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Research Article

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Innovation and technology improvement of hydrant pillar welding process to decrease defect ratio approach to DMAIC methodology, case in small and medium industries (SMIs) in Indonesia

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Abstract The objective of this research is to improve welding process and analyze defect caused and criteria in order to decrease cost of defect and cost of rework using enhanced welding technology of SAW (Submerged Arc Welding) automatic welding machine. Successful implementation of these depends on root cause analysis and defect criteria analysis which affecting to quality acceptance requirement and affecting to rework cost also to customer satisfaction, safety standard and financial performance of the organization in this case. Implementing innovation and technology need more investment which could be compare between benefit value non added value or losses by defect and rework cost value. This paper presents an implementation of welding process technology that applied SAW automatic welding machine process. The product object is Hydrant Pillar which according to NFPA (National Fire Protection Association) and ASME (American Society of Mechanical Engineering) standard of mechanical and requirement, also safety requirement that issued by NFPA. This research approach to Six Sigma DMAIC Methodology which focus in CTQ (Critical To Quality) and DPMO (Defect Per Million Opportunity) analysis and includes a review of break event point analysis in technological investment cost compare to actual rework cost, in order to decrease business process cost and get higher profit in addition to achieve customer satisfaction and safety standard requirement, findings of research accomplished via data collecting in fabricator workshop, defect ratio data, standard requirement and interviews with people in engineering and quality division also top management whom approve and sponsoring for investment of this implementation research. This research proved that the benefit of technological innovation improvement in reduce product defect and reduce cost of rework because of defect, the break event point review also indicates that rework cost value is more bigger cost than quality improvement with technological investment.

Keywords Innovation technology, welding process and defect, DMAIC, DPMO, BEP Analysis,

Introduction

Small and Medium Industries (SMIs) could not survive if they don't do any improvement or innovation strategy especially in business model. The SMIs which has limited resources and manpower should be implement the strategy of innovation to keep the sources that is more diverse than the desires of the market and fundamental insights about the external factors compared to prepare all of the resources and capabilities of its own [1].

To maintain competitiveness and sustainability of SMIs required an improvement in innovation and technology implementation. Innovation and applied technology that improve the efficiency and quality of process mean improve quality of final product, it is derived from the value of a business, but the method can be applied in the activities of an organization [2].

SMIs have an important function in many countries. They should be implementing their business to produce high quality product and services to compete and sustain in their business [3].

The involvement of interdependent factors in the process, such as human resources, market conditions and welding machinery, which varies with the type of metals to be welded and the needs of the customer, require the use of advanced and comprehensive system design and inspection. Designers and manufacturing engineers need to know the full potential of all available welding and joining processes so they can make the best selection of potential manufacturing methods. Scientific knowledge, engineering, and training must be more closely integrated into the welding process to compete with other technologies and fulfill its potential requirement. Another important determinant of the future of welding is the drive to improve efficiency and productivity. To make more qualified and competitive products, they must be made faster, cheaper, and better than those of competitors [4].

This research define the flow process mapping for hydrant pillar fabrication which describe overall current state process as per flow process diagram below;

Drawing 1.1 Fabrication Flow Process

Fabrication process of hydrant pillar shown in flow process above. Start from PPIC send the requirement schedule, specification and quantity of product which have been design by engineering and approved by customer. Next process are material preparation, equipment preparation, procedure preparation and manufacturing/fabrication process (cutting, fit up, welding, finishing, testing, painting, packaging also document accomplishment) as per customer requirement and standard requirement.

Literature Review

Implementing innovations may require major organizational changes to evolve from closed to open model innovation. For example, implementing an innovative service could mean making changes to organization structure, employee training programmes and company procedures [5].

Six Sigma provides a generic quantitative approach that applies to any process. For application, it needs to be tailored to the domain of the process through specific measures and analysis. Basically, it is a high performance data driven approach to analyzing root causes of business problems and solving them. It ties the outputs of a business directly to the customer requirements. The name, Six Sigma, derives from a statistical measure of a process's capability to customer specifications. To most managers and practitioners, Six Sigma is synonymous with Define, Measure, Analyze, Improve and Control (DMAIC) methodology and its associated tool kit. Six Sigma also provides an organizational framework by releasing and training process analysis (called Black Belts and Green Belts) who devote undivided attention to process improvement. User organizations have experienced significant savings by using Six Sigma [6].

Sigma is the measurement used to assess process performance and the results of improvement efforts - a way to measure quality. Businesses use sigma to measure quality because it is a standard that reflects the level degree of control over any process to meet the standard of performance established for that process [7].

