Application of Six Sigma Methodology for Enhancement of Soft Plastic Extrusion Process

Aplicación de la metodología Seis Sigma para la mejora del proceso de extrusión de plásticos blandos

Aplicação da Metodologia Seis Sigma para Aprimoramento do Processo de Extrusão de Plástico Macio

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Summary. - The gasket manufacturing process in "Company A" faced significant challenges and inefficiencies because of high rejection rates and variation in extrusion machine, magnetic insertion machine and welding machine's performance. All three machines were consistently generating major rejections on a daily basis including a high volume of purging rejections from the PVC soft extrusion machine, excessive trimming of oversized magnets during the magnetic insertion process, and significant rejection due to poor joint strength in the welding process of PVC profiles. In order to address these underlying issues, Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology was employed in order to decrease rejection/waste, increase process efficiency and decrease defects of all three machines. The study involved process mapping, cause and effect analysis, quality function deployment (QFD) and statistical process tools such as ANOVA, regression and Cp/Cpk analysis. Root causes were identified and targeted improvements based on the data were introduced including optimized production planning, machine parameter optimization and standardization, improvement of production execution planning and storage availability, temperature controls on welding machines and encoder wheel knurling for magnetic insertion machine. The main objectives were to deal with problems including material waste, variance in magnetic strip size, issues in welding machines and frequent machine stoppages caused by improper production scheduling because of improper availability of storage space for batch production independent of door pre-assembly plan. Following implementation, results show a considerable decrease in extrusion machine rejection %age from 12% to 4.06%, a reduction in purging waste from 17 kg/day to 6.9 kg/day and an increase in machine efficiency from 50.1% to 83.3%. Furthermore, welding machine rejection %age fell from 7% to 3.7% as a result of enhanced temperature management and equipment maintenance. Size variation issue in magnet insertion machine was resolved by knurling of encoder wheel. Overall, these changes resulted in an annual cost savings of roughly 1.5 million PKR for the extrusion process and 1.2 million from magnet insertion machine. The significance of this project originates from its potential to streamline the gasket production process by reducing waste and faults while increasing machine efficiency. The results offer a replicable framework that can be employed across wide range of manufacturing industries for quality improvement and cost optimization.

Keywords: Gasket manufacturing, DMAIC methodology, Six sigma, Process optimization, waste reduction, sustainable production, ANOVA, Statistical process control.

Resumen. - *El proceso de fabricación de juntas en la "Empresa A" se enfrentaba a importantes desafíos e ineficiencias debido a las altas tasas de rechazo y a la variación en el rendimiento de las máquinas de extrusión, inserción magnética y soldadura. Las tres máquinas generaban rechazos importantes a diario, incluyendo un alto volumen de rechazos por purga de la máquina de extrusión blanda de PVC, un recorte excesivo de imanes de gran tamaño durante el proceso de inserción magnética y un rechazo significativo debido a la baja resistencia de las uniones en el proceso de soldadura de los perfiles de PVC. Para abordar estos problemas subyacentes, se empleó la metodología Six Sigma DMAIC (Definir, Medir, Analizar, Mejorar, Controlar) con el fin de reducir el rechazo/desperdicio, aumentar la*

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eficiencia del proceso y disminuir los defectos en las tres máquinas. El estudio incluyó el mapeo de procesos, el análisis de causa y efecto, el despliegue de la función de calidad (QFD) y herramientas estadísticas de proceso como ANOVA, regresión y análisis Cp/Cpk. Se identificaron las causas raíz y se introdujeron mejoras específicas basadas en los datos, incluyendo la planificación optimizada de la producción, la optimización y estandarización de los parámetros de la máquina, la mejora de la planificación de la ejecución de la producción y la disponibilidad de almacenamiento, los controles de temperatura en las máquinas de soldar y el moleteado de la rueda del codificador para la máquina de inserción magnética. Los principales objetivos fueron abordar problemas como el desperdicio de material, la variación en el tamaño de la banda magnética, los problemas en las máquinas de soldar y las frecuentes paradas de la máquina causadas por una programación de producción incorrecta debido a la disponibilidad inadecuada de espacio de almacenamiento para la producción por lotes independientemente del plan de premontaje de la puerta. Después de la implementación, los resultados muestran una disminución considerable en el porcentaje de rechazo de la máquina de extrusión del 12% al 4,06%, una reducción en el desperdicio de purga de 17 kg/día a 6,9 kg/día y un aumento en la eficiencia de la máquina del 50,1% al 83,3%. Además, el porcentaje de rechazo de la máquina de soldar disminuyó del 7% al 3,7% como resultado de una mejor gestión de la temperatura y el mantenimiento del equipo. El problema de variación de tamaño en la máquina de inserción de imanes se resolvió mediante el moleteado de la rueda del codificador. En general, estos cambios resultaron en un ahorro anual de aproximadamente 1,5 millones de rupias pakistaníes (PKR) en el proceso de extrusión y 1,2 millones en la máquina de inserción de imanes. La importancia de este proyecto radica en su potencial para optimizar el proceso de producción de juntas, reduciendo el desperdicio y los fallos, a la vez que aumenta la eficiencia de la máquina. Los resultados ofrecen un marco replicable que puede emplearse en una amplia gama de industrias manufactureras para mejorar la calidad y optimizar los costes.

Palabras clave: *Fabricación de juntas, metodología DMAIC, Six sigma, Optimización de procesos, reducción de desperdicios, producción sustentable, ANOVA, Control estadístico de procesos.*

Resumo. - *O processo de fabricação de juntas na "Empresa A" enfrentou desafios e ineficiências significativos devido às altas taxas de rejeição e à variação no desempenho da máquina de extrusão, da máquina de inserção magnética e da máquina de solda. Todas as três máquinas geravam consistentemente grandes rejeições diariamente, incluindo um alto volume de rejeições por purga da máquina de extrusão de PVC macio, corte excessivo de ímãs superdimensionados durante o processo de inserção magnética e rejeição significativa devido à baixa resistência da junta no processo de soldagem de perfis de PVC. Para abordar essas questões subjacentes, a metodologia Six Sigma DMAIC (Definir, Medir, Analisar, Melhorar, Controlar) foi empregada para diminuir a rejeição/desperdício, aumentar a eficiência do processo e diminuir os defeitos das três máquinas. O estudo envolveu mapeamento de processos, análise de causa e efeito, implantação da função de qualidade (QFD) e ferramentas estatísticas de processo, como ANOVA, regressão e análise Cp/Cpk. As causas-raiz foram identificadas e melhorias direcionadas com base nos dados foram introduzidas, incluindo planejamento de produção otimizado, otimização e padronização dos parâmetros da máquina, melhoria do planejamento da execução da produção e disponibilidade de armazenamento, controles de temperatura em máquinas de solda e recartilhamento da roda do encoder para máquina de inserção magnética. Os principais objetivos eram lidar com problemas incluindo desperdício de material, variação no tamanho da tira magnética, problemas em máquinas de solda e paradas frequentes de máquinas causadas por programação de produção inadequada devido à disponibilidade inadequada de espaço de armazenamento para produção em lote independente do plano de pré-montagem da porta. Após a implementação, os resultados mostram uma redução considerável na porcentagem de rejeição da máquina de extrusão de 12% para 4,06%, uma redução no desperdício de purga de 17 kg/dia para 6,9 kg/dia e um aumento na eficiência da máquina de 50,1% para 83,3%. Além disso, a porcentagem de rejeição da máquina de solda caiu de 7% para 3,7% como resultado do gerenciamento aprimorado de temperatura e manutenção do equipamento. O problema de variação de tamanho na máquina de inserção magnética foi resolvido pelo recartilhamento da roda do codificador. No geral, essas mudanças resultaram em uma economia de custos anual de aproximadamente 1,5 milhão de PKR para o processo de extrusão e 1,2 milhão da máquina de inserção magnética. A importância deste projeto se origina de seu potencial para agilizar o processo de produção de juntas, reduzindo desperdícios e falhas, enquanto aumenta a eficiência da máquina. Os resultados oferecem uma estrutura replicável que pode ser empregada em uma ampla gama de indústrias de manufatura para melhoria de qualidade e otimização de custos.*

Palavras-chave: *Fabricação de juntas, metodologia DMAIC, Seis sigma, otimização de processos, redução de desperdícios, produção sustentável, ANOVA, controle estatístico de processos.*

1. Introduction. - The manufacturing sector constantly strives to minimize rejection and rework during production while simultaneously enhancing production efficiency and product quality (A Paramasivam, 2022). Six sigma methodology (Tjahjono, 2010) (Hill, 2017) (S. Reosekar) (Patel, 2021) in its essence was first introduced in 1986 by Bill smith and Mikel harry, the two engineers from Motorola in 1986. The term "Six Sigma" originates from a statistical concept that describes a process with no more than 3.4 defects per million opportunities (Noori, 2018). Six sigma methodology (Macias-Aguayo, Garcia-Castro, Barcia, McFarlane, & Abad-Moran, 2022) as evident from its name is a six step-based data driven approach which aim to reduce the defects and variability in manufacturing process by using statistical tools and techniques (Yang C-C, 2022). It is a systematic approach and since its implementation by companies across various manufacturing fields, has shown that it is enhances the production process efficiency by reduction in defects and optimization of manufacturing process and as a result of this it increases customer (internal and external) satisfaction (McDermott, et al., 2022). Companies have been able to save huge amount of money by reduction in defects in products and increase in efficiency of production process (Alarcón, Calero, Pérez-Huertas, & Martín-Lara, 2023) (Ndrecaj, Mohamed Hashim, Mason-Jones, Ndou, & Tlemsani, 2023). The most common six sigma methodology that is being used in manufacturing sector is DMAIC and it stands for define, measure, analyze, improve and control (Monika Smętkowska B. M., 2018). It is a closed loop process in which impact of improvement measures is evaluated and improved until the desired results are obtained. After achieving the desired results final phase is control which is of utmost importance as continuous improvement is only possible if is sustainable over longer durations. This DMAIC approach is applicable in broad range of industries including manufacturing, software, sales, quality, service and marketing (LM, 2022).

Gaskets that are produced through extrusion process are very critical part of refrigerator product as they provide sealing of freezer and refrigerator compartments from the atmosphere thus keeping the cooling inside the refrigerator. The profile is made up of polyvinyl chloride (PVC) (Lewandowski & Skórczewska, 2022) material and it contains a magnet that is inserted into the profile before the joining process at the welding station. The magnet ensures the door remains securely locked and airtight due to its strong attraction to the paint-coated material (PCM) side panel. If any issues arise with the magnet, such as being too short, broken, or wavy, or if the profile welding joint opens due to transportation or poor welding, hot air can enter the freezer or refrigerator compartment. This results in poor insulation from the surrounding atmosphere. Quality of the gasket has direct impact on energy efficiency, compressor life, refrigerator's performance and preservation of food.

1.1 Problem statement. - Refrigerator gasket manufacturing process in the company A (for confidentiality reason) has been facing lots of challenges regarding rejection and rework issues during extrusion process for gasket profile manufacturing from PVC material, size variation issue during magnet cutting and magnet insertion station and poor PVC weld joints issue. These issues not only increase process waste at the gasket manufacturing station, leading to significant costs for Company A, but also negatively impact the efficiency of the gasket manufacturing process.

1.2 Objectives. - Objectives of implementation of six sigma methodology on gasket extrusion process are as under:

1- Improve efficiency and productivity of the extrusion process of gasket profile manufacturing process
2- Reduction in rejection and rework of gaskets
3- Enhance the quality and consistency of the gasket profiles
4- Cost savings by waste minimization
5- Reduction in magnet wastage because of size variation issue
6- Reduction in rejection and rework at welding machine station

2. Literature review. - In recent years, global economic landscape is going through one of the toughest times because of rising material costs, fluctuation in demand, more competition from emerging markets (Most. Asikha Aktar, 2021). These issues lead to increase in manufacturing cost and reduction in profit margins as product prices can only be increased up to a certain because purchasing power of general public is also going down (Bailey, 2016). So, in order to make the business sustainable, increase profit margins and bring the cost of manufacturing down, more and more companies from different fields are employing six sigma methodologies in their manufacturing setup (Muraliraj). Six sigma offers a systematic, data driven framework that helps companies identify inefficiencies, rejection and rework reasons, things impacting the quality of the product thereby enabling the company to take corrective measures to resolve these issues leading to increase in cost savings and profit margins even in uncertain economic environment. The application of Six Sigma has produced notable non-financial and financial benefits/results for numerous Fortune 500 firms (Wasage, 2016). Allied Signal, General Electric, Raytheon, Bank of America, Bechtel, Caterpillar and Motorola are a few of these businesses. By applying the six-sigma methodology, these businesses have drastically decreased their defect rates and multiplied their profits by many folds (T. Costa F. S., 2017). Numerous studies have demonstrated the importance of Six Sigma and Lean techniques in driving quality improvements and minimizing

process variability. Smętkowska and Mrugalska (2018) successfully applied Six Sigma DMAIC to reduce rejection rates in manufacturing operations (Monika Smętkowska B. M., 2018). Similarly, Macias-Aguayo et al. (2022) stressed the use of Six Sigma and Industry 4.0 principles to improve operational efficiency (Jaime Macias-Aguayo, 2022).
T. Costa et al. (2017) used Six Sigma to optimize extrusion processes in tire manufacture, resulting in considerable defect reduction, demonstrating the applicability of this methodology to extrusion-based industries such as gasket production (T. Costa F. S., 2017). Furthermore, Hassan Araman et al. (2023) shed light on six sigma and gasket materials' performance, emphasizing the need of exact dimensional control and structural integrity in preserving refrigerator insulation and energy efficiency (Araman, 2023).

