Al Tijarah: Vol. 11 No. 2, December 2025 (71-87)
p-ISSN: 2460-4089 e-ISSN: 2528-2948
Available at: http://ejournal.unida.gontor.ac.id/index.php/altijarah

Analysis Of LPG Tank Defect Control Using the Six Sigma Method at PT. Metal Hitech Engineering

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Abstract

Quality control in the welding process plays an important role in ensuring product quality and production cost efficiency. This study aims to analyse the defect rate, process performance, and effectiveness of the Six Sigma method in welding quality control at PT Metal Hitech Engineering. The research data was obtained from radiographic inspection results during the period 2024–2025. The research methods used included calculating Defects Per Million Opportunities (DPMO) and sigma levels to measure process capability, analysing process stability using C-Chart control charts, identifying defect causes through cause-and-effect diagrams (fishbone diagrams), and analysing quality costs and sigma level interpolation as a basis for improvement planning. The results of the study show that the quality control system implemented by the company is still reactive and focuses on final inspection, so it is not yet able to prevent defects from occurring at the beginning of the production process. The dominant types of welding defects include incomplete fusion, incomplete penetration, porosity, and undercut. Process performance measurements show a sigma level of 3.94 in 2024 and 3.84 in 2025, indicating that process capability is in the intermediate category. Control chart analysis shows that the process is still within statistical control limits, but there are observation points approaching the upper control limit. Interpolation results indicate that an increase in the sigma level has the potential to significantly reduce the number of defects and repair costs.

Keywords: Six Sigma, Quality Control, Welding, C-Chart, Quality Costs.

A. INTRODUCTION

The growth of the manufacturing industry in Indonesia has shown a positive trend over the past five years, despite experiencing a slowdown in 2019–2020 due to the Covid-19 pandemic. In 2021, this sector recorded growth of 3.39%, signalling a recovery in national industrial activity. As industrial development continues to increase, businesses must always produce high-quality goods that are in line with their intended objectives Alfarisy, M. & Dzulquarnain, A. H. (2023). In an increasingly competitive environment, manufacturing companies are required not only to produce quality products at efficient costs, but also to demonstrate a commitment to sustainability through socially and environmentally responsible production processes (Pasaribu et al., 2025). In the metal engineering industry, such as tank and storage equipment fabrication, product quality is a key factor that determines operational reliability and customer trust.

PT Metal Hitech Engineering (PT MHE) is a manufacturing company engaged in tank fabrication, with its main products being LPG tanks and fuel tanks for transportation and storage purposes. LPG tank production is the dominant activity in the production area due to high demand, with capacities ranging from 2,000 kg to 150,000 kg. The LPG tank production process takes approximately 3–4 months, while fuel tanks require 2–3 months. Given the high production intensity and product safety risks, this study focuses on the LPG tank manufacturing process.

In the production process, the roles of Quality Control (QC) and Quality Assurance (QA) are very important to ensure that each stage meets technical standards. Quality control at PT MHE is carried out comprehensively, starting from the initial material inspection, beveling process, plate rolling, plate joining, head forming, to the welding process. In addition, a series of Non-Destructive Tests (NDT) are carried out, such as Visual Testing, Ultrasonic Testing, Magnetic Particle Testing, Liquid Penetrant Testing, Eddy Current Testing, and especially Radiography Testing (RT). RT is the primary method because it can clearly show the internal condition of the welded joints. Every stage of production has the potential to produce defects, so consistent quality control is an important element in maintaining product quality.

Table 1.1 Radiography Test Results Table Data

Month	Number of SPK	Sample Test	Types of Welding Defects (Welding Points)					
			Incomplete Fusion	Incomplete Penetration	Root Undercut	Porosity	Inclusion	Total Defect
January	-	1	-	-	1	7	12	20
February	5	3	-	-	-	13	17	30
March	2	3	1	-	-	18	19	38
June	1	2	2	-	-	7	26	35
July	8	2	2	3	-	1	9	15
August	6	1	10	-	-	8	12	30
September	-	3	4	3	-	15	80	102
October	2	7	17	-	-	23	30	70
November	3	3	7	-	1	18	42	68
December	1	3	16	-	-	18	25	59
Total	32	28	39	6	2	104	256	467

Source: NDT results from PT. MHE

Table 1.2 Radiography Test Results Table Data

Month	Number of SPK	Sample Test	Types of Welding Defects (Welding Points)				
			Incomplete Fusion	Root Undercut	Porosity	Inclusion	Total Defect
January	1	1	1	-	4	7	12
February	10	1	1	-	3	10	14
May	2	1	8	-	5	2	15
June	3	4	3	-	17	36	56
July	1	9	8	-	46	55	109
August	5	2	1	-	19	4	24
September	3	1	-	-	18	4	22
October	4	1	7	-	8	6	21
November	1	2	5	1	10	12	28
Total	30	22	34	1	130	136	301

Source: NDT results from PT. MHE

Data from Radiographic Testing (RT) in 2024 and 2025 shows that the welding process at PT Metal Hitech Engineering still has a relatively high defect rate. In 2024, there were 467 defects recorded, while in 2025, up to October, there were 301 defects recorded. The dominant types of defects include porosity, incomplete fusion, incomplete penetration, root undercut, inclusion, and cracks. Porosity and inclusion defects are generally caused by gas or foreign particles trapped in the weld metal, while incomplete fusion and incomplete penetration are related to imperfections in the union of the parent metal and filler metal. Meanwhile, cracks are the most critical type of defect because they have the potential to cause structural failure in products. The recurring pattern of defects indicates that the quality control system implemented is not yet fully optimal.

These findings are in line with previous studies stating that welding defects have a direct impact on the strength and reliability of welded joints. Alfian Huda and Sri Widiyanesti (2018) stated that manufacturing companies that have not implemented comprehensive quality control tend to experience an increase in defective products due to technical errors, improper machine settings, and variations in operator skills.

To overcome these problems, a structured and data-driven quality control approach is required. The Six Sigma method with DMAIC (Define, Measure, Analyse, Improve, and Control) stages was chosen because it is capable of identifying Critical to Quality (CTQ), measuring process capability through DPMO values and sigma levels. These results are relevant to the research (Arief & Faritsy, 2025) which states that DPMO and sigma level calculations are effective in measuring the quality performance of production processes. In addition, (Hasan & Muhammad, 2022) emphasise that the application of Six Sigma accompanied by quality gates can reduce the amount of rework and maintain product quality consistency. Therefore, this study is expected to provide strategic recommendations in developing a sustainable quality control system that is in line with the ISO 9001:2015.a standard, as well as systematically analysing the root causes of defects. Six Sigma was implemented by reorganising the process flow from planning and welding to final inspection in order to identify critical points that could potentially cause defects.

