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Process Quality Control of Eyeglass Lens Production to Reduce Particle Using Six Sigma and DMAIC

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ABSTRACT

Objectives: *The aim of this research is to examine and maintaining the high product quality while optimizing resource efficiency is a critical challenge in today's competitive global market. PT XYZ, a leading ophthalmic lens manufacturer, struggles with particle defects, particularly in the UV coating process, which contributes to 80% of total production defects.*
Methodology: *To address this issue, the study applies the Six Sigma methodology using the DMAIC framework to identify root causes, reduce defects, and improve production efficiency. This research adopts a quantitative approach with comparative and descriptive methods. Data collection methods include direct observation, focus group discussions, interviews, and historical data analysis.*
Findings: *The initial analysis identified several defect sources, including environmental factors, improper process handling, and machine performance issues. Improvement actions, such as installing an antistatic blower and optimizing pre-cleaning processes, successfully reduced the defect rate from 12% to 4.7%. The Defects Per Million Opportunities (DPMO) dropped from 112,801 to 46,782, while the Sigma level improved from 2.71 to 3.18.*
Conclusion: *This study conclude that implementing Six Sigma and DMAIC methodologies effectively enhances quality control in ophthalmic lens manufacturing. These improvements strengthen PT XYZ's long-term competitiveness while supporting sustainable manufacturing practices aligned with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production).*

Keywords: *Quality Control; Six Sigma; DMAIC; Eyewear Lens; Particle Defects; SDGS.*

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INTRODUCTION

Maintaining high product quality while optimizing resources is a key challenge in today's competitive market. The eyewear industry is growing rapidly due to increasing demand for vision correction, screen exposure, and eye health awareness. According to the Global Eyewear Market Report, the market is projected to grow at a CAGR of 8.10% from 2023 to 2031, rising from USD 172.16 billion in 2022 to USD 344.14 billion.

As competition intensifies, manufacturers strive to enhance product quality to maintain market position. Product quality is a set of characteristic features of goods and services that have the ability to meet needs which is an understanding of the combination of durability, reliability, accuracy, ease of maintenance and other attributes of a product. (Yunita, 2021). For PT. XYZ, a leading manufacturer specializing in ophthalmic lenses, quality control is a crucial aspect of production. In the implementation of quality control is an activity aimed at avoiding product non-conformity with the plan that has been prepared at the quality planning stage. In essence, in this quality control all activities are carried out with the aim of avoiding or eliminating defective products. (Catur Wahyuni, S.T., M.T. & Sulistiyowati, ST., MT., 2020). With effective quality control, companies will achieve high productivity, reduce overall production costs, and minimize production failures.

PT. XYZ, based in Cikarang, Indonesia, has produced high-quality polycarbonate lenses since 1930 for domestic and international markets. Despite its strong presence, the company struggles with coating defects, as particle defects make up 80% of total issues. These particles, ranging from 0.005 µm to 100 µm, result from natural or mechanical activities (Kurniawan, 2019).

PT. XYZ adopts Six Sigma's DMAIC framework to enhance quality control, minimize defects, and improve efficiency. Six Sigma is a well-established quality management strategy designed to minimize defects and improve process efficiency through data-driven decision-making. This method aims to be a quality control tool that can be used to measure the level of defects in the service or manufacturing industry. (Waruwu et al., 2022) By applying this approach, PT. XYZ seeks to identify the root causes of defects, enhance production efficiency, and achieve the company's target yield of 95% per production line.

This study addresses high defect rates in Line 1's UV coating process due to semi-automated handling. By implementing Six Sigma and sustainable manufacturing, PT XYZ aims to improve quality, optimize resources, and support SDG 9 and SDG 12. The findings provide solutions for defect reduction, process optimization, and industry competitiveness.

LITERATURE REVIEW

Glasses

Eyewear lenses are optical components designed to correct vision problems or provide eye protection. It is a lens supported by a frame that is used to help vision or protect the eyes or as a fashion accessory. (Suwarna, 2010). Traditionally, lenses were made from glass, but technological advancements have led to the widespread use of materials such as CR-39 and polycarbonate. These materials offer superior optical properties, durability, and resistance to breakage, making them ideal for modern eyewear production (Suwarna, 2010).