This literature clearly establishes the applicability of Six Sigma in gasket extrusion processes, specifically for identifying root causes of quality issues, improving dimensional accuracy and ensuring overall product integrity and process stability. Six sigma methodologies can be applied across any manufacturing industry. Building upon these insights, the current study applies Six Sigma principles to a real-time manufacturing process of soft plastic gaskets, aiming for practical process enhancements and measurable outcomes.

There are several other key philosophies in the manufacturing industry, such as Lean Manufacturing and Six Sigma. Six Sigma is a data-driven methodology that utilizes statistical tools to minimize defects and reduce process variability. Whereas Lean Manufacturing primarily focuses on eliminating waste and improving process flow. Lean practices typically target Ohno's seven types of waste to enhance production efficiency. Six sigma uses DMAIC methodology in which multiple statistical tools are used during different phases in order to achieve the desired result. All those tools will be discussed in the methodology section in detail. Six Sigma is a statistical term that represents a process in which minimal defects occur. "Sigma" (σ) stands for a process's standard deviation in Six Sigma terminology. A process that achieves a Six Sigma level is said to produce less than 3.4 defects per million opportunities (DPMO), which is an indication of almost perfect quality. This yield %age is equal to 99.9997% error-free output (Raman Sharma, 2018).

Sigma Level	DPMO	Yield
6	3.4	99.9997%
5.5	32	99.9987%
5	233	99.9770%
4.5	1350	99.8700%
4	6210	99.3800%
3.5	22750	97.7000%
3	66807	93.3000%
2.5	158655	84.1000%
2	308538	69.1000%
1.5	500005	50.0000%
1	691462	30.9000%
0.5	841345	15.9000%

Table 1 Sigma level and comparative values of DPMO and Yield %age

Values in Table 1 represents that as sigma level increases defects per million opportunities decreases and yield %age (defect free units) increases. This means that if 1 million parts are produced, the DPMO (defects per million opportunities) represents the number of defective parts out of those 1 million. The yield percentage indicates the %age of the parts produced without any defects.

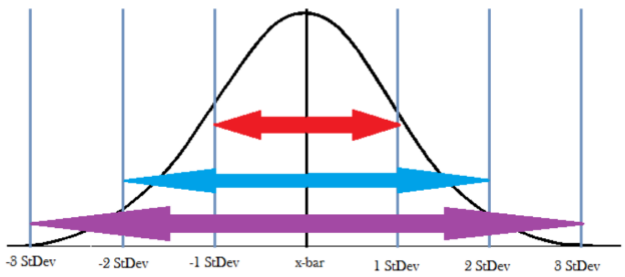

Figure I. Normal distribution curve or Bell curve

The X-bar line in Figure represents that normal data is distributed symmetrically around mean. A normal curve is useful for determining the probability that a given data point in a population will fall within a certain range of the distribution (Amaral, 2022).

The X-bar line in Figure represents the mean and normal data is formed symmetrically around it. A normal curve is useful for determining the chance that a given data point in a population will fall within a certain range of the distribution. Red arrow covers ±1σ from mean and (σ = standard deviation) represents that 68.26% of all data points falls within this range. Blue arrow covers ±2σ from mean and it represents that 95.46% of all data points falls within this range. The purple arrow covers ±3σ from mean and it represents that 99.7% of data points fall in this range. In a perfect bell curve mean median and mode of the data set are same and located at the peak of the curve. The ends of normal distribution curve are known as tails, and these represents extreme values in a data set. In six sigma defects normally fall in these tails. Six sigma practitioners can determine the process capability (Cp & Cpk) which shows how well the process is performing relative to specification limits.

Gasket is an integral part of refrigerator product (Guoqiang Liu, A review of refrigerator gasket: Development trend, heat and mass transfer characteristics, structure and material optimization, 2021) which help keep the refrigerator freezer and refrigerator compartment insulated from environment. Gasket profile is manufactured from the polyvinyl chloride (PVC) material through the extrusion process. Extrusion process is a manufacturing technique in which a material is heated according to the required specifications in a barrel which is then forced through a die to achieve the required profile (Guoqiang Liu, Research on test method of heat transfer coefficient for refrigerator gasket, 2020). After exiting of PVC profile from die it is shifted to cooling station through conveyors where it is cooled down through water jets. These profiles are then shifted to cutting station where they are cut to desired length as per requirement. These profiles are then later on moved to stock area and then as per requirement to magnet insertion machine area where magnets are inserted into the profile as per the required length. After this step all these profiles are moved from magnet insertion machine to welding area where these profiles are inserted into the die, joined by heating them up to required temperature and then die is closed resulting in a joint formation. All these processes are very critical with many potential modes of failures which will be discussed in later part of the paper (Tianyang Zhao, 2024).

2.1 Research gap. - The revenue generated by refrigerator manufacturing industry worldwide is estimated to 121 billion USD. Being a billion-dollar industry, no research has been conducted on combined optimization of extrusion, magnet insertion and welding process. In this project six sigma methodology will be systematically applied in order to identify the key problems in the whole gasket manufacturing process. These defects/problems will then be later addressed by using six sigma DMAIC methodology.

2.2 Significance of the study. - Implementing Six Sigma in optimizing the gasket manufacturing process is highly significant, especially in the context of current economic challenges where high manufacturing costs and price increases are unsustainable. This optimization will enhance process efficiency, reduce rejections & rework thus lowering the overall manufacturing cost of the gaskets. Additionally, it will lead to a reduction in defects, both internally and at the customer end. Furthermore, this project will set a benchmark for the refrigerator manufacturing industry, demonstrating the value of applying Six Sigma methodology not only in gasket production but potentially across all manufacturing processes.

3. Methodology. - In order to carry out this research work, six sigma DMAIC methodology was adopted. DMAIC is a systematic problem-based and customer centric data/target-oriented approach consisting of five basic steps. Those steps/phases are defined phase, measure phase, analyze phase, improve phase and control phase. Define was started by making a project charter in which objective of the project, goals, deliverables and problem statement were defined. Whole gasket extrusion manufacturing process was mapped by using SIPOC diagram (Supplier, Inputs, Process, Outputs, Customer). VOC (voice of customer) vs VOB (voice of business) analysis was done in order to list down the common requirements of customer (internal) and business. FMEA (Failure mode effect analysis) was conducted to identify initial potential failures, evaluate and prioritize risks and suggesting potential solutions/action plan for prevention of those failures in gasket extrusion manufacturing process. Re FMEA will be done at a later stage again in order to evaluate the performance of the project. In second measure phase, data of extrusion machine production, magnetic strip rejection/scrap and welding machines rejection and rework was gathered in order to measure the current process performance and set the baseline for improvements in coming phase. In the third phase i.e., the analysis phase, analysis of top problems was conducted and for this purpose detailed cause and effect diagram were made, and top five problems were prioritized by performing pareto analysis. Quality function deployment (QFD) tool was used to prioritize customer requirements and to their relationship with functional requirement for better finished product.

3.1 Define Phase. - Define phase is one of the first steps in DMAIC methodology. This phase focused on gathering insights from various stakeholders specifically customer, process owner (production team). This helped in identifying critical issues in the gasket manufacturing area. First step in define phase to make a project charter in which objectives, goals, project deliverables, in-scope, out-scope and problem statement were defined.

3.2 Problem Statement. - In the Year 2023, 27,283 gaskets rejected out of 2,84,477 gaskets produced at Gasket Manufacturing Area. Out of these 27,283 rejected gaskets, 7267 gaskets were crushed, and 20,016 gaskets were scrapped. The rejection ratio stands at 9.57% and by 15 kg of average value of purging waste for 287 days, this costed company 3.5 million rupees. As 1.95" magnetic strips get rejected per each profile leading to further cost of 0.96 million rupees. If these issues persist, this could result in a potential loss of 4.5 million rupees to the company in 2024. Now in order to assist planning and keep the track of project during its various phases, a Gantt chart was setup with deadlines of the project phase wise. Gantt chart is available in Figure .

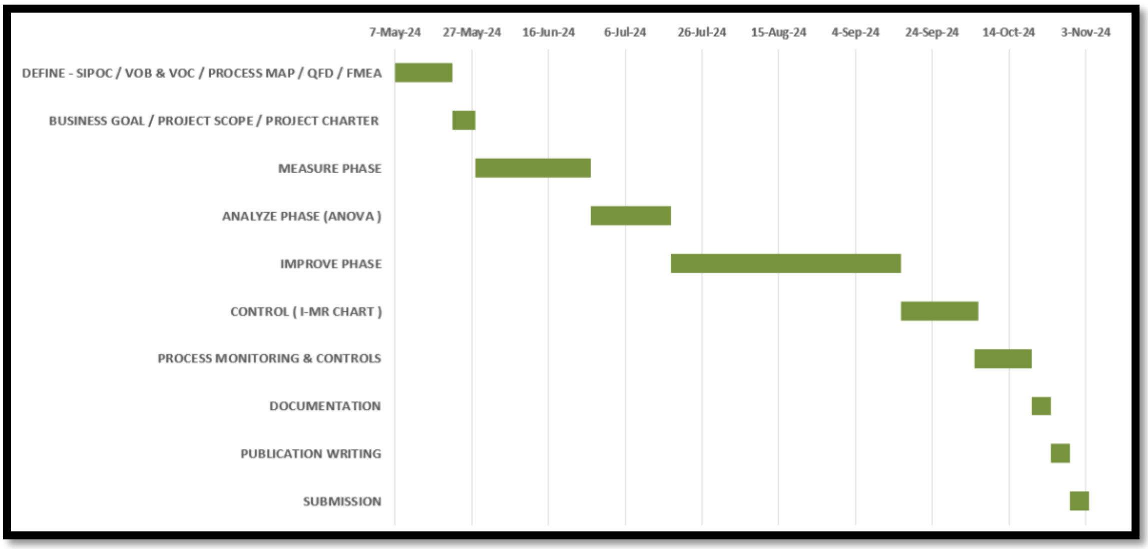

Figure II. Gantt chart with project milestones and deadlines.

Understanding the voice of customer and voice of business was absolutely necessary in order to identify the most important things related to gasket manufacturing process from customer and management point of view. VOB vs VOC was prepared, and intersection points were considered as goals of the projects. VOB vs VOC is shown in Figure .

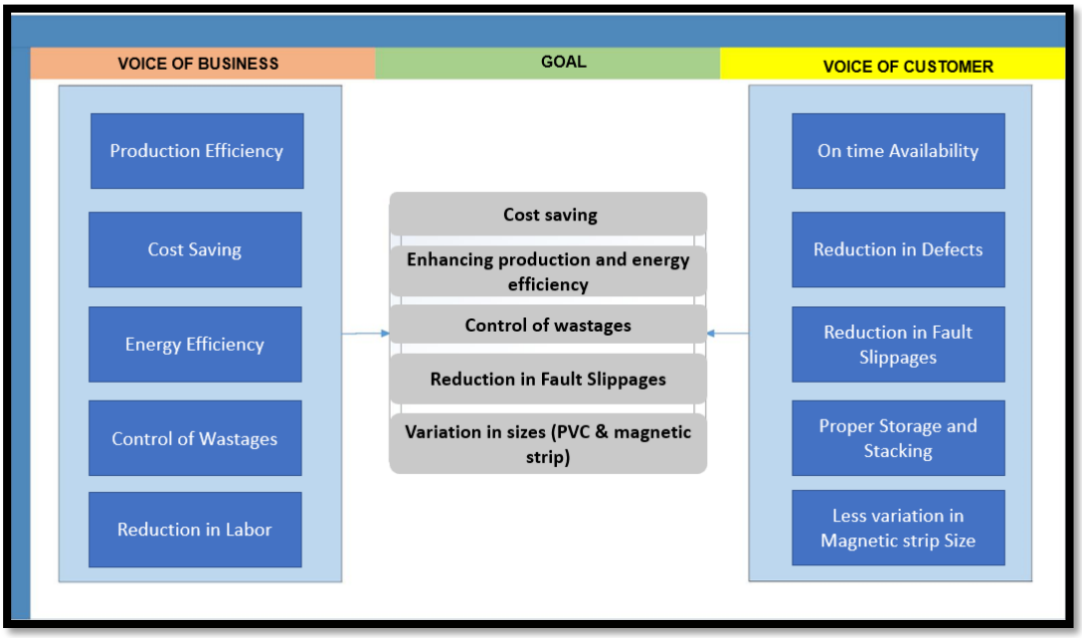

Figure III. Voice of business (VOB) vs Voice of Customer (VOC).