B. LITERATURE REVIEW

Quality control is a series of planned and systematic activities aimed at ensuring that the products produced meet the technical standards and specifications set by the company and applicable regulations. In the context of the manufacturing industry, particularly in the welding process, quality control plays a very important role because the welding results directly affect the strength, reliability, and safety of the product. Modern quality control not only measures the finished product but also the commitment to environmentally friendly processes (Pasaribu et al., 2025). In the metal engineering industry, such as LPG tanks, Quality Control (QC) includes material inspection, NDT (RT, UT, MT), and hydrotesting to prevent structural failure.

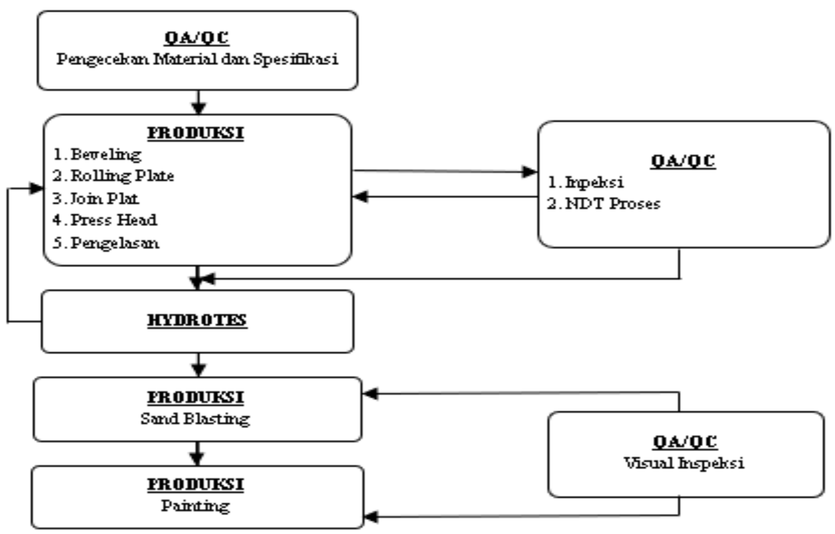


Figure 1.2 QC Process Flow
Source: QA/QC Production Flow

The main welding defects include incomplete fusion (IF), porosity (POR), inclusion (INC), and root undercut (RU) due to unstable WPS parameters (Armijal et al., 2023). Table 1.1 (Defect Types per Process) identifies potential defects in beveling (overcut), rolling (inappropriate diameter), and welding (slag inclusion).

Table: 1.1 Explanation of Production in the QC Department

No	Production Type	Explanation	Defect Type
1.	Beveling	Forming angles on plate edges to prepare for welding	1. Bavel angles are not correct (too large/small), 2. Rough surface, 3. Overcut or under bevel occurs
2.	Rolling Plat	The plate into a cylinder according to the tank diameter	1. Incorrect diameter 2. Uneven curvature 3. Cracks due to excessive pressure
3.	Plate Joining	Joining two or more plates before welding	1. Misalignment between plates 2. Gap too wide/narrow 3. Surfaces not parallel
4.	Press Head	Forming the tank head (*end cap* or *head plate)*	1. Asymmetrical shape 2. Cracks during pressing 3. Uneven thickness
5	Welding	Connecting tank parts into a single unit	1. Welding defects such as porosity, crack, undercut, incomplete fusion, slag inclusion 2. Does not meet WPS standards

The Six Sigma method is a quality control approach that focuses on reducing process variation with the aim of achieving a very low defect rate. Six Sigma uses performance indicators such as Defects Per Million Opportunities (DPMO) and sigma levels to quantitatively measure process capability. The higher the sigma level, the lower the likelihood of defects occurring in the production process, resulting in more consistent and controlled product quality.

Previous studies have shown that the application of the Six Sigma method in the welding process can significantly reduce defect rates and improve production process stability. Root cause analysis of defects conducted using Pareto charts and cause-and-effect diagrams enables companies to identify the main factors that most influence the occurrence of defects. Thus, improvement efforts can be focused on the most critical aspects, so that company resources can be utilised more effectively and efficiently.

Sigma level z (z score)	Probability That An Item Is Nonconforming (Number Of Nonconforming Per Item)	Number Of Nonconforming Per Million Items
2 σ 0.308770168	0.308770168	308,770.168
2,5 σ	0.158686925	158,686.925
3 σ	0.066810599	66,810.599
3,5 σ	0.022750419	22,750.419
4 σ	0.006209684	6,209.684
4,5 σ	0.001349899	1,349.899
5 σ	0.000232629	232.629
5,5 σ	0.000031671	31.671
6 σ	0.000003398	3.398

Source: Terek, M. (2023)

The analysis stage is used to identify the root causes pf problems using Pareto and Fishbone diagrams, which, according to research, are used to determine the sourceof problem by illustrating cause and effect relationship (Arief & Faritsy, 2025).

Conceptual Framework

The conceptual framework of this study describes the line of thinking in analysing the quality issues of the welding process at PT Metal Hitech Engineering. The main issue that is the focus of this study is the high level of welding defects identified through the results of Radiographic Tests (RT) in 2024 and 2025, with the dominant types of defects being porosity, inclusion, incomplete fusion, incomplete penetration, root undercut, and cracks. These conditions indicate uncontrolled process variations that have an impact on increased rework activities and production costs.

To address these issues, this study utilised the Six Sigma approach with DMAIC stages. The Define and Measure stages were used to identify critical quality characteristics (CTQ) and measure process performance through DPMO values and sigma levels. The Analyse stage was conducted to identify the root causes of defects, while the Improve stage focused on developing process improvement proposals. Furthermore, the Control stage aims to ensure that improvements are consistent and sustainable. Through the application of Six Sigma, it is expected that welding quality and process capability will improve significantly.

