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Amendment procedure in sintered bush Manufacturing industry by the utility of Six Sigma DMAIC: A case study

Raja Kumar[1] | Happa Khan[1] | Haris Arquam[1,*] | Ajit Bahadur Verma[1]

[1]Department of Mechanical Engineering, Arya College of Engineering, Jaipur, India 302028

*Corresponding Author: harisarquam@aryacollegejpr.com

Abstract: Six Sigma DMAIC is one such disciplined route that helps us focus on improving the world's best merchandise, processes as well as services. "Sigma" is used to compute how a great deal in a specific manner departs from perfection. Sigma best levels additionally assist to set an impartial for the enhancement of the best of technique with the assist of DMAIC manner. A great execution of DMAIC mode confirms us to getting rid of the motives for fault by means with respect to outcomes of the manner, that's critically critical to the consumers. By means of the use of DMAIC manner, the dissimilarity in the product or technology, loss of cloth and system errors can be minimized. DMAIC cycle is an essential part of Six Sigma. Multiculturalism, the evolution of the era, and enhancement in the call for of the calumet have modified the manner of doing commercial corporation of the groups great is the most vital client-pushed preference element in the desire among participating outcomes and solutions reducing the dissimilarity in outcome dimensions plays a critical pile is the improvement. This paper includes the Six Sigma DMAIC method modified into used to lower the method version of length of bush for reinforcing product exquisite. The outline section of DMAIC approach begins via manner of problem detection through the voice of internal and outside clients. The later level represents calculating the statistics of bush parts of existing ways.

Keywords: Process Capability analysis (PCA), Six Sigma DMAIC, Error Reduction, Process Optimization, Bush Dimension Control

1. Introduction of DMAIC

Six Sigma DMAIC is a noticeably disciplined course that allows commercial global to be cognizant of the improvement of perfect products, techniques in addition to activities. The term "sigma" is used to describe how far a particular method deviates from excellence. With the use of DMAIC, Sigma nice tiers also assist in setting an intention for the enhancement of approach first-rate. technique. A first-rate execution of DMAIC method finalizes us to getting rid of the motives for defects with the resource of regarding on consequences of the technique, this is notably essential to the clients. With the aid of the use of DMAIC technique, the model Fabric waste and system mistakes can be eliminated in the product or process. The DMAIC cycle is an

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important aspect of the Six Sigma process **[1]**. DMAIC was also utilized to describe the project, grade the project, analyse the challenge, beautify the assignment, and track task progress. If you can't define your approach clearly, you won't be able to degree it at the end of the study process. That is, in order to use DMAIC technique correctly in your method or product, you must clearly address the situation **[2]**.

1.1 Introduction of Sintered Bush

Sintering is the process of exposing inexperienced compact metallic material to heat at a temperature lower than the melting point of strong steel. It's one of the powder metallurgical technology processes that allows a simple shape to be transformed into a complex one at a low cost. The opportunity procedure is compressing or pressing, which is applying significant pressure to a properly structured powder mixture at a constant or elevated temperature.

The following powders compressed is known as briquette and is said to be the shape known as inexperienced. Metal powder is mixed in this device at a specific ratio. The parts are then pressed to the needed level at a high stress with a precision system, and at last bonded or combined at high temperature in a furnace under a precautionary environment as an extremely remarkable finished detail, with mechanical properties extra or less equal to parts fabricated in the traditional procedure. Figure 1 illustrates two different types of sintered bush, showcasing the variation in structure and design achieved through the sintering process.

Figure 1: Sintered bush

1.2 Process of Manufacturing

a. The manufacturing process begins with doping and mixing of metal powder, where alloying elements are added to the base metal powder and mixed thoroughly to ensure homogeneity. This step is crucial for achieving the desired material properties.

b. Next, the powder is subjected to die compaction, forming it into green briquettes. This involves pressing the powder in a die under high pressure to achieve the required shape and preliminary strength for handling.

c. The green briquettes are then processed through the sintering method, where they are heated to a temperature below the melting point. This step enables bonding between particles through diffusion, enhancing the mechanical strength and density of the component.

d. Repressing is carried out after sintering to refine dimensions and further increase strength. Sizing is then employed to ensure the final component meets precise dimensional tolerances.

e. Finally, oil impregnation is performed to improve lubrication properties, enhancing wear resistance and functionality in applications.