In this comparison of VOB (Voice of the Business) and VOC (Voice of the Customer), common goals were identified that were important to both the immediate customer, the door assembly line and management. Key objectives included cost savings, improving production efficiency, optimizing machine energy consumption, controlling waste, minimizing defects passed to the customer and reducing variations in the sizes of PVC profiles and magnetic strips.
After that a SIPOC (supplier-input-process-output-customer) was plotted in order to identify all the suppliers (internal and external), inputs, process mapping, outputs and customer (internal). SIPOC is used to understand the process components and relevance as it is a simple tool. This was developed through brainstorming session with the project team and process owner (production team). SIPOC diagram is available in Figure .

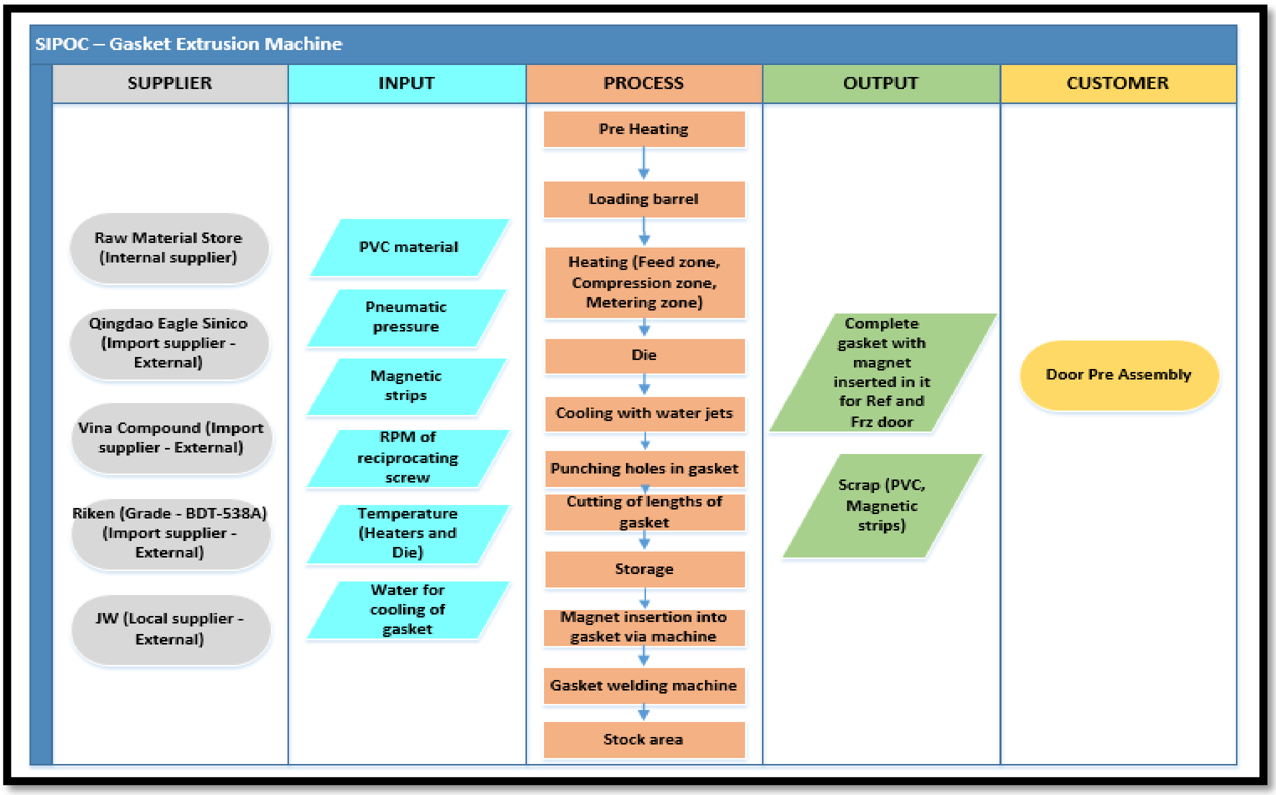

Figure IV. SIPOC of gasket manufacturing process.

In the SIPOC, the process was clearly outlined, with both internal and external suppliers and all process inputs identified. The outcomes, including the finished product and scrap, were also defined, along with the customer, Door Pre-Assembly. This tool enables a comprehensive understanding of all aspects related to the process and helps in identifying critical elements. It provides a foundation for process improvement and acts as a starting point for more detailed analysis in the later stages of the DMAIC methodology.

Visually representing each stage of the gasket manufacturing process, from the input of raw materials to the output of the finished product, is known as process mapping. This involves mapping the extrusion of PVC profiles to inserting magnetic strips in PVC profiles and then welding of these gasket profiles. This process map makes it easy to see how steps in manufacturing link to one another. Now in order to get the clear representation of the workflow and for identification of bottlenecks and inefficiencies, process map was developed and can be seen in Figure .

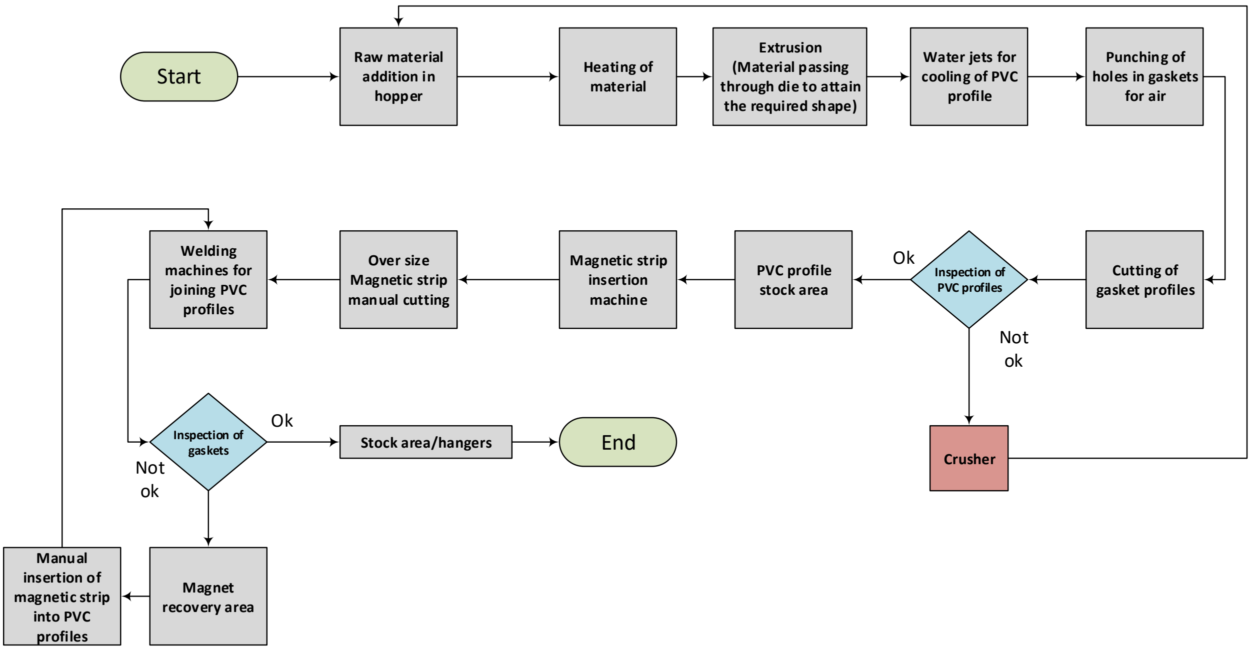

Figure V. Process map of gasket manufacturing process.

3.3 Measure Phase. - Measuring the process's current performance is the main goal of the DMAIC Measure phase. Data is gathered during this phase to measure important metrics about rejection, cycle time, production rates and other important parameters, as well as to provide a baseline for the process. Data was collected from quality inspection reports, production monitoring reports, operator check sheets and from machine logs. In order to ensure the integrity of the analysis and remove any biases in the data, several statistical tools were employed. These tools will be discussed in detail in later section of ANOVA. Prior to making any modifications, it is important to know how the process is working in order to enable more accurate analysis in later phases. In the measure phase, data of gasket manufacturing process was gathered in order to set the baseline of the gasket manufacturing process and identify all the issues and inefficiencies by analyzing the data gathered through check sheets. Gasket manufacturing process was divided into three processes; extrusion of soft PVC (polyvinyl chloride) material in order to make gasket profiles, magnet insertion station and welding station of PVC profiles. For all these three processes, data on machine actual production, rejection reasons, loss time in hours, machine efficiency and parameters monitoring were collected. Extrusion machine efficiency monitoring report is available in Table

Sr. No	Date	Standard Working time	Total Standard Production (kg)	Total Actual Production (kg)	Efficiency
1	10th July, 2024	11	495	51	10%
2	12th July, 2024	16	720	341	47%
3	13th July, 2024	19	855	348	41%
4	15th July, 2024	16	720	416	58%
5	16th July, 2024	22	990	487	49%
6	19th July, 2024	19	855	402	47%
7	20th July, 2024	19	855	477	56%
8	21st July, 2024	19	855	516	60%
9	22nd July, 2024	19	855	436	51%
10	23rd July, 2024	19	855	298	35%
11	24th July, 2024	19	855	454	53%
12	26th July, 2024	19	855	434	51%
13	27th July, 2024	22	990	471	48%

14	28th July, 2024	16	720	350	49%
15	29th July, 2024	19	855	340	40%
16	30th July, 2024	19	855	390	46%
17	31st July, 2024	16	720	415	58%
18	1st Aug, 2024	22	990	550	56%
19	2nd Aug, 2024	16	720	570	79%
20	3rd Aug, 2024	16	720	520	72%
21	4th Aug, 2024	16	720	400	56%
22	5th Aug, 2024	19	855	391	46%
23	6th Aug, 2024	19	855	371	43%
24	7th Aug, 2024	19	855	250	29%
25	8th Aug, 2024	19	855	378	44%
26	9th Aug, 2024	16	720	421	58%
27	10th Aug, 2024	16	720	413	57%
28	11th Aug, 2024	16	720	401	56%
29	12th Aug, 2024	16	720	397	55%
30	13th Aug, 2024	16	720	386	54%

Table II. Extrusion machine efficiency monitoring report.

Extrusion machine rejection data is mentioned in the Table .

Sr. No	Date	Standard Working time (hours)	Total Standard Production (kg)	Total Actual Production (kg)	Rejection %age	Total Rejection (kg)
1	10th July, 2024	11	495	51	88%	45
2	12th July, 2024	16	720	341	12%	40
3	13th July, 2024	19	855	348	13%	44
4	15th July, 2024	16	720	416	12%	48
5	16th July, 2024	22	990	487	12%	57
6	19th July, 2024	19	855	402	9%	37
7	20th July, 2024	19	855	477	6%	30
8	21st July, 2024	19	855	516	11%	58
9	22nd July, 2024	19	855	436	12%	52
10	23rd July, 2024	19	855	298	18%	54
11	24th July, 2024	19	855	454	12%	54
12	26th July, 2024	19	855	434	6%	27
13	27th July, 2024	22	990	471	9%	42
14	28th July, 2024	16	720	350	13%	45
15	29th July, 2024	19	855	340	12%	41
16	30th July, 2024	19	855	390	11%	43
17	31st July, 2024	16	720	415	12%	49
18	1st Aug, 2024	22	990	550	7%	38
19	2nd Aug, 2024	16	720	570	12%	70
20	3rd Aug, 2024	16	720	520	15%	78
21	4th Aug, 2024	16	720	400	14%	54
22	5th Aug, 2024	19	855	391	9%	35

23	6th Aug, 2024	19	855	371	12%	46
24	7th Aug, 2024	19	855	250	16%	41
25	8th Aug, 2024	19	855	378	11%	42
26	9th Aug, 2024	16	720	421	11%	45
27	10th Aug, 2024	16	720	413	8%	35
28	11th Aug, 2024	16	720	401	10%	39
29	12th Aug, 2024	16	720	397	13%	53
30	13th Aug, 2024	16	720	386	15%	56
		Grand Total		12076	11.6%	1398

Table III. Extrusion machine rejection data

Welding machines efficiency monitoring report is mentioned in the Table .