Production process

The production process is the core of a manufacturing company's activities, which affects the costs and quality of the products produced. (Indriati et al., 2019). The production process is a series of activities carried out to convert raw materials into finished products that are ready to be sold or used. (Nurdini et al., 2021). The production process is one of the production factors in a company in producing a product. The good or bad production system in a company will affect the implementation of the production process in the company concerned. (Budiartami & Wijaya, 2019). From the description above, it can be concluded that the production process is the core of a manufacturing company's activities which is very important in running a business.

Concept of Quality

Definition of quality, namely the ability of a product to consistently meet or exceed customer desires or expectations is the definition of quality. (Stevenson, 2018). Service quality is the totality of the features and characteristics of a product or service that support its ability to satisfy needs directly or indirectly. (Indrasari, 2019). Quality is also a unity of characteristics in a product that is needed or desired by consumers in real or hidden ways. (Heizer et al., 2020).

If examined further, the definition of quality is always related to needs, customers and customer satisfaction. This condition illustrates that quality is an assessment given by customers to a product to meet the need to obtain a level of satisfaction. The ultimate goal of quality is to provide customer satisfaction. (Wiwik Sulistiyowati & Wahyuni, 2020).

Six Sigma

Six sigma is a business process to improve quality, reduce costs, and increase customer satisfaction. (Stevenson, 2018). Six Sigma is a methodology widely used in various industries to improve quality, reduce defects, and increase overall efficiency. The six sigma process control approach allows for a mean shift in each individual CTQ of an industry process to shift by 1.5 sigma from a target requirement from the consumer, resulting in a value of 3.4 DPMO. (Gaspersz, 2002).

In its stages, the Six-Sigma methodology is completed with six sigma metrics, process performance measurement is carried out using DPMO and sigma. Therefore, in the implementation stage of six sigma quality control, the DMAIC methodology can be used. The DMAIC framework is used in Six Sigma projects to identify problems, analyze root causes, implement solutions, and ensure continuous improvement. (Rawendra & Puspita, 2020), (Henny et al., 2019)

DMAIC

DMAIC is to improve process performance and product design. The DMAIC method emphasizes the use of statistical tools to collect data at each stage. (Novitasari, 2022). A methodology that uses data to minimize product defects, damage or product waste that occurs in the manufacturing, service, management, and other business production processes. (Jakti, 2024). (Heryadi & Sutopo, 2018). In the process, DMAIC is able to find out what customers need into an operational term that must be done and followed up and define important tasks and processes to meet what customers actually need. (Juran, 1999). DMAIC is a process for continuous improvement towards the Six Sigma target. DMAIC is carried out systematically, based on science and facts / systematic, scientific and fact based. (Gaspersz, 2002).

METHOD

This study uses a quantitative approach with comparative and descriptive methods, applying Six Sigma's DMAIC framework to reduce particle defects in PT XYZ’s Line 1 UV coating process. The methodology consists of five phases:.

- Define – Identify key issues affecting lens quality.
- Measure – Assess process performance using DPMO, Yield, and Sigma Level.
- Analyze – Find root causes of defects with statistical tools.
- Improve – Implement corrective actions to reduce defects.
- Control – Ensure long-term quality and process standardization.

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PT XYZ applies systematic methods to reduce defects, improve quality, and boost efficiency through:

- Observation - Direct inspection of UV coating operations.
- FGD - Discussions with production teams and quality vendors.
- Interviews - Insights from operators, supervisors, and maintenance teams.
- Document Analysis - Review of production data for defect trends.

RESULTS AND DISCUSSION

DEFINE

Define stage identifies problems by creating the SIPOC, CTQ, and Project Charter. Issues are analyzed using production data from January 2023 to June 2024.

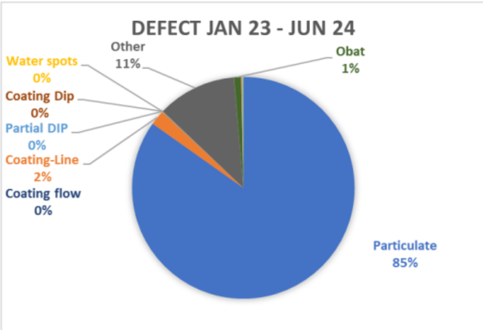

Figure 1. Scater Diagram Defect All Line

scatter diagram shows particle defects make up 85% of total defects. Further analysis is needed to identify the production line with the highest occurrence.