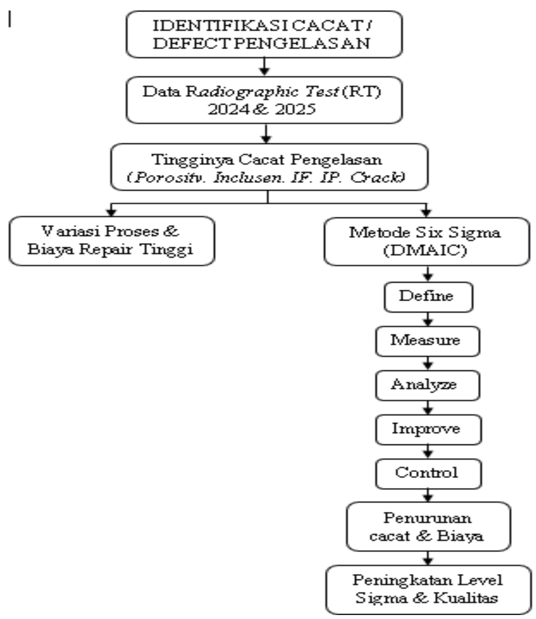


Figure 1.1 Conceptual Framework

C. RESEARCH METHODOLOGY

This study employs a descriptive method with a qualitative approach to obtain an in-depth description of the actual conditions and processes occurring in the field. This approach was chosen because it allows researchers to explore phenomena directly in their actual context. According to Sugiyono (2010:1), qualitative research is a research method used to study natural conditions (as opposed to experiments) where the researcher is the key instrument, data collection techniques are triangulated (combined), data analysis is inductive, and qualitative research results emphasise meaning rather than generalisation.

Considering these characteristics, a qualitative approach is considered appropriate for this study because the dynamics of the work process, communication flow, and quality control practices in the company can only be fully understood through direct involvement, either through observation or through interviews with relevant parties. This research was conducted at PT MHE Gresik using purposive sampling: Informant 1 (Operations Manager), Informant 2 (QA/QC), Informant 3 (Welder). Primary data: semi-structured interviews, observation; secondary data: RT 2024 (467 defects), 2025 (301 defects). Miles & Huberman analysis (reduction→display→conclusion) integrated with DMAIC. Validity: source triangulation + member check.

D. RESULTS AND DISCUSSION
RESULTS
Research Location Profile

PT. Metal Hitech Engineering is a company engaged in manufacturing, specifically in the manufacture of pressure vessels, LPG cylinders, and car bodies to support the needs of the energy, oil and gas, and transportation industries. The company was established in 2007 as a result of the merger between two companies, namely PT. Metal Hitech Engineering (MHE) and PT. Geluran Adikarya. At the time of its establishment, the company's operational activities were carried out at Jl. Sadang Indah Timur Industri No. 8-9, Sadang, Sidoarjo Regency. The company's main focus at that time was to produce various steel-based components to meet the needs of medium to large-scale industrial construction.

In February 2008, PT. Metal Hitech Engineering decided to separate from PT. Geluran Adikarya and establish itself as an independent business entity. The company then built a new head office located at Jl. Darmo Baru Barat III/31, Surabaya. PT. Metal Hitech Engineering is professionally managed as a family business by Mr. Michael Subhakti Sutjitra, who is also the founder and majority shareholder in the company's ownership structure.

In the same year, the company established a production workshop located at Jl. Raya Cerme Metatu Km. 4, Cerme District, Gresik Regency. This location has been the centre of its main production operations to date, including fabrication, assembly, and quality control processes. Its main products include transport tanks and storage tanks, made from materials such as aluminium, stainless steel, and carbon steel. The production system is job order-based. Its customers come from the gas station, LPG, and other industries that require high-quality products that meet standards.

The DMAIC stages in Six Sigma
1. Define stage
a.) Identification of Critical to Quality (CTQ)

In the welding process, various factors affect the quality of the welding process (CTQ), with weld defects being one of the main indicators. Based on Radiographic Test (RT) data and PT. MHE QC reports, the types of defects that significantly affect the quality of welded joints in tank fabrication have been identified.

Table 4.1 Identification of CTQ

Critical to Quality	Potential CTQ (Type of defect)	Description
(Zero Defect)	*Incomplete Fusion* (IF)	Welding defects that occur when the weld metal does not fuse perfectly with the base metal or between weld layers. This results in small gaps in the joint area.
	Incomplete Penetration (IP)	A condition where the weld penetration does not reach the root of the joint. The weld only sticks to the surface, but does not fuse completely on the inside.
	Root Concavity (RC)	A defect that occurs at the root of the joint, when the weld metal sinks (concave) from what should be a flat line.
	Root Undercut (RUC),	A defect in the form of an elongated depression along the root of the weld due to erosion of the base metal caused by heat or incorrect welding techniques.
	Porosity (POR),	A defect in the form of cavities or small holes (gas entrapment) that form in the weld metal when gas cannot escape before the metal solidifies.
	Inclusion (INC)	A defect when foreign matter is trapped in the weld metal, such as slag, oxides, or other non-metallic particles.
	Crack (CRK).	Defects in the form of cracks in the weld metal or base metal that are very critical. Cracks can be longitudinal, transverse, or hot/cold cracks.

From the CTQ table above, it is possible to conclude the type of defect in the welding process. Next, the researcher sought information and obtained data on welding defects for the annual period using the NDT testing method, namely the radiography test process. The data obtained was on welding in 2024 and 2025:

Table 4.2 Welding Process Defect Data for 2024

Month	Output	Defect Qty	Defect Type (Poin)				
			Incomplete Fusion	Incomplete Penetration	Root Undercut	Porosity	Inclusion
1	192	20	-	-	1	7	12
2	732	30	-	-	-	13	17
3	740	38	1	-	-	18	19
6	379	35	2	-	-	7	26
7	359	15	2	3	-	1	9
8	388	30	10	-	-	8	12
9	618	102	4	3	-	15	80
10	1460	70	17	-	-	23	30
11	956	68	7	-	1	18	42
12	575	59	16	-	-	18	25
Total	6399	467	59	6	2	128	272
Percentage			12,63%	1,28%	0,43%	27,40%	58,24%

Source: NDT results, 2024

Table 4.3 Welding Process Defect Data for 2025

Month	Output	Defect Qty	Defect Type (Poin)			
			Incomplete Fusion	Root Undercut	Porosity	Inclusion
1	184	12	1	-	4	7
2	186	14	1	-	3	10
5	187	15	8	-	5	2
6	744	56	3	-	17	36
7	1671	109	8	-	46	55
8	368	24	1	-	19	4
9	194	22	-	-	18	4
10	193	21	7	-	8	6
11	200	28	5	1	10	12
Total	3927	301	34	1	130	136
Percentage			11,30%	0,33%	43,19%	45,18%

Source: NDT results, 2025

Based on the results of the RT inspection, the welding process at PT Metal Hitech Engineering in 2024 recorded a total of 467 defects from 6,399 outputs, with Inclusion (58.24%) and Porosity (27.40%) as the most dominant types of defects, followed by Incomplete Fusion, Root Undercut, and Incomplete Penetration in much smaller proportions. This indicates that more than 85% of the total defects in 2024 were concentrated in Inclusion and Porosity, reflecting significant problems related to welding cleanliness, consumable control, and process parameters. In 2025, an improvement trend is observed with total defects reduced to 301 points from 3,927 outputs, although Inclusion (45.18%) and Porosity (43.19%) remain the main contributors to defects. The relative decrease in total defects indicates that partial corrective actions may have been implemented, but the persistence of the same dominant defect types suggests that the root causes have not been fully eliminated. Therefore, the combined dominance of

Inclusion and Porosity in both years (>85%) justifies their prioritisation in the Pareto analysis during the Analyse–Improve stage of DMAIC to achieve more effective and sustainable quality improvements.