1.3 Process Capability Analysis

Device functionality examines how variability affects a system and provides metrics to quantify these variations. Such analyses offer insights into method performance under different conditions, setting overall performance targets. Method functionality is used to investigate process data and improve design, planning, and assessment methodologies, helping eliminate production flaws through better system design. Principal Component Analysis (PCA) identifies changes without distribution assumptions, making device functionality essential for quality improvement **[3]**. Computer systems evaluate process outputs and compare variations to product tolerance. PCA statistically records process performance using capability indices such as C_p and C_{pk}, which are widely used in manufacturing to quantify process capability and performance **[4]**. Process variation arises from common and specific causes, affecting production outcomes. In the context of bush length manufacturing, process capability assessment helps identify sources of variation and implement corrective measures to reduce variability, ensuring better quality control **[5-7]**.

A process refers to a combination of four essential elements, equipment, labor, materials, and methods. It is a series of actions or procedures through which raw materials and pre-machined components are further processed to create a finished product **[8]**. These studies are conducted when a change in production parameters or the introduction of a new product occurs. It is a method of evaluating whether a system is statistically capable of meeting a specified set of criteria. The goal is for the output to conform to the required specifications. A capability study can be performed to determine the extent to which the process aligns with the specified engineering tolerance **[9]**. The key concept of capability studies involves the interaction of process parameters and product standards. These indices are used quantitatively to assess performance, considering both the process and the system **[10]**. The capacity of a process is measured through performance indices, which should meet or surpass the established minimum values **[11]**. Commonly used indices include C_p and C_{pk}, which are frequently applied in evaluating process capabilities as shown in Table 1 **[12]**.

2. Literature Review

Patel and Patel critically reviewed Lean Six Sigma (LSS) and its methodologies, emphasizing its widespread application across industries. They identified key benefits such as enhanced operational efficiency, cost reduction, and quality improvement. The study highlighted challenges like limited leadership commitment and employee resistance, suggesting these as primary barriers to successful implementation. Furthermore, they underscored the need for an integrative framework to bridge the gap between Lean and Six Sigma practices **[1]**.

Pongboonchai-Empl et al. explored the integration of Industry 4. 0 technologies into the Lean Six Sigma DMAIC framework. Their systematic review revealed that technologies such as IoT, AI, and big data analytics have enhanced real-time decision-making in LSS projects. They emphasized how such integration has improved process automation, data accuracy, and resource optimization. However, the study also pointed out the need for a skilled workforce to leverage these technologies effectively **[3]**.

Ramakrishna and Alzoubi examined the mediating role of the Six Sigma approach in rationalizing the Cost of Quality (COQ) in service sectors. Their empirical findings demonstrated that implementing Six Sigma methodologies reduces errors, improves service quality, and optimizes operational costs. They also highlighted the importance of leadership involvement and organizational culture in the successful deployment of LSS practices within service-oriented businesses **[4]**.

Table 1: Process capability indices and their usage **[13, 14]**

Index	Estimate Equation	Usage
C_p	$C_p = \frac{USL-LSL}{6\sigma}$	It predicts what the system is capable of manufacturing if the proposed methods are focused between the specified limit. It analyzes the intensity of the actual variation to the specification variations allowed for the procedure.
C_{pk}	$C_{pk} = \min(C_{pl}, C_{pu})$ $\frac{USL-u}{3\sigma}$	It estimates what the technique is able to produce; thinking that the technique advocate may not be centered within the specification limits. It is determined by the distance between the common method and the nearest specification restriction.
C_{pl}	$C_{pl} = \frac{u-LSL}{3\sigma}$	It estimates the process capability for a lower specification limit only.
C_{pu}	$C_{pl} = \frac{USL-u}{3\sigma}$	It estimates the process capability for a lower specification limit only.
C_{pm}	$\frac{C_p}{\sqrt{1+\left(\frac{\bar{\bar{x}}-t}{\sigma}\right)^2}}$	It estimates the capability of the technique around a goal (t) is all the time more than zero. It assumes the procedure output is more or less generally allotted.