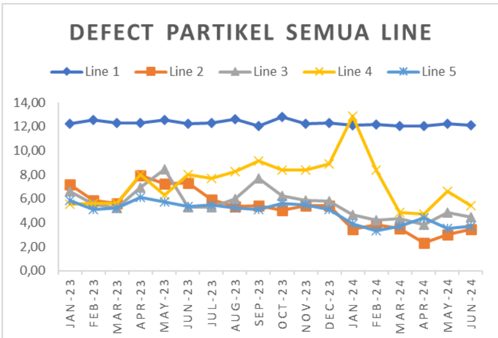

Figure 2. Line Diagram of Particle Defects Across All Lines

Particle defects are the most significant issue, with Line 1A being the most affected. These defects fall into two types:

- Spike particles: Caused by high mechanical activity in uncontrolled environments.
- Spread particles: Linked to pre-coating quality, especially in pre-cleaning.

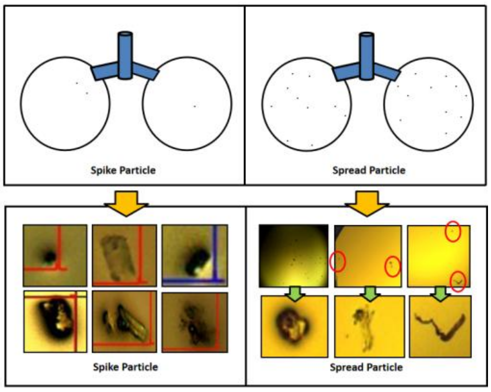

Figure 3. Types of Particle Defects

A. SIPOC

SIPOC diagram outlines the production flow, from Suppliers to Customers, identifying key areas in eyewear lens manufacturing that contribute to defects.

Table 1. SIPOC Diagram

Supplier	Input	Process	Output	Customer
Molding	Coating machine and equipment	Prezap	Defect or Reject information	Degate, QC & packaging
	Coating Solution (UV/TNTC)	Ultrasonic		
	Working Instruction	Washing		
		Coating		
		Dabbing		
		Stay Hepa		
		Final Cure		
		Stay Lorry / Transfer to Oven		

Based on the table above, the UV eyewear lens production process flow can be clearly outlined, allowing for identification and monitoring of each stage in the manufacturing process.

B. CTQ (Critical to Quality)

it is essential to identify the critical areas that contribute to particle defects in the UV lens production process on Line 1. Below is the production process flow for Line 1.

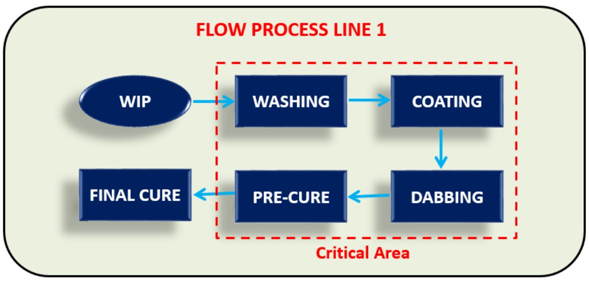

Figure 4. Critical area proses line 1

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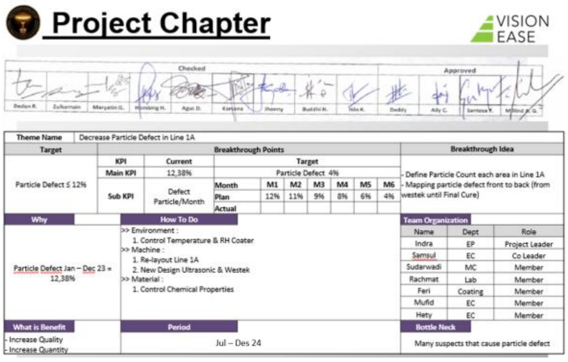
Based on the Flow Process of Line 1, stages such as Washing, Coating, Dabbing, and Pre-Cure are critical areas that require strict monitoring and control to ensure quality.

C. Project Chapter

Project Charter defines the project's scope, objectives, and responsibilities, ensuring focus on key goals. Below is the charter for the Line 1 UV eyewear lens study.