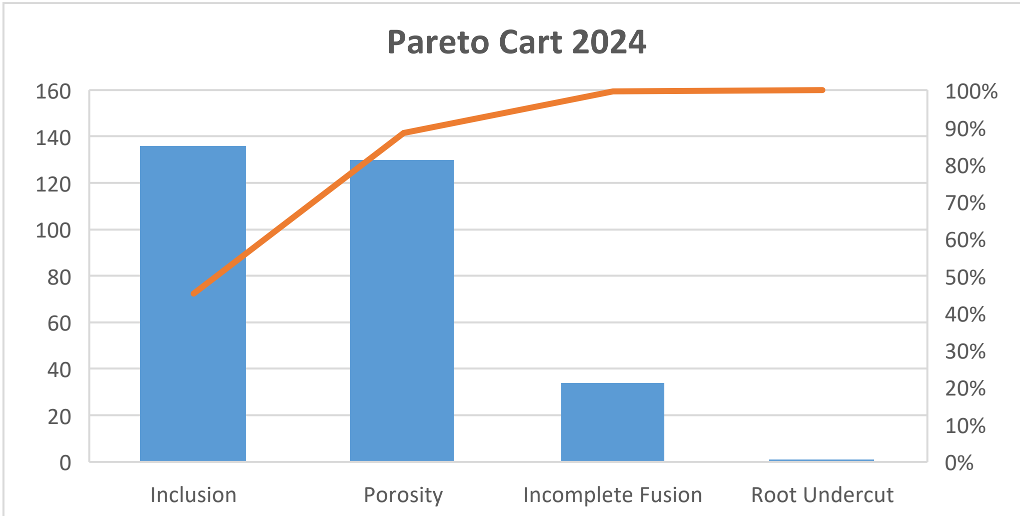


Figure 4.2 Pareto Diagram 2024

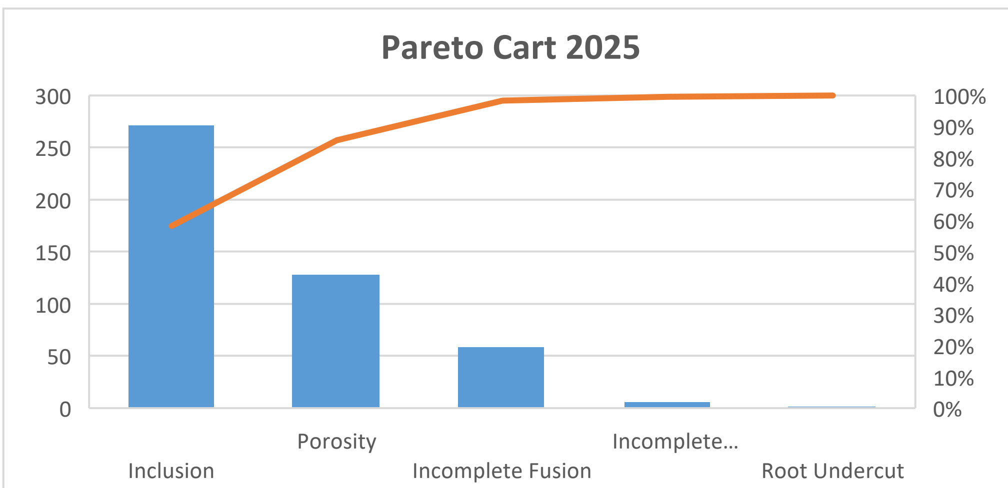


Figure 4.3 Pareto Diagram 2025

b.) SIPOC Diagram

The purpose of designing a SIPOC diagram is to understand the welding process flow from the supplier to the end recipient. The warehouse provides the materials, which are then pre-cut according to standards, after which the fitters carry out assembly and fit-up. The welder performs welding according to the parameters. The weld results are tested by NDT through radiography, analysed by the QC Inspector, and repaired if there are defects. The final stage is final fabrication before being submitted to the Project Engineer.

Tabel 4.4: Diagram SIPOC

Supplier	Input	Process	Output	Customer
Shop / Warehouse	Welding materials (welding wire, flux), material transport reports	Handling of cut materials	Material pre-cut & data traceability	Pre-cut Supervisor
Pre-cut Supervisor	Base metal, cutting report	Cutting process	Plate/pipe that has been cut to size	Fitter
Fitter	Metal components, cover plates	Fit-up / assembly	Fit-up results worth checking	Welder
Welder	Joint fit-up, welding machine, welding parameters	Welding Process	Weldment (initial welding results)	NDT Agency
NDT Agency	Weldment	NDT Testing (Radiography/RT)	Radiography films & test result reports	QC Inspector
QC Inspector	Radiography films & test reports	Welding quality inspection	Identification of welding defects & repair recommendations	Production Department
Production Department	List of welding defects & repair areas	Repair welding	Repaired weldment	Final Fabrication
Final Fabrication Team	Flaw-free weldment	Finishing / clean-up	Final product with a smooth surface	Project Engineer

2. Measurement Stage

a.) Process Stability Measurement

The application of the C-Chart control chart in this study was carried out on welding defect data for tanks during a specific observation period at PT Metal Hitech Engineering. The defect data was used to determine the upper control limit (Upper Control Limit), lower control limit (Lower Control Limit), and centre line (Center Line) to assess whether the welding process was stable or experiencing uncontrolled variations. A summary of the number of defects as the basis for calculating the control limits is presented in the figure below.