Citybabu and Yamini conducted a bibliometric analysis to evaluate the convergence of Lean Six Sigma with Industry 4.0 technologies. Their study identified key research trends, influential authors, and critical journals in the domain. They proposed a conceptual framework emphasizing future research agendas, including digital transformation and the role of machine learning in enhancing LSS outcomes **[5]**.

Kumar et al. investigated the linkage between Lean Six Sigma attributes and new product development (NPD) processes. The study mapped quality performance improvements achieved through integrating LSS principles into NPD stages. It found that the adoption of LSS led to reduced lead times, minimized defects, and enhanced customer satisfaction in product development cycles **[6]**.

Reosekar and Pohekar provided a structured review of the Six Sigma methodology, focusing on its evolution and application in diverse sectors. They categorized Six Sigma tools and techniques and discussed their role in achieving process excellence. The study emphasized the adaptability of Six Sigma to changing market demands and suggested the incorporation of sustainability metrics to align with modern business goals **[15]**.

3. Methodology

The process begins with acquiring and recording length statistics to analyze the current performance. CAD drawings are utilized to define specification limits, ensuring compliance with design requirements. Using MINITAB 18.0 software, control charts and a process capability report are generated to monitor variations and assess process efficiency **[16]**. A cause-and-effect diagram is prepared to identify potential factors contributing to deviations. Corrective measures are then suggested based on the findings. These recommendations are implemented systematically following a defined flow chart to address root causes, enhance process stability, and improve overall product quality, ensuring consistent adherence to specifications and customer satisfaction.

To degree the variability in bush element production, the Six Sigma DMAIC method was followed which is explained in Figure 2.

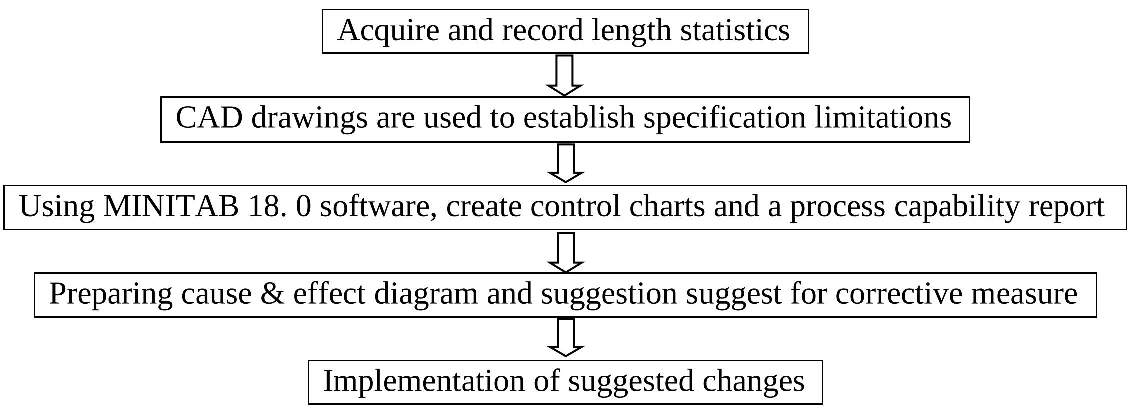

Figure 2: Flow chart of methodology **[17]**

3.1 Length Variation

In the sintered division, throughout the manufacture bush at some point of compaction and sizing system, we faced the period variant problem due to the machine problem, labour problem, and best trouble. Because of the duration variant, bush making problem at some point of using bush. Duration version trouble faces in such ways like duration oversize, period undersize, and period in tapper. In order that’s why we solve this trouble by using the DMAIC procedure **[18]**.

During the compaction system while we bush is manufactured by means of powder by the use of the urgent operation, and their duration version trouble faces so scrap material might be improved, wear dealing with time and money losses problem. If this material might be sintered and sizing the material. So, we're facing excessive losses of money due to the fact green fabric will be grinding and making powder effortlessly but after sintering it's tough **[19]**.