Project Chapter

VISION EASE

Checked | Approved

Theme Name	Decrease Particle Defect in Line 1A									
Target	**Breakthrough Points**									**Breakthrough Idea**
Particle Defect ≤ 12%	**KPI**	**Current**	**Target**							- Define Particle Count each area in Line 1A - Mapping particle defect front to back (from westek until Final Cure)
	Main KPI	12,38%	Particle Defect 4%							
	Sub KPI	Defect Particle/Month	**Month**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	
			Plan	12%	11%	9%	8%	6%	4%	
			Actual							

Why

Particle Defect Jan – Dec 23 = 12,38%

How To Do

>> Environment :
1. Control Temperature & RH Coater

>> Machine :
1. Re-layout Line 1A
2. New Design Ultrasonic & Westek

>> Material :
1. Control Chemical Properties

Team Organization

Name	Dept	Role
Indra	EP	Project Leader
Samsul	EC	Co Leader
Sudarwadi	MC	Member
Rachmat	Lab	Member
Feri	Coating	Member
Mufid	EC	Member
Hety	EC	Member

What is Benefit

- Increase Quality
- Increase Quantity

Period

Jul – Des 24

Bottle Neck

Many suspects that cause particle defect

Figure 5. Project Chapter

After developing the Project Charter and identifying particle defects as the critical focus area, the next step is to proceed to the Measure phase.

MEASURE

In the Measure phase, DPMO and Sigma level calculations assess quality performance and process efficiency. The table below presents the results.

Table 2. DPMO and Sigma Level

Month	Start	GPP	Reject Partikel	DPMO	SIGMA
Jan-23	151.553	135.296	16.563	109.289	**2,73**
Feb-23	92.332	83.155	10.415	112.801	**2,71**
Mar-23	150.813	137.317	16.908	112.113	**2,72**
Apr-23	32.200	27.847	3.424	106.327	**2,75**
May-23	27.476	24.513	3.074	111.872	**2,72**
Jun-23	111.703	97.757	11.989	107.328	**2,74**
Jul-23	65.815	54.448	6.700	101.794	**2,77**
Aug-23	91.993	78.191	9.859	107.172	**2,74**
Sep-23	78.489	68.190	8.223	104.763	**2,75**
Oct-23	84.930	71.869	9.206	108.397	**2,74**
Nov-23	116.044	102.278	12.520	107.889	**2,74**
Dec-23	38.548	33.738	4.150	107.649	**2,74**
Jan-24	134.300	119.008	14.417	107.349	**2,74**
Feb-24	70.228	63.049	7.662	109.107	**2,73**
Mar-24	66.348	56.837	6.854	103.301	**2,76**
Apr-24	37.898	33.602	4.042	106.655	**2,74**
May-24	44.289	37.790	4.616	104.222	**2,76**
Jun-24	111.410	94.449	11.432	102.616	**2,77**
			Average	107.258	2,74

Example of calculating DPMO and six sigma values

$$\text{DPMO} = \frac{16533}{151533 \times 1} \times 1000000$$

DPMO = 109289

Calculation of sigma value using the following Ms.Excel software

Sigma Value = NORMSINV ((1000000 - DPMO) / 1000000 + 1,5
Sigma Value = NORMSINV ((1000000 - 109289) / 1000000 + 1,5
Sigma Value = 2,73

ANALYZE

In the Analyze phase, an FGD was held to identify and evaluate key factors causing issues. The fishbone diagram below presents the findings.

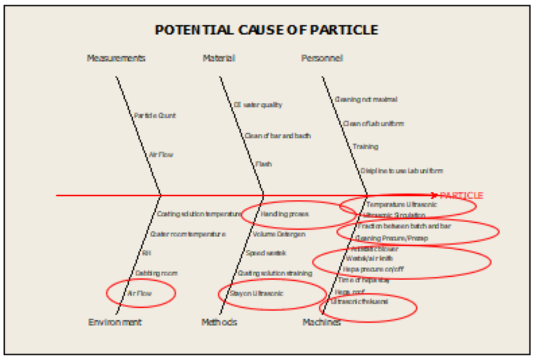


Figure 6. Fishbone Diagram

Based on the FGD brainstorming results, several potential factors that could cause particle defects were identified:

- Environmental factors: Airflow is a significant potential cause of particle defects.
- Method factors: Two processes could lead to particle defects: handling during the process and the lenses staying in the ultrasonic.
- Machine factors: Several aspects of the machinery may contribute to particle defects, including ultrasonic frequency, the ON/OFF status of the HEPA area, friction between the bar and the batch, and ultrasonic temperature.