3rd of 14 Deming view: "Cease dependence on inspection"

Instead of inspecting the product for quality after production, infuse quality at the beginning itself with production quality control, as this will ensure no raw materials are wasted for the sake of quality. All Inspection can do is cull out most of the defective ones, which will be reworked or thrown out. That is too extensive and not satisfactory. Quality comes from relentlessly improving the processes that make the product [8].

The submerged arc welding process, in which the weld and arc zone are submerged by a layer of flux, is the most efficient fusion welding process in plate and structural work such as ship building, bridge building, and pressure vessel fabrication, assuming the work pieces can be properly positioned and the equipment accurately guided. However, when welds must be made out of position or when several short welds are required on many pieces involving frequent moves of the welder or the workpiece, a flexible process such as shielded metal arc welding, gas metal arc welding, or flux cored arc welding should be considered. The optimum process is selected based on a compromise between welding speed (deposition rate), versatility, and portability [4].

Submerged Arc Welding (SAW), or Sub Arc as it's generally referred to, is an unique welding process because there is no visible evidence that a weld is being made. The welding zone is completely shielded by blanket of granular flux. Exposed are eye protection is not normally used since the arc should be completely covered. The welding operator must, however, employee good safety practices to assure protection of the eye and face, by contacting the American welding Society (AWS). Any arc welding process can produce furnes and gases that could be harmful to health. It required to maintain good ventilation in welding area. Use special care in confined apaces. The American Welding Society (AWS) defines Sub-marged Arc Welding (SAW) as follow: "An arc welding process which produces coalescence of metals by healting them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc and molten metal are shielded by a blanket of granular, fusible material in the working pressure is not used, and filter metal is obtained from the electrode and sometimes form a supplemental source (welding rod, lux or metal granules)". This process has been used successfully for years to produce high quality welds in compliance with such code of agencies as: ASME, AWS, API and the American Bureau of shipping. Submerged arc welding has found usage in nearly all industries [9]

Research Methods

The Six Sigma methodology builds on the Six Sigma metric. Six Sigma practitioners measure and assess process performance using DPMO and sigma. They apply the rigorous DMAIC (Define, Measure, Analyze, Improve, Control) methodology to analyze processes in order to root out sources of unacceptable variation, and develop alternatives to eliminate or reduce errors and variation. Once improvements are implemented, controls are put in place to ensure sustained results. Using this DMAIC methodology has netted many organizations significant improvements in product and service quality and profitability over the last several years [7].