Sr. No	Date	Standard Working hours (hrs.)	Total No. of Machines	Total UPH	Actual Production	Standard Production	Efficiency
1	10th July, 2024	11	5	200	1255	2200	57%
2	12th July, 2024	11	5	200	970	2200	44%
3	13th July, 2024	22	10	400	1610	4400	37%
4	15th July, 2024	22	8	320	1848	3520	53%
5	16th July, 2024	8	4	160	1004	1280	78%
6	19th July, 2024	22	8	320	2053	3520	58%
7	20th July, 2024	19	9	360	2485	3360	74%
8	21st July, 2024	22	8	320	2270	3520	64%
9	22nd July, 2024	11	3	120	1046	1320	79%
10	23rd July, 2024	22	7	280	2085	3080	68%
11	24th July, 2024	22	7	280	1764	3080	57%
12	26th July, 2024	22	7	280	2078	3080	67%
13	27th July, 2024	22	7	280	1626	3080	53%
14	28th July, 2024	19	7	280	1416	2720	52%
15	29th July, 2024	22	7	280	1676	3080	54%
16	30th July, 2024	11	4	160	1004	1760	57%
17	31st July, 2024	22	7	280	2376	3080	77%
18	1st Aug, 2024	22	6	240	1790	2640	68%
19	2nd Aug, 2024	11	4	160	1108	1760	63%
20	3rd Aug, 2024	11	4	160	986	1760	56%
21	4th Aug, 2024	11	4	160	1120	1760	64%
22	5th Aug, 2024	11	5	200	385	2200	18%
23	6th Aug, 2024	11	4	160	419	1760	24%
24	7th Aug, 2024	11	4	160	944	1760	54%
25	8th Aug, 2024	11	5	200	1222	2200	56%
26	9th Aug, 2024	11	4	160	328	1760	19%
27	10th Aug, 2024	11	4	160	525	1760	30%
28	11th Aug, 2024	11	4	160	929	1760	53%
29	12th Aug, 2024	11	4	160	885	1760	50%
30	13th Aug, 2024	11	4	160	508	1760	29%

Table

Sr. No	Date	Standard Working hours (hrs.)	Total No. of Machines	Total UPH	Actual Production	Standard Production	Efficiency
1	10th July, 2024	11	5	200	1255	2200	57%
2	12th July, 2024	11	5	200	970	2200	44%
3	13th July, 2024	22	10	400	1610	4400	37%
4	15th July, 2024	22	8	320	1848	3520	53%
5	16th July, 2024	8	4	160	1004	1280	78%
6	19th July, 2024	22	8	320	2053	3520	58%
7	20th July, 2024	19	9	360	2485	3360	74%
8	21st July, 2024	22	8	320	2270	3520	64%
9	22nd July, 2024	11	3	120	1046	1320	79%
10	23rd July, 2024	22	7	280	2085	3080	68%
11	24th July, 2024	22	7	280	1764	3080	57%
12	26th July, 2024	22	7	280	2078	3080	67%
13	27th July, 2024	22	7	280	1626	3080	53%
14	28th July, 2024	19	7	280	1416	2720	52%
15	29th July, 2024	22	7	280	1676	3080	54%
16	30th July, 2024	11	4	160	1004	1760	57%
17	31st July, 2024	22	7	280	2376	3080	77%
18	1st Aug, 2024	22	6	240	1790	2640	68%
19	2nd Aug, 2024	11	4	160	1108	1760	63%
20	3rd Aug, 2024	11	4	160	986	1760	56%
21	4th Aug, 2024	11	4	160	1120	1760	64%
22	5th Aug, 2024	11	5	200	385	2200	18%
23	6th Aug, 2024	11	4	160	419	1760	24%
24	7th Aug, 2024	11	4	160	944	1760	54%
25	8th Aug, 2024	11	5	200	1222	2200	56%
26	9th Aug, 2024	11	4	160	328	1760	19%
27	10th Aug, 2024	11	4	160	525	1760	30%
28	11th Aug, 2024	11	4	160	929	1760	53%
29	12th Aug, 2024	11	4	160	885	1760	50%
30	13th Aug, 2024	11	4	160	508	1760	29%

Table IV. Welding machine efficiency monitoring report.

Welding machines rejection data is attached in Table .

Sr. No	Date	Standard Working hours (hours)	Actual Production (Nos)	Standard Production (Nos)	Rejection Quantity	Rejection %age
1	10th July, 2024	11	1255	2200	90	7%
2	12th July, 2024	11	970	2200	80	8%

3	13th July, 2024	22	1610	4400	70	4%
4	15th July, 2024	22	1848	3520	85	5%
5	16th July, 2024	8	1004	1280	101	10%
6	19th July, 2024	22	2053	3520	109	5%
7	20th July, 2024	19	2485	3360	105	4%
8	21st July, 2024	22	2270	3520	95	4%
9	22nd July, 2024	11	1046	1320	87	8%
10	23rd July, 2024	22	2085	3080	115	6%
11	24th July, 2024	22	1764	3080	111	6%
12	26th July, 2024	22	2078	3080	102	5%
13	27th July, 2024	22	1626	3080	104	6%
14	28th July, 2024	19	1416	2720	110	8%
15	29th July, 2024	22	1676	3080	95	6%
16	30th July, 2024	11	1004	1760	90	9%
17	31st July, 2024	22	2376	3080	89	4%
18	1st Aug, 2024	22	1790	2640	112	6%
19	2nd Aug, 2024	11	1108	1760	120	11%
20	3rd Aug, 2024	11	986	1760	131	13%
21	4th Aug, 2024	11	1120	1760	87	8%
22	5th Aug, 2024	11	385	2200	55	14%
23	6th Aug, 2024	11	419	1760	41	10%
24	7th Aug, 2024	11	944	1760	31	3%
25	8th Aug, 2024	11	1222	2200	59	5%
26	9th Aug, 2024	11	328	1760	67	20%
27	10th Aug, 2024	11	525	1760	61	12%
28	11th Aug, 2024	11	929	1760	80	9%
29	12th Aug, 2024	11	885	1760	71	8%
30	13th Aug, 2024	11	508	1760	51	10%

Table V. Welding m/c's rejection data.

Magnet that is inserted into PVC profile before welding is one of the most critical stations as far as oversized magnet strip rejection per profile is concerned. Its data is gathered and is present in the Table .

Sr. No	Date	Standard Working hours (hours)	Actual Production (Nos)	Rejection per profile (m)	Rejection per gasket (m)	Total rejection of magnet per day (m)	Total rejection magnet per day (kg)
1	10th July, 2024	11	1255	0.044	0.176	221	13
2	12th July, 2024	11	970	0.044	0.176	171	10
3	13th July, 2024	22	1610	0.044	0.176	283	17
4	15th July, 2024	22	1848	0.044	0.176	325	20
5	16th July, 2024	8	1004	0.044	0.176	177	11
6	19th July, 2024	22	2053	0.044	0.176	361	22
7	20th July, 2024	19	2485	0.044	0.176	437	26
8	21st July, 2024	22	2270	0.044	0.176	400	24
9	22nd July, 2024	11	1046	0.044	0.176	184	11
10	23rd July, 2024	22	2085	0.044	0.176	367	22

11	24th July, 2024	22	1764	0.044	0.176	310	19
12	26th July, 2024	22	2078	0.044	0.176	366	22
13	27th July, 2024	22	1626	0.044	0.176	286	17
14	28th July, 2024	19	1416	0.044	0.176	249	15
15	29th July, 2024	22	1676	0.044	0.176	295	18
16	30th July, 2024	11	1004	0.044	0.176	177	11
17	31st July, 2024	22	2376	0.044	0.176	418	25
18	1st Aug, 2024	22	1790	0.044	0.176	315	19
19	2nd Aug, 2024	11	1108	0.044	0.176	195	12
20	3rd Aug, 2024	11	986	0.044	0.176	174	10
21	4th Aug, 2024	11	1120	0.044	0.176	197	12
22	5th Aug, 2024	11	385	0.044	0.176	68	4
23	6th Aug, 2024	11	419	0.044	0.176	74	4
24	7th Aug, 2024	11	944	0.044	0.176	166	10
25	8th Aug, 2024	11	1222	0.044	0.176	215	13
26	9th Aug, 2024	11	328	0.044	0.176	58	3
27	10th Aug, 2024	11	525	0.044	0.176	92	6
28	11th Aug, 2024	11	929	0.044	0.176	164	10
29	12th Aug, 2024	11	885	0.044	0.176	156	9
30	13th Aug, 2024	11	508	0.044	0.176	89	5

*Every gasket has 4 profiles
*1-meter magnet = 60 gm

Table VI. Magnet insertion machine data

3.4 Analyze Phase. - FMEA (Failure Modes and Effects Analysis) is a tool used in the Six Sigma methodology to identify probable failure modes in the production process and evaluate their impact on product quality. FMEA helps in the identification of potential flaws such as size variances, joining problems or material issues by examining crucial steps including PVC extrusion, magnetic strip insertion and welding of gasket profiles. For this gasket manufacturing process, a detailed FMEA was developed in which teams prioritized process improvements by using the risk priority number (RPN) that was assigned on factors including severity, occurrence and detection. This is in line with Six Sigma's objective of reducing variances and improving quality by ensuring defect reduction, process optimization and overall product reliability. FMEA is available in Figure

Sr. No	Process steps	Potential failure mode	Potential effects	Severity	Failure causes	Occurrence	Current controls	Detection	Risk Profile Number RPN	Recommended actions
1	Pre-Heating in Oven	Improper heating	Moisture Issue Warpage Crack formation Bubble formation	5	Thermocouple issue Heater issue Un even temperature distribution	3	Temperature monitoring	4	60	1- Thermoregulator should be present for temperature control 2- Uniform heating should be present
2	Material (PVC) loading in hopper	Improper heater temp set at Feed zone	Accumulation of PVC material in the hopper base	8	Premature heating in Feed zone temperatures	2	Training of machine operators	3	48	Training of machine operators
3	Extrusion - Feed zone	Material clogging Poor material melting	In consistent flow of material	7	1- Improper temperature settings 2- Heater malfunction	6	1- Regular cleaning of hopper 2- Temperature monitoring and visual inspection of gasket	3	126	1- Monitoring of temperature and Gasket 2 Regular cleaning
4	Extrusion - Compression zone	1- Uneven compression 2- Over heating	1- In consistent gasket thickness 2- Burnt section of gasket	7	1- In correct temperature settings 2- Excessive friction between screw and barrel 3- Material quality issue	3	1- Regular maintenance 2- Temperature monitoring	3	63	1- Machine health review (screw, heaters, pressures etc)
5	Extrusion - metering zone	1- Flow inconsistencies 2- Die Swell	1- Dimensional inaccuracy 2- Excessive material expansion	7	1- Variations in screw speed or partial blockage 2- Material properties issue	3	1- Reguar maintenance 2- Material quality check	4	84	1- Reguar maintenance 2- Material quality check
6	Cooling	Slow cooling of gasket because of higher temp of water	Warpage, shrinkage	6	1- Improper cooling rate 2- Water temperature too high	2	Chiller water temperature monitoring	3	36	1- Adjust chiller temperature
7	Profile Formation at Die	1- Improper profile of gasket 2- Bubble formation in gasket profile	1- Material waprapage 2- Bubble formation on gasket	7	1- Improper cooling rate 2- Moisture issue	3	1- Chiller water temperature monitoring 2- Pre-heating of material	3	63	1- Adjust chiller temperature 2- Pre-heating of material
8	Cutting	Un even cutting	Improper joints formation	8	1- Blade wear 2- Blade misalignment	4	Visual inspection of gasket and blades	3	96	1- Regular maintenance of cutting assembly (blade checks, alignment etc)
9	Magnet insertion	1- Magnet cutting size variation 2- Magnet manual cutting issue	Manual cutting of magnet - Loss in productivity and improper joints during welding	8	1- Machine settings issue	4	Visual inspection	2	64	Preventive machine maintenance
10	Manual cutting of magnet	Un even cutting	Improper joints formation	8	1- Variation in magnet cutting machine 2- Manual cutting of magnet by worker	6	Visual inspection	3	144	Preventive machine maintenance
11	Welding	Weak weld joints Gasket joint overlap Gasket joint hole	1- Gasket joint tear 2- Imrproper fitting	8	1- In correct weld temperatures 2- Alignement issues during welding	7	1- Temperature checks 2- Alignment checks	4	224	1- Implement precise temperature control 2- Alignment fixtures
12	Storage	Waviness issue because of improper storage	Gaps and waviness issue after assembly	10	Storage/stacking on floor	7	1- Storage on hangers	3	210	1- Enhanced monitoring 2- Training of production workers 3-Design new hangers for storage

Figure VI. Failure modes and effect analysis

Objective of cause-and-effect diagram was to determine the root causes of the problems as well as sources of inefficiencies and variations in the manufacturing process. After analyzing the data collected in the measure phase and potential causes and failure modes in FMEA, fishbone diagram of complete gasket manufacturing process was developed. Fishbone or cause and effect diagram is mentioned in the Figure below.