IMPROVEMENT

In the Improvement phase, we aimed to reduce Line 1's particle defects from 12% to 4%. Through FGD sessions, we identified 11 key improvement actions for implementation.

Table 3. List Improvement

No	Trial	PIC	Spike Part	Spread Part
1	Antistatic Blower After Westek (TOP)	Sudarwadi	Not Significant	Significant
2	Fraction between batch and bar	Veri	Not Significant	Significant
3	Airknife filter position	Mufid	Not Significant	Significant
4	Filter coating solution	Rachmat	Not Significant	Significant
5	Antistatic Blower Line after westek (Bottom)	Sudarwadi	Not Significant	Not Significant
6	Pre-wash with ultrasonic	Indra	Significant	Significant
7	Hepa on Pre-cure	Sudarwadi	Not Significant	Not Significant
8	Cupboard + Hepa	Samsul	Significant	Significant
9	Dabbing Room	Indra	Significant	Significant
10	Installation Grill + Return	Samsul	Significant (particle count)	
11	Double door on dabbing	Sudarwadi	Not Significant	Significant

Here is an example of the improvements made

1. Antistatic Blower After Westek Position on Top
   Data was collected in two conditions:
   - With the blower on, to observe its effect on neutralizing static charge.
   - With the blower off, to compare results and assess its impact on particle defects.

Figure 7. Antistatic Blower

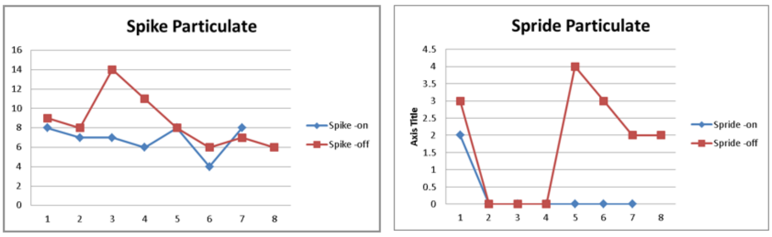


Figure 8. Graphic DPU Particle

The chart highlights differences before and after improvements. Minitab analysis validated the impact, revealing patterns, trends, and the effectiveness of the antistatic blower in reducing defects.

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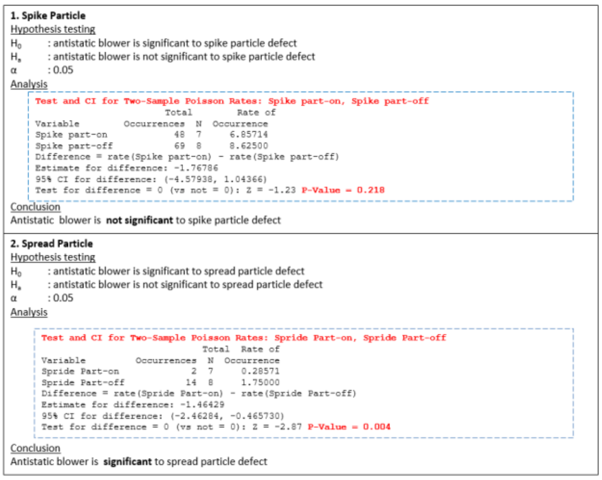

1. Spike Particle

Hypothesis testing

H_0 : antistatic blower is significant to spike particle defect

H_a : antistatic blower is not significant to spike particle defect

α : 0.05

Analysis

```
Test and CI for Two-Sample Poisson Rates: Spike part-on, Spike part-off
                          Total         Rate of
Variable        Occurrences  N  Occurrence
Spike part-on            48  7     6.85714
Spike part-off           69  8     8.62500
Difference = rate(Spike part-on) - rate(Spike part-off)
Estimate for difference: -1.76786
95% CI for difference: (-4.57938, 1.04366)
Test for difference = 0 (vs not = 0): Z = -1.23 P-Value = 0.218
```

Conclusion

Antistatic blower is **not significant** to spike particle defect

2. Spread Particle

Hypothesis testing

H_0 : antistatic blower is significant to spread particle defect

H_a : antistatic blower is not significant to spread particle defect

α : 0.05

Analysis

```
Test and CI for Two-Sample Poisson Rates: Spride Part-on, Spride Part-off
                              Total  Rate of
Variable         Occurrences  N  Occurrence
Spride Part-on             2  7     0.28571
Spride Part-off           14  8     1.75000
Difference = rate(Spride Part-on) - rate(Spride Part-off)
Estimate for difference: -1.46429
95% CI for difference: (-2.46284, -0.465730)
Test for difference = 0 (vs not = 0): Z = -2.87 P-Value = 0.004
```

Conclusion

Antistatic blower is **significant** to spread particle defect

Figure 9. Result Analysis Hypothesis Testing

The antistatic blower significantly reduced spreading-type particle defects, as confirmed by Minitab analysis (P-value = 0.004), below the 0.05 threshold.