3.2 Measure Phase

The current technique statistics of the bush period were measured during the measurement phase of DMAIC, as shown in Table 2.

Table 2: Observation table of length

S. N.	Observation of length					x bar	R
	1	**2**	**3**	**4**	**5**		
1	9.85	9.88	9.8	9.83	9.87	9.85	0.08
2	10	10.08	10.05	10.03	10.02	10.04	0.08
3	9.95	9.9	9.93	9.95	9.94	9.93	0.05
4	9.98	9.99	9.98	9.9	9.8	9.93	0.19
5	9.95	10	9.89	9.85	9.7	9.88	0.30
6	10.2	10.02	10	10.09	10.08	10.08	0.20
7	10	9.97	9.99	9.98	9.99	9.99	0.03
8	9.96	9.95	9.96	9.98	9.99	9.97	0.04
9	9.91	9.9	9.92	9.91	9.9	9.91	0.02
10	10.05	10.04	10.06	10.06	10.05	10.05	0.02
11	9.95	10.05	10	9.9	10.06	9.99	0.16
12	9.77	9.75	9.85	9.8	9.95	9.82	0.20
13	10.06	10.05	10.05	10.08	10.05	10.06	0.03
14	10.08	10.05	10.04	10.06	10	10.05	0.08
15	9.95	9.96	9.94	9.95	9.92	9.94	0.04
16	10.01	10.05	10	10.04	10.02	10.02	0.05
17	9.7	9.8	9.78	9.88	9.89	9.81	0.19
18	9.93	9.98	9.95	9.91	9.92	9.94	0.07
19	10.06	10.02	10.03	10	10.05	10.03	0.06
20	9.95	9.96	10	9.92	9.98	9.96	0.08
						$\bar{\bar{X}}$= 9.96	$\bar{R}$ = 0.10

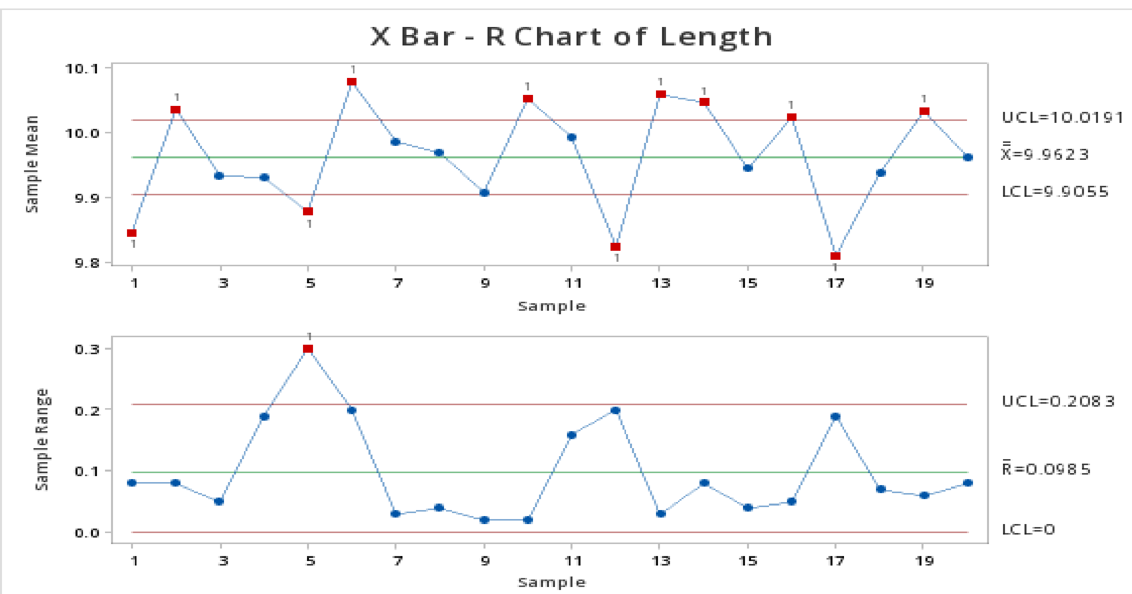

Figure 3: X bar and R chart for Length

After examining the above data to determine if the process is statistically controlled or not, and the capability of the process, create X-bar R charts for Length using the MINITAB 18.0 programme, as shown in Figure 3.