Table 4.5 Stability Measurements for 2024

Month	Incomplete Fusion	Incomplete Penetration	Root Undercut	Porosity	Inclusion	Number of Defect Points	Radio Graphy Test Results	Sample Test
January	-	-	1	7	12	20	192	1
February	-	-	-	13	17	30	732	3
March	1	-	-	18	19	38	740	3
June	2	-	-	7	26	35	379	2
July	2	3	-	1	9	15	359	2
August	10	-	-	8	12	30	388	1
September	4	3	-	15	80	102	618	3
October	17	-	-	23	30	70	1460	7
November	7	-	1	18	42	68	956	3
December	16	-	-	18	25	59	575	3
Total	59	6	2	128	272	467	6399	28

Source: Author's Data Analysis, 2024

Table 4.6 Stability Measurements for 2025

Month	Incomplete Fusion	Root Undercut	Porosity	Inclusion	Total Defect	Radio Graphy Test Results	Sample Test
January	1	-	4	7	12	184	1
February	1	-	3	10	14	186	1
May	8	-	5	2	15	187	1
June	3	-	17	36	56	744	4
July	8	-	46	55	109	1671	9
August	1	-	19	4	24	368	2
September	-	-	18	4	22	194	1
October	7	-	8	6	21	193	1
November	5	1	10	12	28	200	2
Total	14	1	107	118	301	3534	22

Source: Author's Data Analysis, 2025

Steps to create a C-Chart:

1.) Determining the Central Line (CL) Value

Year 2024:

CL = C¯ $= \frac{\sum Di}{m}$

$= \frac{467}{28}$ = 16,679

Year 2025:

CL = C¯ $= \frac{\sum Di}{m}$

$= \frac{301}{22}$ = 13,682

2.) Determining the Upper Control Limit (UCL)

Year 2024

UCL = C¯ + 3√ C¯

= 16,679 + 3√16,679

= 16,679 + 12,252 = 28,931

Year 2025

UCL = C¯ + 3√C¯

= 13,682 + 3√13,682

= 13,682 + 11,097 = 50,65

Determining the Lower Limit of Control (LCL)

Year 2024

LCL = C¯−3√C¯

= 16,679 - 3√16,679

= 16,679– 12,252 = 4,427

Year 2025

LCL = C¯−3√C¯

= 13,682 - 3√13,682

= 13,682 – 11,097 = 2,585

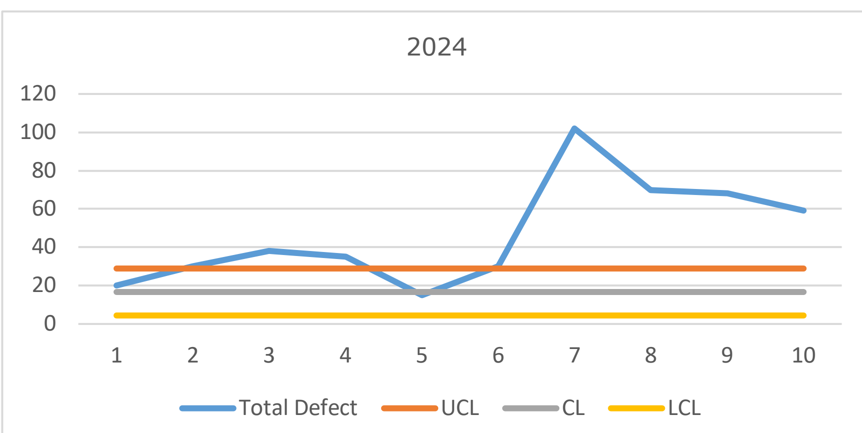


Figure 4.4 P Chart Diagram

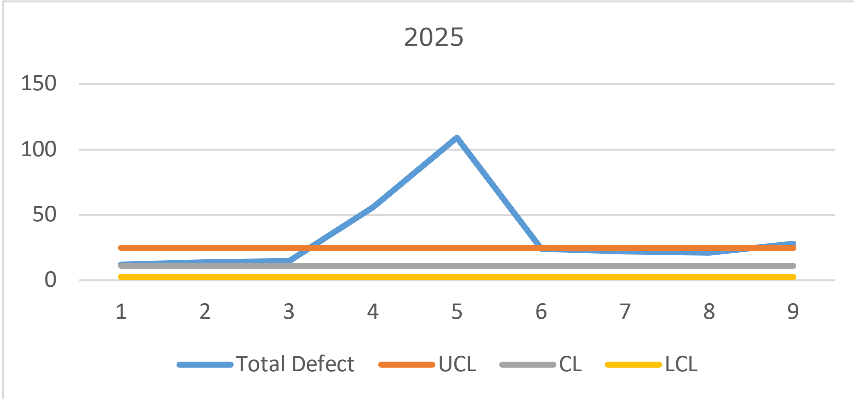


Figure 4.5 P Chart Diagram

Based on welding defect data, a C-Chart control chart was compiled by determining the Central Line (CL) value as the average number of defects per period. In 2024, the CL value was 16.679, with an upper control limit (UCL) of 28.931 and a lower control limit (LCL) of 4.427. Meanwhile, in 2025, the CL value decreased to 13.682, with a UCL of 24.779 and an LCL of 2.585. The decrease in the CL value in 2025 indicates a reduction in the average number of welding defects compared to the previous year. This indicates an improvement in welding process performance and a statistically more controlled level of process variation.

b.) Process Capability Measurement

Welding process capability measurement is carried out by calculating DPMO to determine the defect rate relative to the defect probability. The DPMO value is then converted into a sigma level to assess the process's ability to produce products that meet quality standards, as presented in Table 5 as the basis for Six Sigma analysis.

Table 4.7 Stability Measurements for 2024

Month	Number of Defect	Radio Graphy Test Results	DPO	DPMO	Sigma Level	
1	20	192	0,010417	10416,66667	989583	3,8
2	30	732	0,004098	4098,360656	995902	4,1
3	38	740	0,005135	5135,135135	994865	4,0
6	35	379	0,009235	9234,828496	990765	3,8
7	15	359	0,004178	4178,272981	995822	4,1
8	30	388	0,007732	7731,958763	992268	3,9
9	102	618	0,016505	16504,85437	983495	3,6
10	70	1460	0,005993	5993,150685	994007	4,0
11	68	956	0,008891	8891,213389	991109	3,8
12	59	575	0,012826	12826,08696	987174	3,7
Total	**467**	**6399**	**Average**	**8.501,05**		**3,94**

Source: Author's Data Analysis, 2024

Table 4.8 Stability Measurements for 2025

Month	Number of Defect	Radio Graphy Test Results	DPO	DPMO	Sigma Level	
1	12	184	0,007246	7246,37681	992754	4,0
2	14	186	0,008363	8363,20191	991637	3,9
5	15	187	0,008913	8912,65597	991087	4,0
6	56	744	0,008363	8363,20191	991637	3,9
7	109	1671	0,007248	7247,82233	992752	4,0
8	24	368	0,007246	7246,37681	992754	3,9
9	22	194	0,0126	12600,2291	987400	4,0
10	21	193	0,01209	12089,81	987910	3,9
11	28	200	0,008363	8363,20191	991637	4,0
Total	**301**	**3927**	**Average**	**8.936,99**		**3,84**

Source: Author's Data Analysis, 2025

Based on the table above, in 2024 there were 467 defects from 6,399 RT results with an average DPMO of 8,501.05 and a Sigma Level of 3.94, indicating moderate process capability but still in need of improvement. In 2025, there were 301 defects from 3,927 RTs with a DPMO of 8,936.99 and a Sigma Level of 3.84, indicating a decline in capability, thus requiring continuous improvement based on Six Sigma.