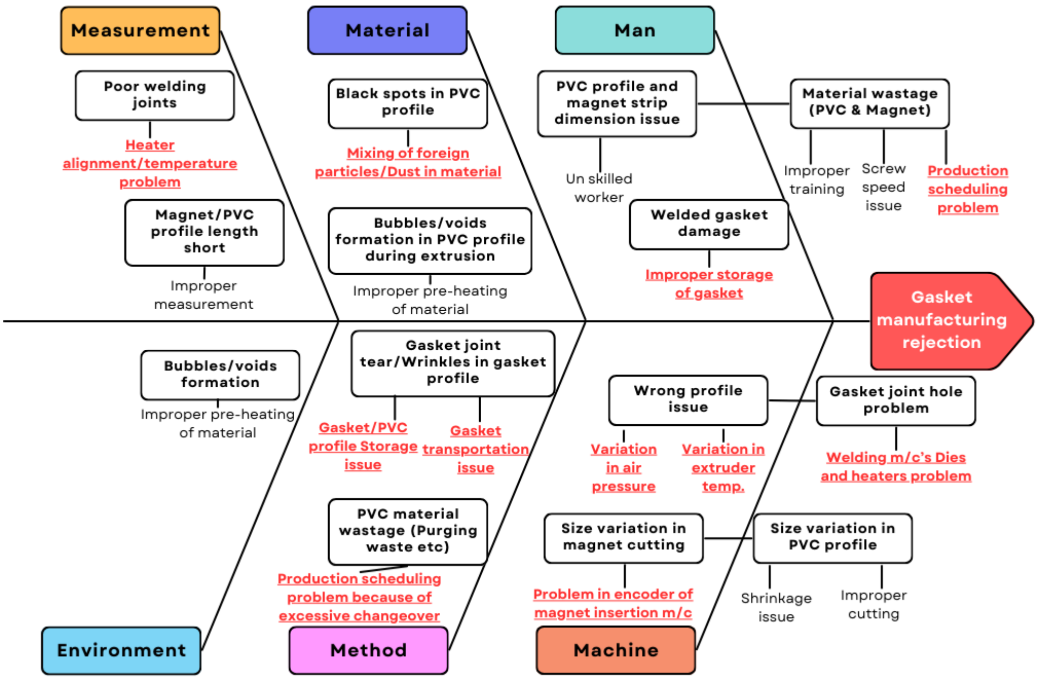

Figure VII. Cause-and-effect diagram.

In the gasket manufacturing process, several key factors contributing to high rejection rates were identified. These included improper storage and transportation systems, issues with welding dies and heaters, inaccurate cutting of the magnetic strip, poor quality PVC material and frequent color changes during gasket profile production. Together, these issues were leading to inefficiencies and increased rejection rates during the gasket manufacturing process.

Now cause and effect matrix was developed in order to prioritize the identified causes based on their impact on critical customer requirements. It can be seen in Figure .

Cause and Effect Matrix

Project: Gasket Manufacturing Process — Correlation: 9: High | 3: Medium | 1: Low | 0: No correlation

Sr. No	Causes Variables (Xs) ↓ / Effects Variables (Ys)	1 Dust in Material	2 Excessive changeover in extrusion m/c	3 Purging Waste	4 Wrong profile	5 Size variation in magnetic strip	6 Holes in gasket joints	7 Rejection of Gasket	Weighted Score (X)	%	Rank	Status (critical, potential, or eliminated)
	Importance to customer (1-10)	10	5	5	1	9	9	9				
1	Production Scheduling	0	9	9	9	0	0	9	180	11.5%	6	Critical
2	Extruder Temperature	0	3	9	9	0	0	0	69	4.4%	7	Eliminated
3	Air Pressure	0	1	1	9	0	0	3	46	2.9%	10	Eliminated
4	Screw speed	0	3	9	0	0	0	0	60	3.8%	9	Eliminated
5	PVC profile cutter	0	3	0	0	0	3	3	69	4.4%	7	Eliminated
6	Magnet strip cutting machine	0	0	0	0	9	9	9	243	15.6%	5	Critical
7	Welding m/c heaters	0	9	9	9	0	9	9	261	16.7%	4	Critical
9	Welding m/c dies	0	9	9	9	9	9	9	342	21.9%	1	Critical
11	Storage	3	9	9	9	0	9	9	291	18.6%	3	Critical
13	PVC material quality	9	9	9	9	0	3	9	297	100.0%	2	Critical
	Weighted Score (Y)	120	275	320	63	162	378	540	1561			
Comments/Conclusion:	Rank	6	4	3	7	5	2	1				

Figure VIII. Cause-and-Effects Matrix

In cause-and-effect matrix, critical causes were prioritized based on their impact on critical customer requirements. Critical causes that were identified were production scheduling issue, magnet strip cutting machine variation issue, welding machine heaters and dies health issue, improper storage for gaskets and PVC profiles issue and PVC material quality issue that impacts on the final product quality.

After that QFD was developed based on the cause-and-effect diagram and cause and effect matrix in order to link customer requirements with technical requirements that need improvement. QFD is available in Figure .

Quality Function Deployment

Project title: Gasket Ectrusion
Project leader: Adeel Tabassum
Date: 06-Jul-24

Relationships: 9 Strong | 3 Moderate | 1 Weak | 0 None

	Customer importance rating (1: low, 5: high)	Customer Requirements - (What's) ↓ / Functional Requirements (How's) →	Raw Material	Production Scheduling of extrusion m/c	Trained Labour	Welding m/c health (heaters and dies)	Extrusion Machine Health	Extrusion machine Parameters	PVC Profile cutting m/c	Magnet cutting machine	Storage of gasket	Weighted Score
1	5	Timely delivery of gaskets	1	9	9	9	3	3	9	9	1	265
2	5	Reduction in defects	1	9	3	9	9	3	9	9	9	305
3	5	Reduction in fault slippages	0	0	1	1	3	3	9	9	9	175
4	4	Flexible	9	0	0	0	0	0	0	0	0	36
5	4	No Dust	9	0	0	0	0	0	0	0	9	72
6	2	Propper Storage and stacking	1	9	3	0	0	0	3	3	9	56
7	5	Magnetic strip size variation	1	1	3	0	0	0	0	9	0	70
8												0
9												0
		Technical importance score	89	113	86	95	75	45	141	186	149	979
		Importance %	9%	12%	9%	10%	8%	5%	14%	19%	15%	100%
		Priorities rank	6	4	7	5	8	9	3	1	2	

Figure IX. Quality function deployment (QFD)

After analyzing the data from the previous year (2023) using the Pareto principle, the results are illustrated in the Figure , Figure and Table below.

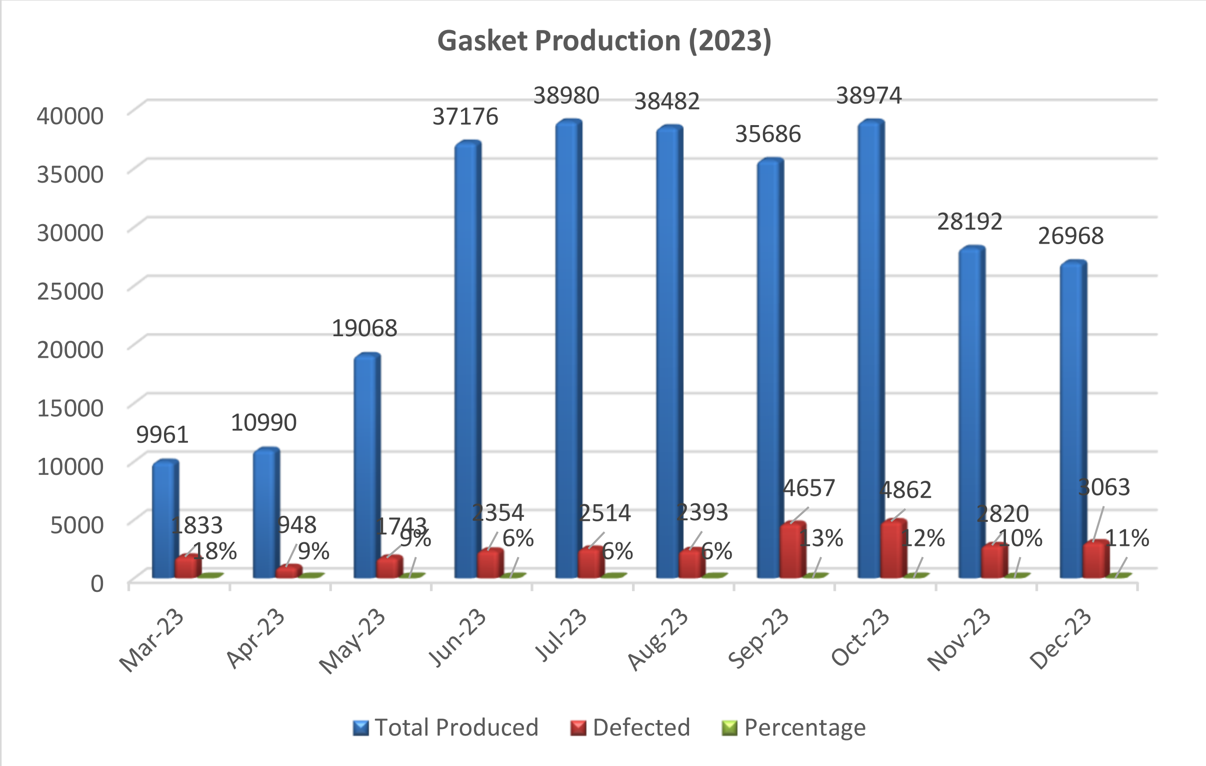

Figure X. Gasket production and rejection data of 2023.

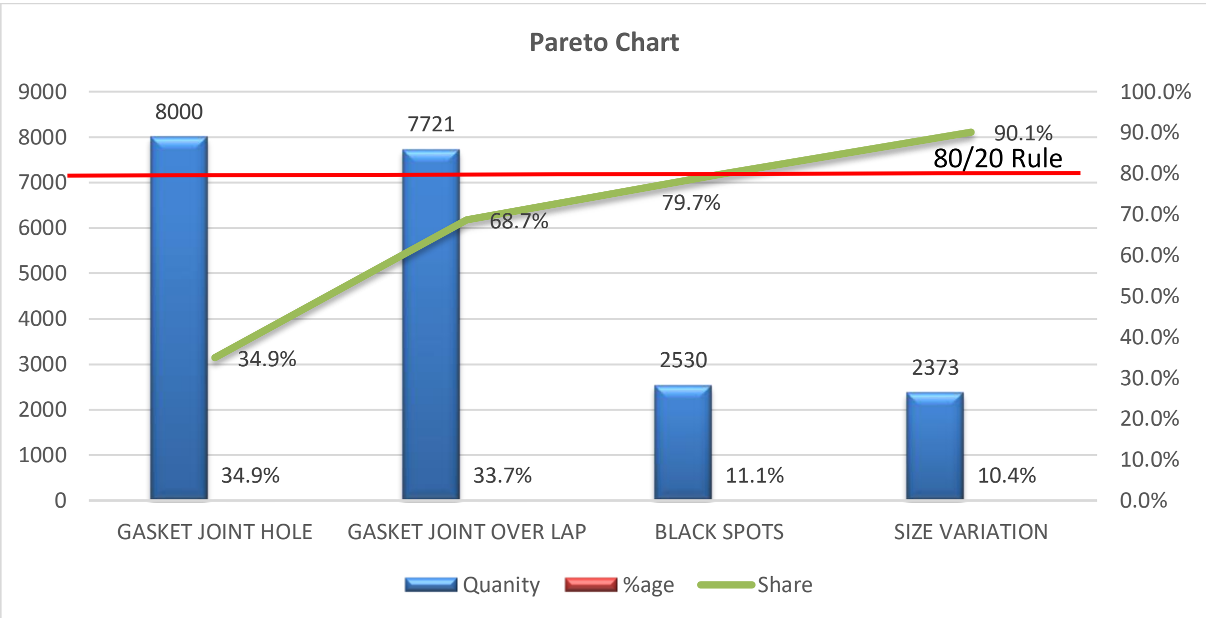

Figure XI. Pareto analysis of the data of 2023.