According to the X-bar R chart's analysis, the procedure is under statistical control, as all pattern points were inside the lower and upper manipulation limits. Additionally, move for PCA using Minitab 18.0. There is no software programme. Figure 3 validates the technique analysis **[20]**.

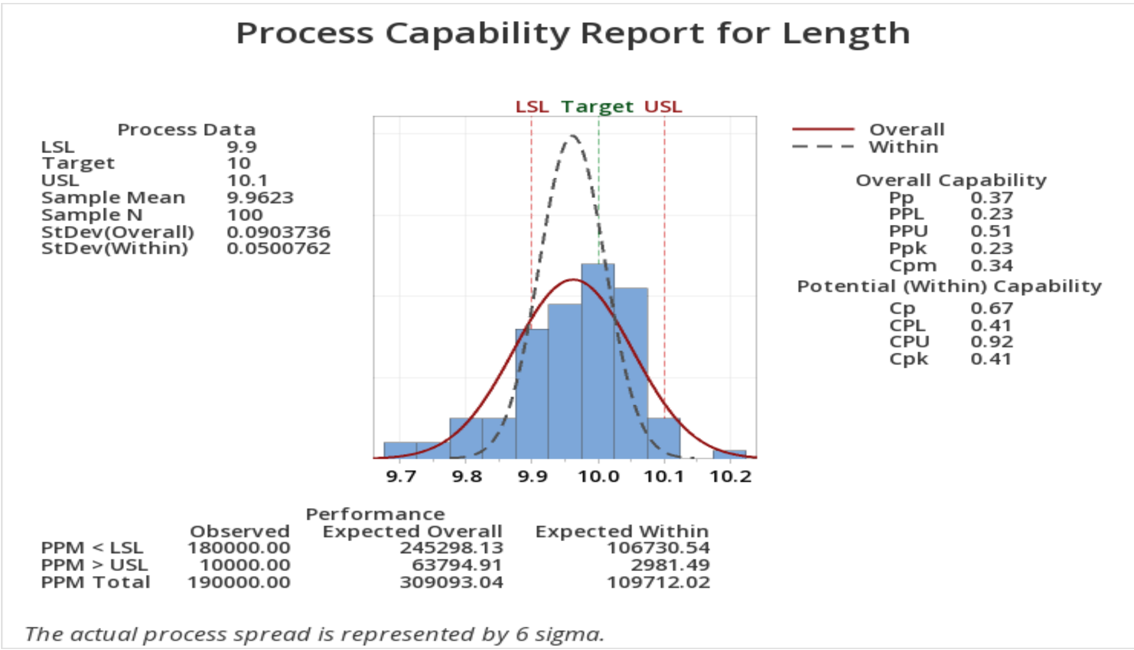

Figure 4: Process capability report for length

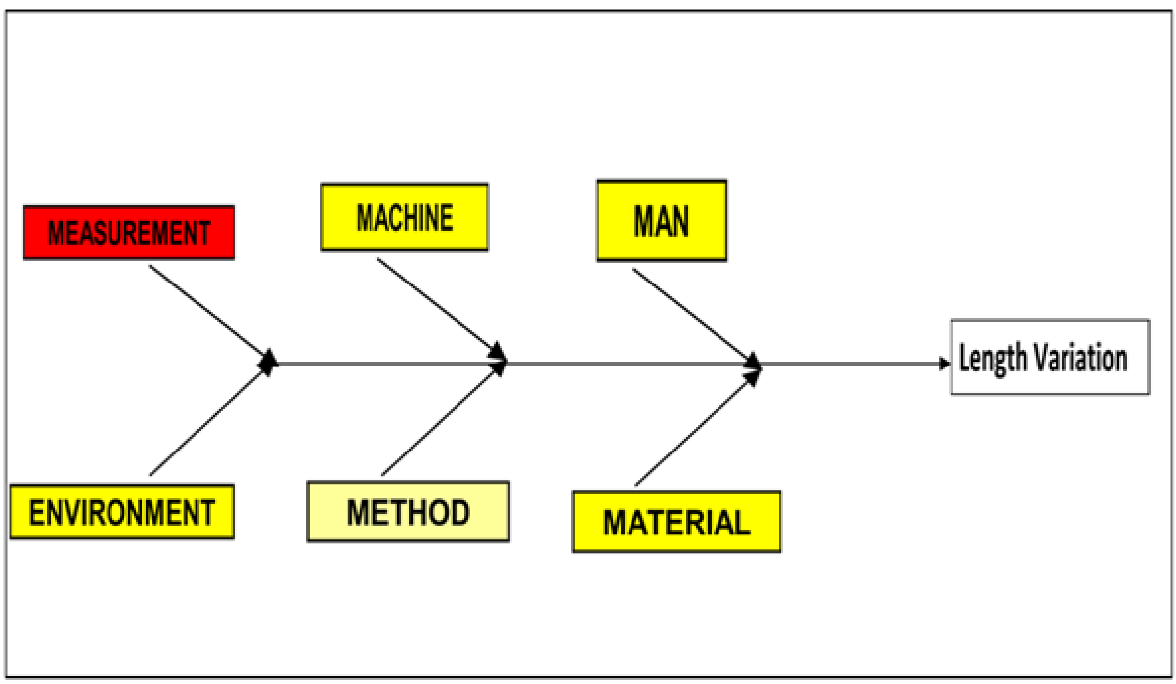

Figure 5: Cause-and-effect diagram **[20]**

From the PCA, found the values of PCIs (C_p = 0.67, C_{pk} = 0.41 and C_{pm} = 0.34) and standard deviation (0.0500762). The values of capability indices are less than one (<1)), which means the process is not capable as shown in Figure 4. In This section of DMAIC become aware of accountable assignable causes for negative exceptional or variability in the existing technique. Those accountable reasons are stated in the reason and effect diagram determined in Figure 5.

Table 3: Observation table of improved process

S. N.	Observation of length					X bar	R
	1	2	3	4	5		
1	9.99	9.98	9.99	10	9.99	9.99	0.02
2	10	10.01	10	10.02	10.01	10.01	0.02
3	9.97	9.99	9.98	9.97	9.98	9.98	0.02
4	9.98	9.99	9.98	9.99	9.98	9.98	0.01
5	9.96	9.97	9.95	9.96	9.96	9.96	0.02
6	10.05	10.04	10.04	10.05	10.04	10.04	0.01
7	10	9.99	9.99	10	9.99	9.99	0.01