c.) Calculation of DPO and DPMO Values

Year 2024

DPO $= \frac{Total\ Defect}{Unit\ yang\ diProduksi\ x\ CTQ}$

$= \frac{467}{6399\ x\ 10}$ = 0,007298

DPMO =DPO x 1.000.000

DPMO =0,007298 x 1.000.000 = 7.298

Year 2025

DPO $= \frac{Total\ Defect}{Unit\ yang\ diProduksi\ x\ CTQ}$

$= \frac{301}{3927\ x\ 9}$ = 0,008516

DPMO = DPO x 1.000.000

DPMO = 0,008516 x 1.000.000 = 8.516

d.) Sigma Value Calculation

Level Sigma = Normsinv $(\frac{1000000-DPMO}{1000000})$ + 1,5

Year 2024

Level Sigma = Normsinv $(\frac{1000000-DPMO}{1000000})$ + 1,5

Level Sigma **=** Normsinv $(\frac{1000000-7298}{1000000})$ + 1,5

Level Sigma = Normsinv (0,992702) + 1,5

= 3,94225

Year 2025

Level Sigma = Normsinv $(\frac{1000000-DPMO}{1000000})$ + 1,5

Level Sigma = Normsinv $(\frac{1000000-DPMO}{1000000})$ + 1,5

Level Sigma = Normsinv (0,991439) + 1,5

= 3,88601

3. Tahapan *Analyse* (Identifying Defects with Cause-and-Effect Diagrams)

Analyse is a process whereby efforts are made to understand the reasons that cause problems to occur (root cause). This process will show how tank defects, particularly defects such as incomplete fusion, incomplete penetration, root undercut, porosity, and inclusion, occur in the welding process using the cause and effect method.

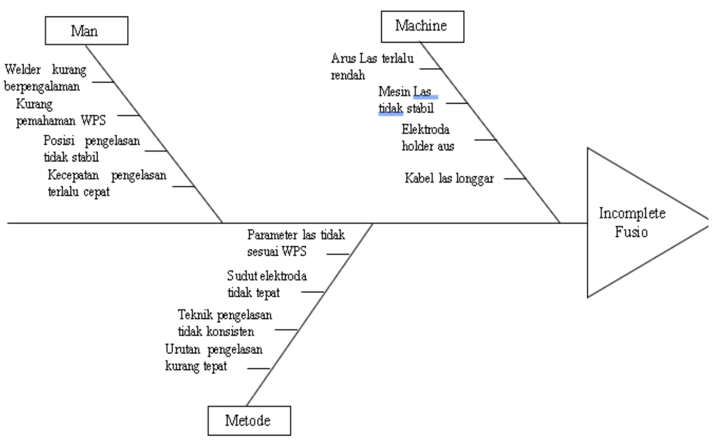


Figure 4.4 Diagram Fishbone Incomplete Fusion

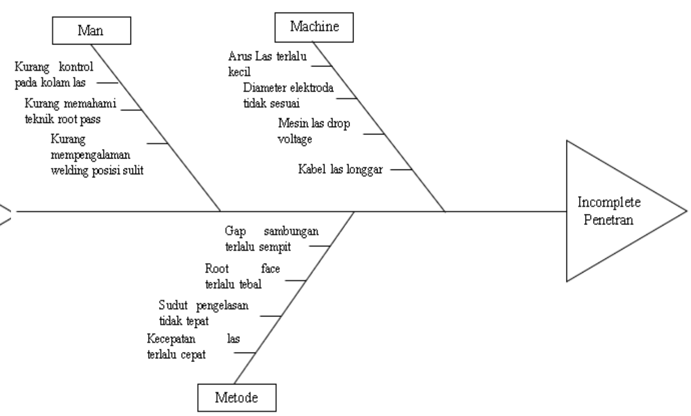
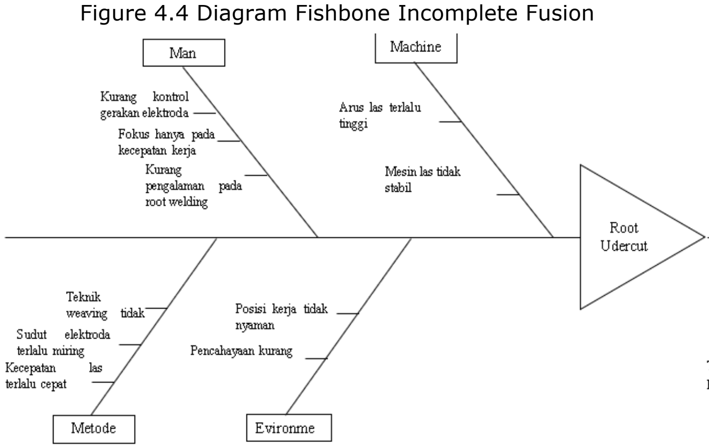