Problem	Quantity	%age	Cause of the defect
GASKET JOINT HOLE	8000	29%	Welding M/C
GASKET JOINT OVER LAP	7721	28%	
GASKET PROFILE WRONG	4893	18%	Extrusion Machine
BLACK SPOTS	2530	9%	Material
SIZE VARIATION	2373	9%	Extrusion Machine

Table VII. Cause of defect identification based on 2023 data.

Summary of the data that was gathered in measure phase is mentioned in Table , Table and Table .

PVC Extrusion M/c Data				
Sr. No	Total Production (kg)	Efficiency	Rejection Qty. (kg)	Rejection %age
1	12076	50%	1398	12%

Table VIII. Summary of PVC Extrusion machine data.

Welding M/c's Data				
Sr. No	Total Production	Efficiency	Rejection Qty.	Rejection %age
1	39,715	54%	2604	7%

Table IX. Summary of welding machine's data.

Magnet insertion m/c data			
Sr. No	Total Production of gaskets	Total Rejection of magnet (kg)	Average Rejection per day (kg)
1	39,715	419	14

Table X. Summary of magnet insertion m/c data.

3.5 ANOVA. - ANOVA (Analysis of Variance) is used on the data collected during the measure phase of the gasket manufacturing process to evaluate whether there are statistically significant differences between the means of various groups or factors that may be impacting the process. In the measure phase data was gathered in order to better understand the variability in the gasket production process, such as differences in total rejection, purging rejection, machine parameter settings, variation in production plan and machine efficiency. ANOVA allows manufacturers to determine which factors have a major impact on the quality or performance of their gaskets. This analysis aids in identifying sources of variation that must be addressed during the improve phase of the process.

The "Total Rejection" data's normality was thoroughly tested in this study using four statistical tests: the Kolmogorov-Smirnov test, the Kolmogorov-Smirnov test with Lilliefors correction, the Shapiro-Wilk test and the Anderson-Darling test. The Kolmogorov-Smirnov test produced a statistic of 0.09 and a p-value of 0.982, suggesting no significant departure from a normal distribution. Similarly, the Kolmogorov-Smirnov test with Lilliefors correction, which accounts for small sample sizes, yielded a statistic of 0.09 and a p-value of 1, providing additional support for the normality assumption. The Shapiro-Wilk test, which is known for being effective with small to intermediate sample sizes, yielded a statistic of 0.97 and a p-value of 0.606, supporting the conclusion of normality. Finally, the Anderson-Darling test, which is especially sensitive to tail deviations, returned a statistic of 0.24 and a p-value of 0.779, suggesting no significant departure from normalcy. Collectively, these tests provide strong evidence that the "Total Rejection" data follows a normal distribution, supporting the use of parametric statistical approaches in following investigations. Data is mentioned in Table

Normality tests	Statistics	p
Kolmogorov-Smirnov	0.09	0.982
Kolmogorov-Smirnov (Lilliefors Corr.)	0.09	1
Shapiro-Wilk	0.97	0.606
Anderson-Darling	0.24	0.779

Table XI. Tests for normal distribution of Total Rejection.

The Durbin-Watson test was used to determine whether the regression model's residuals had autocorrelation. The test produced a statistic of 2.37, which is near to the ideal value of two, indicating no significant first-order autocorrelation.

The corresponding p-value of 0.348, which is greater than the conventional significance level of 0.05, supports this result by indicating that the null hypothesis of no autocorrelation cannot be discarded. The autocorrelation coefficient of -0.24 suggests a small negative connection between residuals, although it is not statistically significant. Overall, the results indicate that the residuals are independent, and the regression model meets the requirement of no autocorrelation. This discovery improves the trustworthiness of the regression analysis and its conclusions and is mentioned in Table

Autocorrelation	Statistics	p
-0.24	2.37	0.348

Table XII. Durbin-Watson-Test

Now multicollinearity test was performed. It is used to confirm that the regression model is reliable and valid by determining whether the predictor variables were significantly linked with one another. Multicollinearity can generate a number of problems in regression analysis, including exaggerated standard errors of coefficient estimates, incorrect significance tests, and difficulties evaluating each predictor's unique contributions. Multicollinearity, which happens when predictor variables in a regression model are highly correlated, can impair model dependability by increasing the variance of coefficient estimates and making it harder to analyze each predictor's individual effect. To diagnose multicollinearity, two crucial metrics are commonly used: tolerance and the Variance Inflation Factor (VIF). Tolerance levels less than 0.10 or VIF values greater than 10 are typically regarded indicators of problematic multicollinearity. In this analysis, the Tolerance and VIF values for all predictors, such as "purging rejection" (Tolerance = 0.81, VIF = 1.23), "Gasket size variation issue" (Tolerance = 0.88, VIF = 1.14), and "machine stop for lunch break" (Tolerance = 0.63, VIF = 1.58), are well within acceptable ranges. None of the predictors have Tolerance values less than 0.10 or VIF values greater than 10, indicating that multicollinearity is not a major concern in this model. This implies that the predictors are sufficiently independent, and the regression analysis can proceed without concern for multicollinearity influencing the results. Results are available in Table .

Model	Tolerance	VIF
Purging rejection	0.81	1.23
Gasket size variation issue	0.88	1.14
Color changeover rejection	0.68	1.47
Pre-heating	0.58	1.73
Machine parameter setting	0.7	1.44
Machine stop - No plan	0.67	1.49
Machine stop - Gasket color change	0.49	2.02
Machine stop for lunch break	0.63	1.58

Table XIII. Multicollinearity test.

Now model summary and ANOVA table were prepared from regression analysis in order to evaluate the performance of the model. The regression analysis showed a robust association between predictors and the dependent variable ($R = 0.91$ and $R^2 = 0.84$), accounting for 84% of the variation. The improved R^2 (0.76) verified the model's robustness, and the standard error of 5.9 indicated acceptable prediction accuracy. The ANOVA findings ($F = 10.86$, $p < .001$) showed the model's overall significance. This investigation confirmed the model's fit and predictive capability, indicating its suitability for evaluating variable relationships. It confirmed that the predictors together had a significant effect on the dependent variable. Above mentioned values are available in Table 2 and Table.

R	R^2	Adjusted R^2	Standard error of the estimate
0.91	0.84	0.76	5.9

Table 2 Model summary

Model	df	F	p
Regression	8	10.86	<.001

Table XV. ANOVA.

Now Pareto diagram was prepared in order to identify and prioritize the most significant factors that results in the instability of the process leading it to deviate from mean and perform erratically. This pareto diagram (Figure) will also validate the significant factors diagnosed in the previous mentioned tools like cause-and-effect diagram, cause and effect matrix, quality function deployment and FMEA.

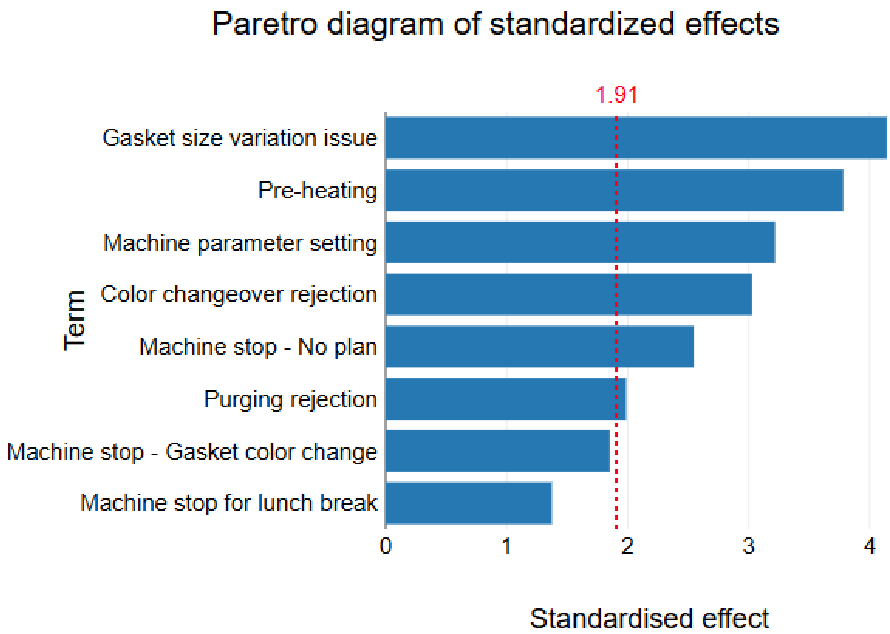

Figure XII. Pareto diagram of standardized effects.

In this pareto diagram, factors such as gasket size variation issue, pre-heating, machine parameter setting, color changeover rejection, machine stop – no plan, purging rejection were evaluated and then ranked for their impact. This highlights the ones that require immediate attention and will yield maximum results with optimized allocation of resources.

3.6 Improve Phase. - The goal of improve phase is to implement the solutions of the problems/causes that were identified in the analyze phase. This involves designing and testing the suggested improvements of the problems to enhance efficiency, reduce defects and variations in the manufacturing process. Detailed solutions to each cause identified in analyze phase are given below in Table .

Sr. No	Problem	Root cause	Suggestions for improvement
1	Purging Waste & Wrong profile issue	Excessive changeover issue	1- Gasket manufacturing plan should be independent from DPA plan 2- Gasket production planning should be done as per stock area 3- Stock area for PVC profiles should be designed in such a way that extrusion machine must not be used for production every single day. Batch production planning should be done
2	Magnetic Strip cutting Waste	Cutting machine sensors not ok	1-In first step, knurling of encoder wheel as grooves on the wheel are practically eliminated 2- If problem of size variation is not resolved then secondly will remove the mechanical delay between the rocker arm and limit switch 3- In case the problem is still not resolved then will replace the existing the encoder with rotary increment encoder
		Manual Cutting	4- For a temporary solution, manual cutting should be done as we are already performing this process at later stage
3	Welding Joints	Welding Dies health issue	1-Repairing of Dies
		Uncontrolled heaters temperatures for welding	2- Usage of K type thermocouples with microsensor to control the temperature 3- Replacing the existing filament type electric heaters with tube type electric heaters
		Storage issue for finished gasket	4-Use trollies or hangers for transportation 5-Improve design of Hangers
4	Black spots	Dust in Crush	1-Use less crush or no crush
		Foreign particles mixing in virgin material	2- Supplier material evaluation should be done

Table XVI. Suggestions for improvements for gasket manufacturing process.

Detailed feasibility analysis of the improvements mentioned in Table was performed. Cost of these improvements is mentioned in Table , Table and Table .

Item	Price (PKR)
Price of Thermocouple	2500
Price of MAX6675	2350
Price of Arduino UNO	2000
Cost of single setup	6850
Total No. of welding Machines	8
Total Cost	54,800

Table XVII. Welding machine heaters temperature controller.

Item	Quantity
Number of coils on each hanger	50
Cost of improvement on each hanger	50
(scrap metal will be used - Cost is of labor and welding)	50
Total Cost	75000

Table XVIII. Redesigning of hangers for gasket storage.

Item	Quantity with 1 m/c production (PKR)
Cost of each box (PKR)	5,000
Total Cost (PKR)	90,000

Table XIX. Construction of wooden boxes for PVC profile storage.

3.7 Control phase. - After the implementation of improvement suggestions that were mentioned in improve phase, control phase in the gasket manufacturing process focuses on sustaining the improvements made in previous stages to guarantee consistent product quality with little variance. Control mechanisms are put in place during this phase to keep an eye on important process variables like material wastage control by controlled production scheduling, controlling of defects related to welding machines, controlling the defects related to storage of gaskets and PVC profiles, extrusion machine parameters and magnetic strip insertion precision. Control charts are used to monitor these variables over 30 days of time in order to identify any deviations. Remapping of process was done in order to improve the existing setup. Summary of extrusion machine data is available in the Table below.

PVC Extrusion M/c Data (After Improvement) Date = 20th Aug, 2024 – 10th Sep, 2024				
Sr. No	Total Actual Production (kg)	Efficiency %age	Total Rejection (kg)	Rejection %age
1	13200	83.2%	536	4.06%
PVC Extrusion M/c Data (Before Improvement)				
Sr. No	Total Production (kg)	Efficiency	Rejection Qty. (kg)	Rejection %age
1	12076	50%	1398	12%

Table XX. Summary of extrusion m/c data (Before vs After Improvement).

In this research, Cp and Cpk (Statistical Process Control metrics) were used to evaluate the process's capability before and after making modifications to the gasket manufacturing process. These indices were used for studying how modifications affected production efficiency, rejection %age, and purge rejection. Cp assesses the process's potential capability by comparing its spread to the specification limitations, whereas Cpk accounts for process centering, providing information about how well the process mean aligns with the target. Before improvement, the process had low Cp and negative Cpk values, indicating inadequate capability and a considerable variation from the target values.