8	9.99	9.99	9.98	9.98	9.99	9.99	0.01
9	9.96	9.96	9.97	9.98	9.97	9.97	0.02
10	10.05	10.04	10.04	10.05	10.05	10.05	0.01
11	10.03	10.02	10.02	10.03	10.02	10.02	0.01
12	10	9.99	9.98	9.98	9.99	9.99	0.02
13	10.06	10.05	10.05	10.05	10.05	10.05	0.01
14	10.02	10.02	10.01	10.01	10.02	10.02	0.01
15	9.95	9.96	9.96	9.95	9.96	9.96	0.01
16	10.01	10.01	10	9.99	10	10.00	0.02
17	9.98	9.97	9.98	9.97	9.98	9.98	0.01
18	9.99	9.99	10	9.99	10	9.99	0.01
19	10.06	10.05	10.04	10.04	10.05	10.05	0.02
20	9.97	9.98	9.97	9.98	9.98	9.98	0.01
						$\bar{\bar{X}}$=10.00	$\bar{R}$=0.01

In the development phase of DMAIC, after determining the underlying causes, the following actions must be taken:

- The device's existence must be closely monitored device must be adjusted not after the ongoing manufacturing batch, in a number of the persevered production lots to lower the viable version **[21]**.
- An alternative to current cooling purifiers with a shorter mesh length. After a specific duration or device run time, the coolant and liquid clear-out are adjusted. Also, after each manufacturing batch, smooth the coolant clear out and check the amount of coolant in the tank **[22, 23]**.

- Before you begin manufacturing, go over all of the machine settings on a daily basis.
- For specifications, apply a decal on raw material.