Figure 4.5 Diagram Fishbone Incomplete Penetran



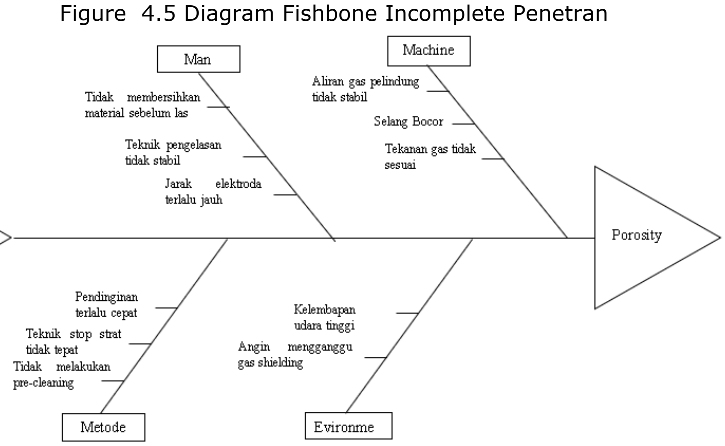


Figure 4.6 Diagram Fishbone Root Undercut

Figure 4.7 Diagram Fishbone Porosity

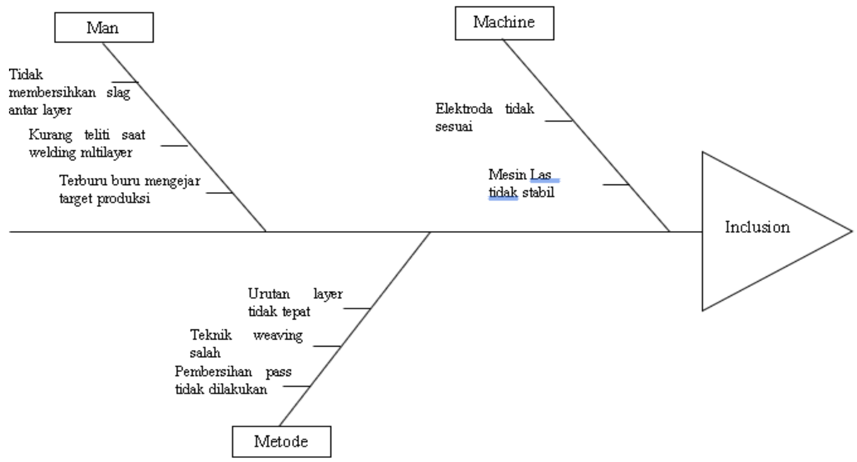


Figure 4.8 Diagram Fishbone Inclusion

4. Improvement Stages

a.) Based on the Results of the Ishikawa Diagram

Improvements are focused on increasing welder competence through RT-oriented training, strengthening WPS supervision, stabilising machines and protective gases, implementing preventive maintenance, standardising work methods, and controlling the welding environment in order to reduce dominant defects such as inclusions and porosity.

b.) Continuous Improvement Based on Sigma Level

Based on DPMO calculations, the quality performance of the welding process at PT Metal Hitech Engineering shows variation in each observation period. Through the Six Sigma approach, the company targets an increase in process capability towards sigma level 4 with a standard of 6,210 DPMO, as well as a long-term aspiration to reach sigma level 4.5 with a standard of 1,350 DPMO.

c.) Interp mprovement Interpolation to the Next Sigma Level

Year 2024

$$\text{DPMO} = \frac{Number\ of\ Defect}{Units\ Produced\ x\ CTQ} \text{ x } 1.000.000$$

$$6.210 = \frac{Number\ of\ Defect}{6399\ x\ 10} \text{ x } 1.000.000$$

$$6.210 = \frac{Number\ of\ defect}{63990} \text{ x } 1.000.000$$

397.377.900 = Number of Defect x 1.000.000

Number of Defects Based on Interpolation

= 397,3779 ~ 397 Welding Points

Actual number of defects = 467 welding points

Difference = 467 – 397 = 70 Welding Points

Therefore, PT. MHE must reduce by 70 Welding Defect Points in order to achieve a sigma 4 rating

Year 2025

$$\text{DPMO} = \frac{Number\ of\ Defect}{Units\ Produced\ x\ CTQ} \text{ x } 1.000.000$$

$$6.210 = \frac{Number\ of\ Defect}{3733\ x\ 9} \text{ x } 1.000.000$$

$$6.210 = \frac{Number\ of\ Defect}{33597} \text{ x } 1.000.000$$

208.637.370 = Number of Defect x 1.000.000

Number of Defects Based on Interpolation

= 208,6373 ~ 208 Welding Points

Actual number of defects = 301 welding points

Difference = 301 – 208 = 93 Welding Points

Therefore, PT. MHE must reduce by 93 Welding Defect Points in order to achieve a sigma 4 rating

d.) Interpolasi Perbaikan ke Level Sigma Tingkat Lanjut

Year 2024

$$\text{DPMO} = \frac{Number\ of\ Defect}{Units\ Produced\ x\ CTQ} \text{ x } 1.000.000$$

$$1.350 = \frac{Number\ of\ Defect}{6399\ x\ 10} \text{ x } 1.000.000$$

$$1.350 = \frac{Number\ of\ defect}{63990} \text{ x } 1.000.000$$

86.386.500 = Number of Defect x 1.000.000

Number of Defects Based on Interpolation

Year 2025

$$\text{DPMO} = \frac{Number\ of\ Defect}{Units\ Produced\ x\ CTQ} \text{ x } 1.000.000$$

$$1.350 = \frac{Number\ of\ Defect}{3733\ x\ 9} \text{ x } 1.000.000$$

$$1.350 = \frac{Number\ of\ Defect}{33597} \text{ x } 1.000.000$$

45.355.950 = Number of Defect x 1.000.000

Number of Defects Based on Interpolation

= 86,386 ~ 86 Welding Points
Actual number of defects = 467 Welding Points
Difference = 467 – 86 = 381 Welding Points
Therefore, PT. MHE must reduce by 381 Welding Defect Points in order to achieve a sigma 4,5 rating

= 45,3556 ~ 45 Welding Points
Actual number of defects = 301 Welding Points
Difference = 301 – 45 = 256 Welding Points
Therefore, PT. MHE must reduce by 256 Welding Defect Points in order to achieve a sigma 4,5 rating

e.) Sigma Level Interpolation with Operational Costs

Table 4.13 Cost Calculation for 2024

Month	Defect Qty	Price / Film	NDT	Price PT. MHE	Number	Overall Total
January	20	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 31.200.000
February	30	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 46.800.000
March	38	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 59.280.000
June	35	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 54.600.000
July	15	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 23.400.000
August	30	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 46.800.000
September	102	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 159.120.000
October	70	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 109.200.000
November	68	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 106.080.000
December	59	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 92.040.000
Total	467					Rp 728.520.000

Source: Author's Data Analysis, 2025

Table 4.14 Cost Calculation for 2025

Month	Defect Qty	Price / Film	NDT	Price PT. MHE	Number	Overall Total
January	12	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 18.720.000
February	14	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 21.840.000
May	15	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 23.400.000
June	56	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 87.360.000
July	109	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 170.040.000
August	24	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 37.440.000
September	22	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 34.320.000
October	21	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 32.760.000
November	28	Rp 60.000	Rp 1.000.000	Rp 500.000	Rp 1.560.000	Rp 43.680.000
Total	301					Rp 469.560.000

Source: Author's Data Analysis, 2025

In 2024, PT Metal Hitech Engineering incurred repair costs of Rp 728,520,000 due to 467 defects (Rp 1,560,000/defect), with a spike in September–November. In 2025, defects decreased to 301 points with a cost of IDR 469,560,000, resulting in savings of IDR 258,960,000. At a sigma level of around 3, costs are still high, so an increase to sigma 4 has the potential to significantly reduce repair costs.