The findings show that effectiveness of the improvement steps taken on manufacturing line in increasing production efficiency, lowering rejection rates, and reducing purge rejection, resulted in a more capable and stable manufacturing process that revolves around.
Cp and Cpk calculation of before and after improvements are mentioned in Table and Table.

Parameters	Production Efficiency	Rejection %age	Purging rejection
Target	80%	4.0%	7
+ Tol	20%	0.5%	3
- Tol	5%	0.5%	3
USL	100%	4.5%	10
LSL	75%	3.5%	4
AVE	48%	13.1%	14
MAX	61%	88.4%	21
MIN	10%	4.6%	4
USL-LSL	25%	1.0%	6
s	9.7%	15.4%	4
CpU	1.785	-0.19	-0.40
CpL	-0.926	0.21	0.94
Cp	0.429	0.01	0.27
Cpk	-0.926	-0.19	-0.40

Table XXI. Cp & Cpk calculations of gasket manufacturing process - Before improvement.

Parameters	Production Efficiency	Rejection %age	Purging rejection
Target	80%	4%	7.000
+ Tol	20%	0.5%	3.000
- Tol	5%	0.5%	3.000
USL	100%	4.5%	10.000
LSL	75%	3.5%	4.000
AVE	83%	4.1%	6.852
MAX	90%	4.3%	8.000
MIN	78%	3.7%	5.000
USL-LSL	25%	1.0%	6.000
s	2.8%	0.1%	0.972
CpU	1.996	1.023	1.080
CpL	0.975	1.290	0.979
Cp	1.486	1.157	1.029
Cpk	0.975	1.023	0.979

Table XX. Cp & Cpk calculations of gasket manufacturing process - After improvement.

I-MR control chart of production efficiency, rejection %age and purging rejection are given below and explained in detail.

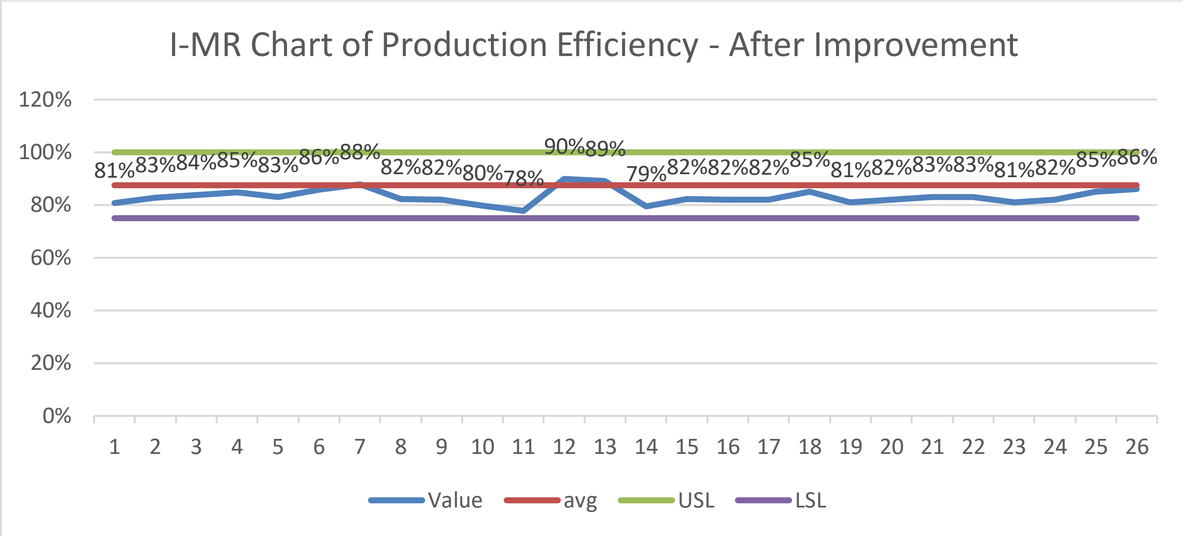

Figure XIII. I-MR control chart of purging rejection after improvement.

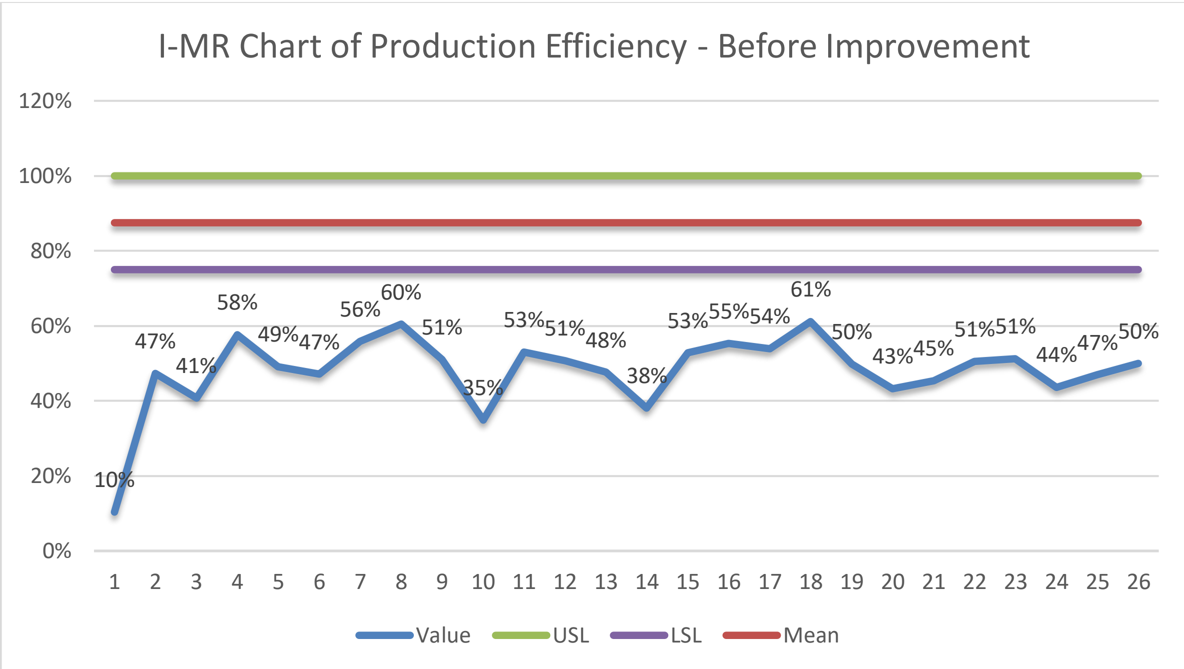

Figure XIV. I-MR control chart of purging rejection before improvement

As it can be seen in **Error! Reference source not found.** and **Error! Reference source not found.** that average rejection reduced from 17 kg/day to 6.9 kg/day. Average rejection per day dropped from 47 kg to 24 kg just because of improving production planning and storage area for PVC profiles. Cost of PVC material per kg is 395 PKR including energy consumption and labor cost per day. This results in a saving of 5,135 PKR per day just from extrusion machine. This amounts to 1.5 million PKR per year from one extrusion machine only.

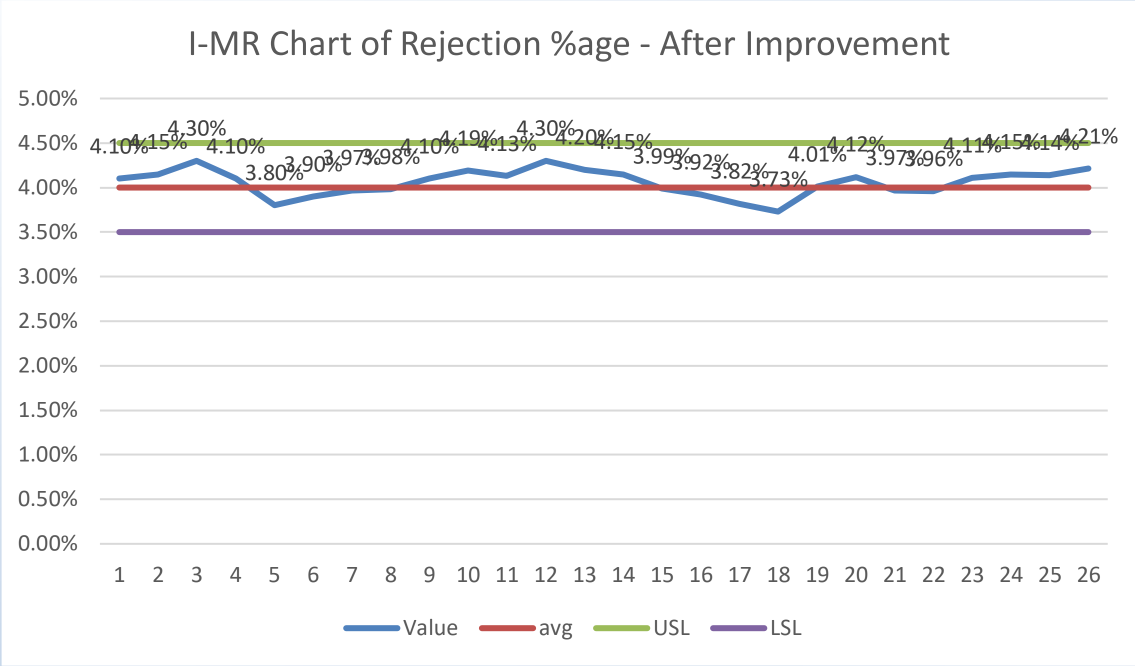

Figure XV. I-MR chart of date vs rejection %age after improvement.

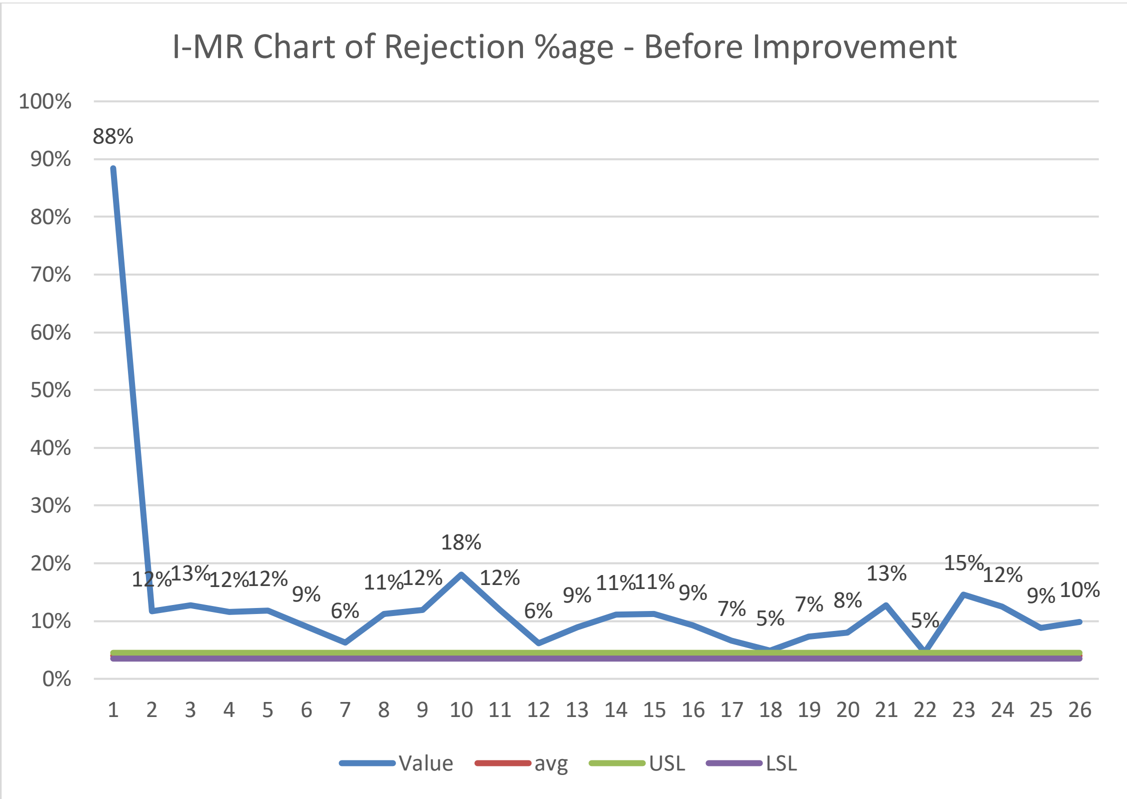

Figure XVI. I-MR control chart of date vs rejection %age before improvement.