Following the implementation of the aforementioned corrective steps, it is possible that the advanced approach will outperform the current method in terms of productivity, quality, and cost-effectiveness **[15]**. Machining data was gathered and evaluated once more for duration. The length of information gathered after performing corrective motions is shown on desk three. This information collection has 20 observations as shown in Table 3. X-bar R charts were prepared for Length using the MINITAB 18.0 software, as shown in Figure 6.

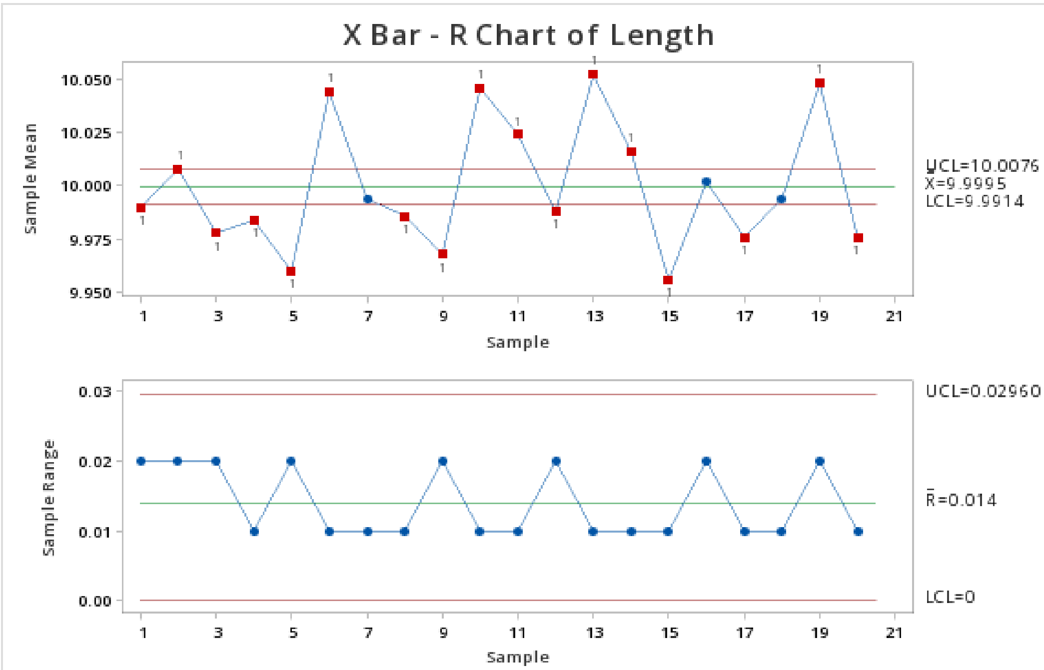

Figure 6: X bar and R chart for Length

The process is under statistical control, based on the analysis of X-bar R chars, therefore go for PCA utilising MINITAB 18.0 programme.

The values of technique functionality indices (C_p = 5.04, C_{pk} = 5.01 and C_{pm} = 1.12) were determined and a deviation (0.0066161) of the usage of Minitab 18.0 was observed, as shown in Figure 7. The values of functionality indices progressed as much as more than one (>1), which means the stepped-forward system is better than the prevailing procedure, as shown in Table 4.

Table 4: Process capability indicators before and after improvement are compared.

		C_p	C_{pk}	C_{pm}	Std. Dev.
Length	Before Improvement	0.67	0.41	0.34	0.0500762
	After Improvement	5.04	5.01	1.12	0.0066161

- **Control Phase**

Keep and continue the superior system for preserving the business enterprise in an aggressive market. The stepped-forward method is used until there is an additional improvement. The approach/product variability is reduced as a result of the effects approach, and incredibly good and customer satisfaction may be advanced **[21]**.

