk issues associated with process change, guaranteeing the robustness and applicability of optimized parameters across different environments.

## 5. Synergy of lessons learned

The main output from the lesson learned section of the 'Synergy of Lessons Learned' section of the Six Sigma project is the main learning of how to use process improvement across a variety of different manufacturing products, as well as exactly what was done to achieve a particular goal.

The project uses the DMAIC (Define, Measure, Analyze, Improve, Control) methodology which goes through the manufacturing process for various products, from gas meter production to food packaging. The main outcome outlined in the project includes how to set precise goals for a particular business outcome, what variables need to be measured for that outcome, how to analyze those variables to identify inefficiencies in a process, and how to improve the process using that data for the particular business outcome.

By outlining exactly where the project was inefficient before setting goals, using the data to improve the process using Lean Manufacturing principles, how much the scrap rate of raw materials was reduced, and how much less electricity and dollar costs it took to produce products or services identifies the crucial need for not only precise goal setting but also making sure the right data is collected and collected in the right way, to mitigate those wasteful areas of manufacturing, which should be the case with all manufacturing since the beginning of the Industrial Revolution and beyond it.The project not only re-enforced the need to use a methodical and careful approach to problem-solving for improving processes in manufacturing, but it also outlines how easy it could be for businesses or other global industries to take that same method and apply it to their industry or companies to increase overall productivity and make products or services.

**6. References**

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