The graphs in Figure and Figure show a significant reduction in the average rejection %age, dropping from 12% to 4.06%. This substantial decline in rejection %age is primarily due to increased productivity. The boost in production and decrease in stoppage times led to a reduction in purging rejection and machine setup rejection, ultimately contributing to the overall decrease in the rejection %age.

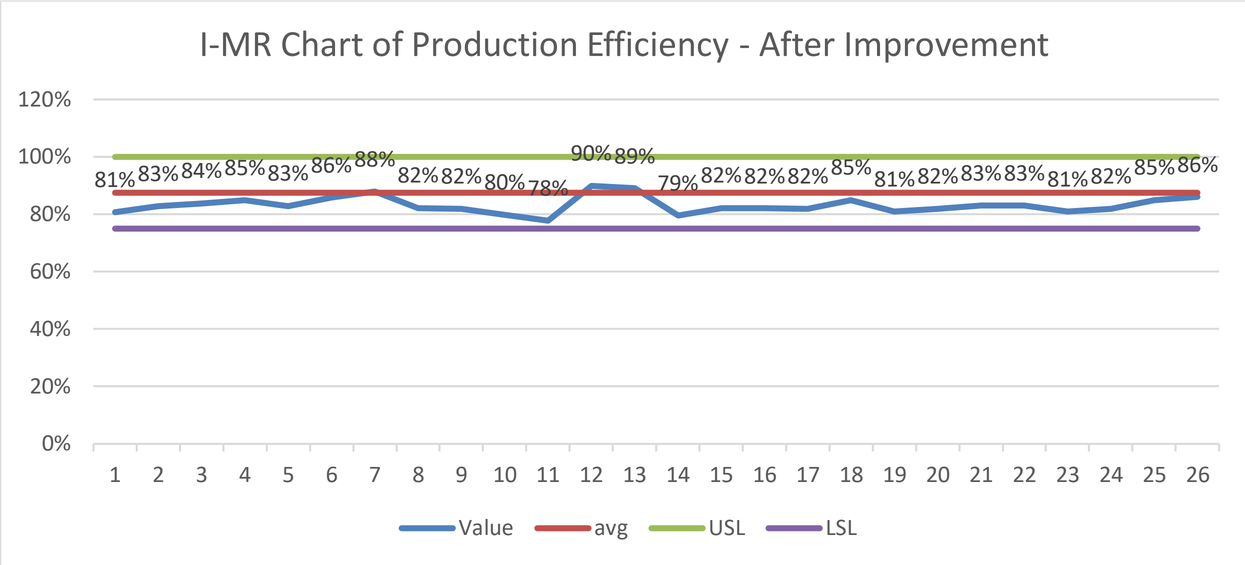

Figure XVII. I-MR control chart of efficiency after improvement.

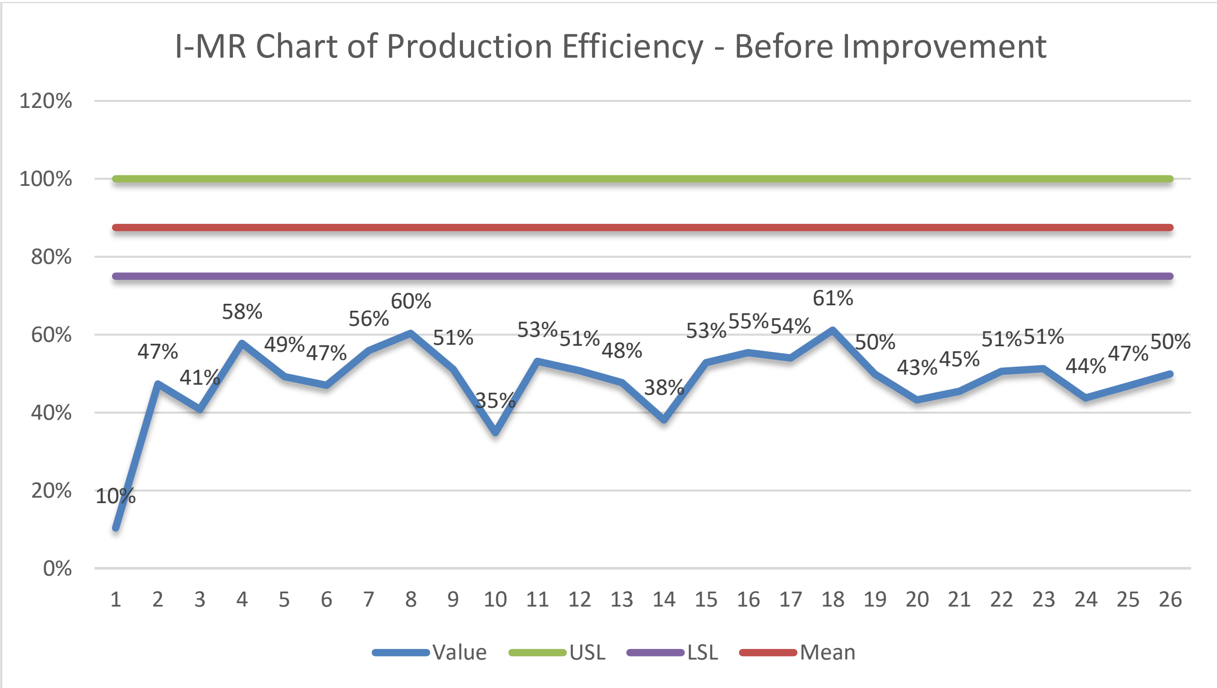

Figure XVIII. I-MR control chart of production efficiency before improvement.

It can be seen from the Figure and Figure that efficiency of extrusion machine increased from 50.1% to 83.3% which is a huge change. This was only possible by reducing the number of changeovers and stoppage times.

Rejection because of size variation in magnet cutting machine issue was resolved after the knurling of encoder wheel. Average value of magnetic strip rejection per day was 14 kg. At a cost of 17 PKR/meter and 1 meter of magnet weighs 60 gm. This saves company almost 1.2 million PKR in 1 year (300 working days).

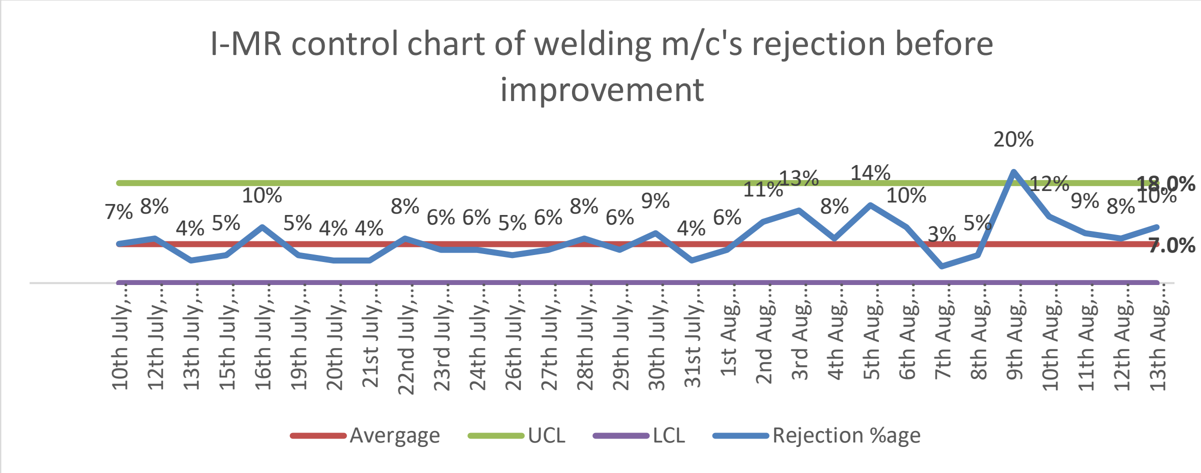

Figure XIX. I-MR control chart of welding m/c's rejection before improvement.

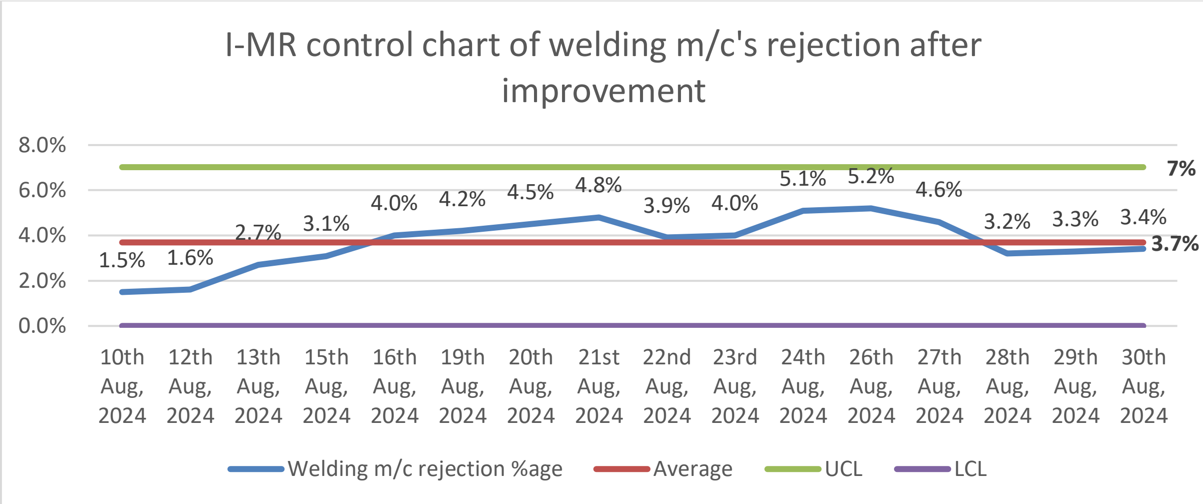

Figure XX. I-MR control chart of welding m/c's rejection after improvement.

It can be seen in Figure and Figure that average welding rejection was reduced from 7% to 3.7%. This happened because of implementing temperature controller for heaters and repairing of dies. Efficiency monitoring report was not prepared for welding m/c's as their plan is dependent upon door pre-assembly and production on welding machines start and stop based on the requirement of door pre-assembly.

4. Conclusion. - The six-sigma project, based on DMAIC methodology, for gasket manufacturing process has resulted in significant improvement in gasket manufacturing process resulting in increase in efficiency, waste reduction, process improvement thus improving the overall product quality.

4.1 PVC extrusion machine. - The overall rejection %age of the extrusion machine decreased significantly from 12% to 4.06%. The average purging rejection per day was reduced from 17 kg to 6.9 kg and the total daily rejection dropped from 47 kg to 24 kg. This reduction translates into a savings of 5,135 PKR per day, amounting to 1.5 million PKR annually (based on 300 working days). Additionally, the efficiency of the extrusion machine improved from 50.1% to 83.3%, marking a substantial increase in productivity. Also, next month plan was completed in 20 days thus saving a considerable amount of energy cost, labour cost and other costs associated with it.

4.2 Magnet insertion m/c. - There was loss of 14 kg of magnet per day and as 1-meter magnet weighs 60 gm so there was a loss of 233.3 meters of magnet per day. This loss was reduced to zero by knurling of encoder wheel thus saving company 1.2 million rupees in one year (300 working days) at a cost of 17 PKR/meter.

4.3 Welding m/c's. - Since the welding machines operate based on the requirements of the door pre-assembly process, the rejection %age of the welding machines was monitored after the improvements were implemented. The rejection rate dropped from 7% to 3.7%, primarily due to enhancements in the temperature control of the welding heaters and repairs to the dies, which contributed to better overall performance and reduced defects.

In conclusion this six-sigma project not only achieved significant improvements in gasket manufacturing process by optimizing the production process and production scheduling by developing the storage area of gasket profiles in order to smoothen the production of extrusion machine and remove it dependency on door pre-assembly plan because of absence of storage space. Also, a significant problem was resolved by knurling of encoder wheel at magnet insertion station by improving the threading of encoder wheel so that it can accurately read the length of magnet during production. Major issues of welding machines were resolved by adding a temperature controller for heater and repairing of dies. In addition to these changes, comprehensive operator training sessions were conducted, and Standard Operating Procedures (SOPs) were established to guide production execution and quality inspection processes. As a result of this final product is improved significantly along with process. By continuing to monitor and control these improvements can be sustained as there is not ample time available for preventive maintenance because of extrusion m/c production plan completion before time with at least 10 days to spare.

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Author contribution:
1. Conception and design of the study
2. Data acquisition
3. Data analysis
4. Discussion of the results
5. Writing of the manuscript
6. Approval of the last version of the manuscript

MMUZS has contributed to: 1, 2, 3, 4, 5 and 6.
AT has contributed to: 1, 2, 3, 4, 5 and 6.

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