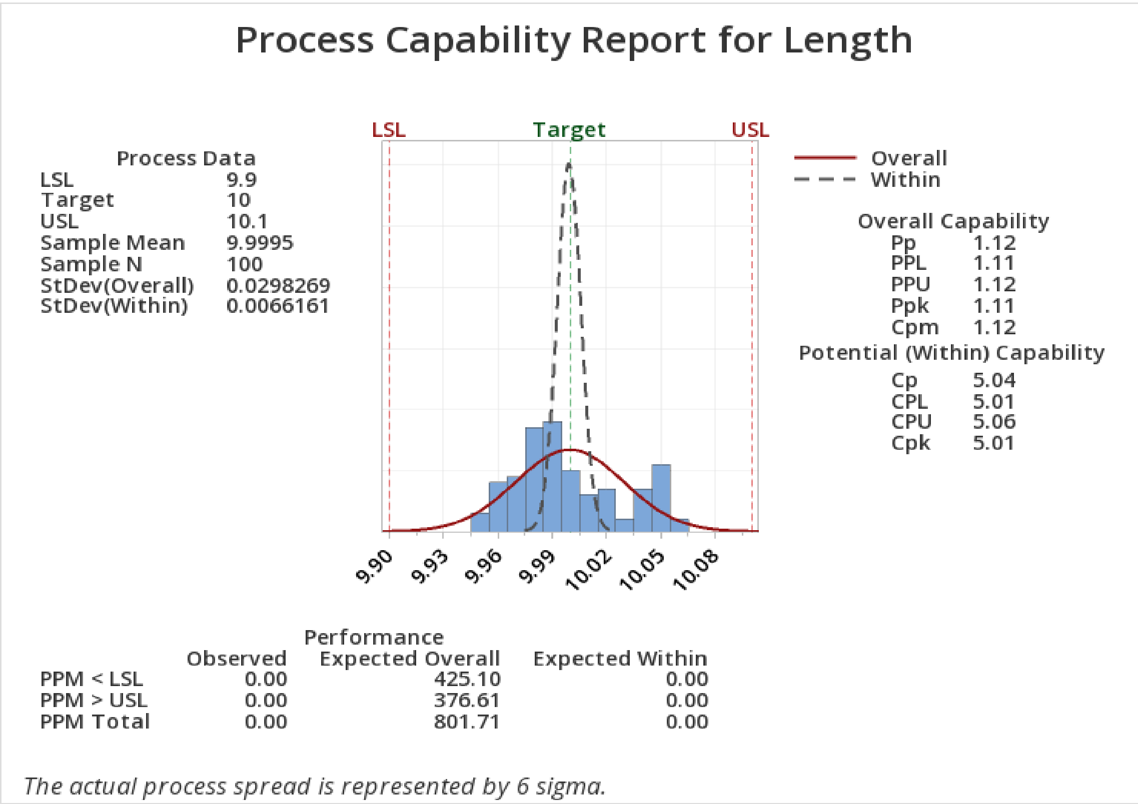

Figure 7: Process capability report for length

9. Results

The application of the Six Sigma DMAIC approach yielded significant improvements in process performance and cost efficiency. The preferred deviation was successfully reduced from 0.0500762 to 0.0066161, demonstrating a remarkable enhancement in precision and process stability. Capability indices showed notable progress: C_p improved from 0.67 to 0.41, indicating better overall process capability; C_{pk} increased significantly from 0.34 to 5.04, reflecting enhanced alignment of the process mean with specification limits; and C_{pm} advanced from 5.01 to at least 1.12, showcasing reduced variability and improved process centering. These results highlight the effectiveness of the DMAIC methodology in achieving cost reductions and quality improvements.

10. Conclusion

Six Sigma DMAIC is a highly powerful technique for determining the true need for a process for improvement. The six Sigma DMAIC approach also provides a viable alternative for information analytical evaluations. Outcomes with a Six Sigma fulfillment implementation in really good packages are shown:

- Decreased costs of terrible first-rate
- Beautify way functionality
- System improvement

In this study, the Six Sigma DMAIC strategy was found to be effective for technique improvement in a bush element production organization. The values of the manner functionality indices c, C_{pk}, and C_{pm} for the current approach were determined in the first phase. The numbers were set to be significantly less than one in order to improve the method's values. With the help of a motive and impact diagram, functionality indices can be used to lower the root causes of device variability. The charge of machine capability indices has been advanced in the improvement part and detected more than one after corrective actions have been taken.

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