Table 4.15 Sigma Level 4 Repair Costs for 2024

Before(Level Sigma 3,94)	After (Level Sigma 4)
Biaya = Number of Defects x Repair Cost Biaya = 467 x 1.560.000/defect Biaya = 728.520.000	Biaya = Number of Defects x Repair Cost Biaya = 397 x 1.560.000/defect Biaya = 619.320.000

Source: Author's Data Analysis, 2025

Table 4.16 Sigma Level 4 Repair Costs for 2025

Before (Level Sigma 3,84)	After (Level Sigma 4)
Biaya = Number of Defects x Repair Cost Biaya = 301 x 1.560.000/defect Biaya = 469.560.000	Biaya = Number of Defects x Repair Cost Biaya = 208 x 1.560.000/defect Biaya = 324.480.000

Source: Author's Data Analysis, 2025

Table 4.17 Sigma Level 4,5 Repair Costs for 2024

Sebelum (Level Sigma 3,94)	Sesudah (Level Sigma 4,5)
Biaya = Number of Defects x Repair Cost Biaya = 467 x 1.560.000/defect Biaya = 728.520.000	Biaya = Number of Defects x Repair Cost Biaya = 86 x 1.560.000/defect Biaya = 134.1600.000

Source: Author's Data Analysis, 2025

Table 4.18 Sigma Level 4,5 Repair Costs for 2025

Sebelum (Level Sigma 3,84)	Sesudah (Level Sigma 4,5)
Biaya = Number of Defects x Repair Cost Biaya = 301 x 1.560.000/defect Biaya = 469.560.000	Biaya = Number of Defects x Repair Cost Biaya = 45 x 1.560.000/defect Biaya = 70.200.000

Source: Author's Data Analysis, 2025

Based on Tables 4.15–4.18, the implementation of Six Sigma has the potential to significantly reduce repair costs. In 2024, costs of 728,520,000 (467 defects; sigma 3.94) could be reduced to 619,320,000 at sigma 4 and 134,160,000 at sigma 4.5. In 2025, the cost of 324,480 (sigma 4) and 70,200 (sigma 4.5) could potentially be reduced from 469,560 (301 defects; sigma 3.84), demonstrating substantial cost efficiency.

5. Control Stage

The Control stage aims to ensure that improvements made during the Improve stage are maintained consistently to prevent a recurrence of welding defects. Control is carried out through continuous monitoring of Radiographic Test (RT) results as the main indicator for evaluating defect trends and the effectiveness of improvements. The estimated cost of improvements is used to assess the cost efficiency gained from the reduction in defects. In addition, welder performance is evaluated, the role of Quality Control during the process is strengthened, and welding SOPs are standardised and documented. With structured control, quality improvements are expected to be sustainable in accordance with the Six Sigma principle of continuous improvement.

6. Interview Results

The interviews in this study were conducted in a semi-structured manner with three key informants who were directly involved in the welding and quality control processes, namely the Operations Manager, the QA/QC department, and the welder operator. The interview results showed that although the welding quality at PT Metal Hitech Engineering met certain standards, defects were still found both visually and through Radiographic Testing (RT), with the dominant types of defects being incomplete fusion, porosity, and slag inclusion.

According to operational management, the factors causing defects included operator skills, equipment conditions, CO_2 gas settings, and production target pressures that affected work precision. This situation has led to an increase in rework activities, which has implications for production time and costs. The QA/QC department emphasised that quality standards refer to WPS and ASME, and noted that defects tend to recur due to the cleanliness of the welding area, work position, and welder skills. Defect data is used as a basis for evaluation and continuous improvement.

Meanwhile, welder operators stated that the main obstacles stem from gas regulator conditions, machine stability, work position, and operator fatigue. These interview findings indicate that human, method, and equipment factors contribute to process variation, as reflected in the DPMO and sigma level values prior to improvement, making enhanced training and process control a primary need.

Discussion

1. Condition of Tank Defect Levels at PT Metal Hitech Engineering

Based on the processing of quality control data at PT Metal Hitech Engineering, the welding defect rate is still relatively high, with a sigma level of 3.94 in 2024 (467 defects) and 3.84 in 2025 (301 defects). This condition indicates that process performance is in the medium industry category with significant process variation and reactive quality control. A similar phenomenon was also found in similar industries, such as the research by Prasetyo et al. (2022) at PT Galuran and Hidayat and Sari (2021) at PT Aweco, which reported dominant welding defects and sigma levels below 4. Therefore, it is necessary to implement data-based quality control through Six Sigma to close the quality improvement gap, in line with Montgomery's (2020) view.

2. Application of the Six Sigma Method in Reducing Product Defect Rates

The application of Six Sigma in this study was carried out by interpolating the sigma level from the actual condition to a higher target sigma. The measurement results showed that PT MHE was at a sigma level of 3.94 in 2024 and 3.84 in 2025, which was then interpolated to a target sigma level of 4 and 4.5 to estimate the potential reduction in defects. According to Milan Tarek (2023), sigma level 4 is equivalent to 6,210 DPMO and sigma level 4.5 is around 1,350 DPMO. Based on these standards, PT MHE needs to reduce defects to 397 and 86 points in 2024, and 208 and 45 points in 2025. This approach is in line with Kumar et al. (2021), who proved that an increase in sigma level

3. Comparison of Defect Rates and Operational Costs Before and After Improvement

A comparison of conditions before and after improvement shows a significant reduction in defect rates and operational costs. In 2024, a sigma level of 3.94 resulted in 467 defects at a cost of Rp 728,520,000; simulation of an increase to sigma 4 reduced this to 397 defects (Rp 619,320,000), and to sigma 4.5 to 86 defects (Rp 134,160,000). In 2025, sigma level 3.84 resulted in 301 defects at a cost of Rp 469,560,000; an increase to sigma 4 reduces defects to 208 (Rp 324,480,000), and to sigma 4.5 to 45 defects (Rp 70,200,000). These results are in line with Susanto et al. (2022) at PT Meco, who reported a reduction in rework costs of more than 60%, confirming that Six Sigma effectively improves quality and production cost efficiency.

E. Conclusion

Based on the results of research on welding quality control at PT Metal Hitech Engineering using the Six Sigma approach, it can be concluded that the quality control system implemented is still reactive and focused on final inspection, so it is not yet optimal in preventing defects from the early stages of the production process. This is reflected in the recurrence of welding defects such as incomplete fusion, incomplete penetration, porosity, and undercut during the 2024–2025 period.

The process capability measurement results show that the sigma level is in the range of 3.67, which indicates that the welding process still has quite high variation and has not reached optimal capability. Control chart analysis shows that the process is relatively statistically controlled, but there are several points that are close to the upper control limit, which could potentially cause process instability. Identification of the causes of defects through a fishbone diagram shows that defects are influenced by a combination of human, method, machine, material, and work environment factors. The implementation of the Analyse and Improve stages in DMAIC has proven to reduce the number of defects, increase the sigma level to close to level 4, and reduce repair costs. Thus, the systematic application of Six Sigma not only improves the quality of welding results but also provides economic benefits and supports the company's operational efficiency.

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