CONTROL

This phase ensures sustained improvements and alignment with original goals by controlling critical parameters. In the Control phase, two key factors require focus due to their impact on particle defects.

A. Chemical Properties

. These parameters directly affect product quality, especially the stability of the chemical formulation. Therefore, they are closely monitored to maintain consistency.

B. Environmental Conditions

Environmental control ensures production stability. SPC monitors key parameters, and any deviations trigger corrective actions to maintain consistency.

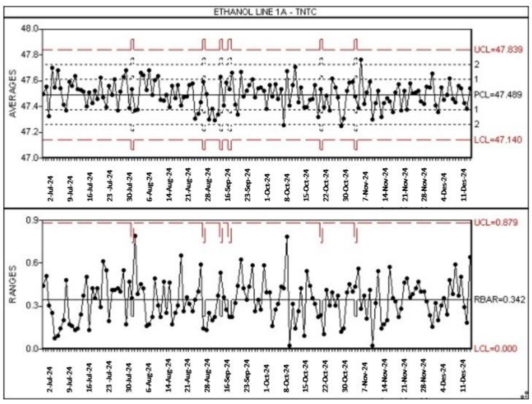

Figure 10. SPC Chemical Properties

By strictly controlling critical parameters, PT. XYZ sustains improvements and strengthens the foundation for continuous quality enhancement.

RESULT IMPROVEMENT

The defect rate started at 12%, dropping to 11% in the first month through improvements and teamwork. With continuous effort, it reached 4.73%, marking significant progress in quality enhancement and defect reduction.

Table 3. Result Improvement

Month	Yield existing	Actual Yield	Achievement	Start	GPP	Reject Particle	DPMO	SIGMA
Jul-24	12%	11,51%	104,2%	65.688	61.829	7.119	**108.374,20**	**2,74**
Aug-24	12%	10,34%	116,1%	95.690	91.454	9.456	**98.821,65**	**2,79**
Sep-24	12%	9,0%	133,2%	137.452	133.084	11.991	**87.235,21**	**2,86**
Oct-24	12%	7,6%	157,2%	71.106	69.182	5.282	**74.278,37**	**2,94**
Nov-24	12%	5,2%	230,9%	144.574	141.671	7.363	**50.926,67**	**3,14**
Dec-24	12%	4,7%	253,7%	124.258	122.892	5.813	**46.782,45**	**3,18**

This progress not only demonstrates technical success but also reflects a strong commitment to continuous improvement.

CONCLUSION

This study analysed production performance before and after quality improvements. Initially, the DPMO was 112,801 with a Six Sigma level of 2.71, indicating high defects. After implementing root cause analysis, process optimization, and corrective actions, the DPMO dropped to 46,782, raising the Six Sigma level to 3.18. This reflects improved process consistency and higher product quality.

Using the Six Sigma DMAIC method, the study identified three key causes of particle defects: work methods, environmental conditions, and machine performance. These factors previously contributed to defect rates as high as 12%.

To address these challenges, 11 improvement initiatives were proposed and implemented on Line 1 of PT XYZ's UV coating process. These measures included the installation of an Antistatic Blower (top and bottom), optimization of air knife filter positioning, pre-washing with ultrasonic, filter coating solution, Hepa on Pre-cure, Cupboard + Hepa, Dabbing room,, airflow control improvements with installation grill and return, and the introduction of double doors in critical areas. As a result, particle defect rates were reduced from 12% to 4.7%, leading to a substantial improvement in overall production quality.

This stud y highlights the effectiveness of Six Sigma and DMAIC in reducing defects, improving efficiency, and enhancing product quality. These improvements strengthened process stability and reaffirmed PT XYZ's commitment to quality and innovation.

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