Research Frame Work Cycle

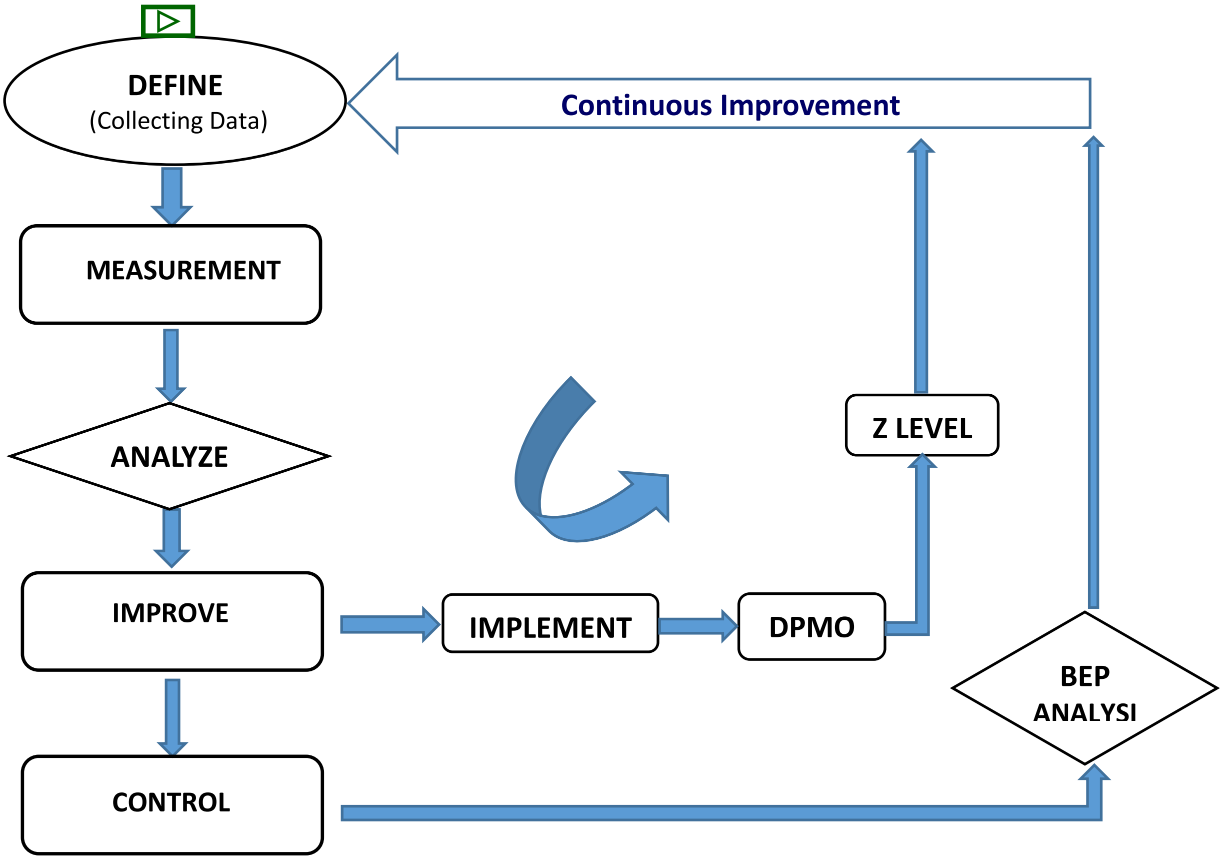

Diagram 1.1 Research Frame Work

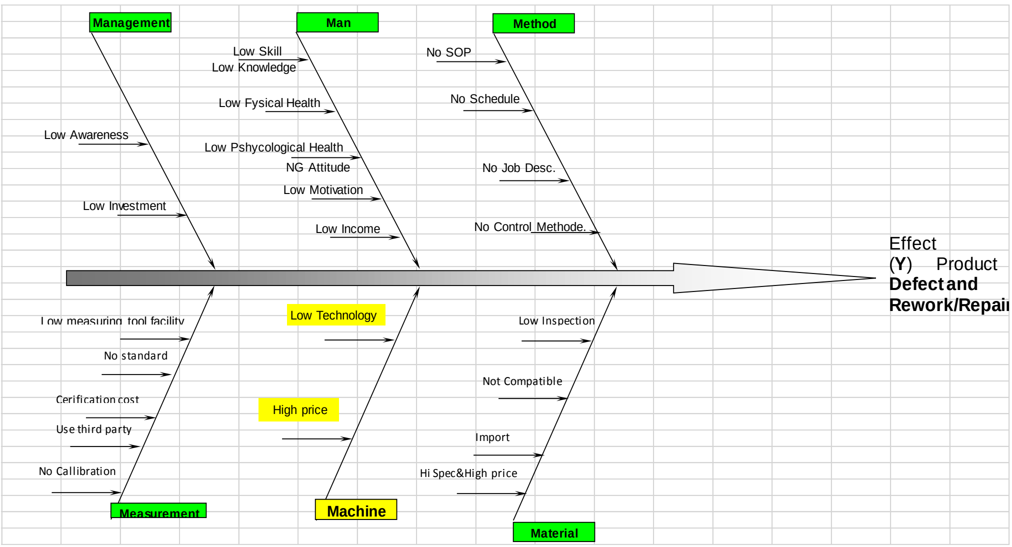

Diagram 1.2 Defect Root cause fish bone diagram

This research approach to Six Sigma methodology that known as DMAIC (Define, Measurement, Analyze, Improve, Control). The flow process of DMAIC tools were reflection of actual condition of the fabrication process and defect potential in the fabrication process especially in welding process lines. We determine the sampling 100 units of Hydrant Pillar which are process use manual welding / welder, and 100 units of Hydrant Pillar use SAW Automatic Welding. From the sampling of both process have any defect quantity which calculate become defect rate ratio then caculate the value of Defect Per Million Opportunity (DPMO) use DPMO calculator and get the Z level of Six Sigma from Z Level table.
The Object of this research issued are defect criteria which have a big affecting Critical To Quality. There are many optional tool for measurement using Non Destructive Test (NDT), in this research limitation of applied NDT referred to NDT requirement as per customer specification and standard examination required and approved by technical association in charge.

Defect Analysis and DMAIC

Define defect – Fishbone Diagram Root Cause of Defect

Root cause fish bone diagram above are explain about major cause of defect in this research that focus in technology innovation that caused to product defect.

Defects can be grouped under three main classifications [10];

Planar Defects: linear from at least one dimension

- Cracks may occur in welded materials are caused generally by many factors and may be classified by shape (Longitudinal, Transverse, Branched, Chevron) and position (HAZ, Centre line, Crater, Fusion zone, Parent metal).
- Solid Inclusion (Loss of gas shield, Damp electrodes, Contamination, Arc length too large, Damaged, electrode flux, Moisture on parent material, Welding current too low, Slag originates from welding flux, MAG and TIG welding, process produce silica inclusions Slag is caused by inadequate cleaning Other inclusions include tungsten and copper Inclusions from the TIG and MAG welding process.
- Slag inclusions are defined as a non-metallic inclusion caused by some welding process.
- Lack of fusion, poor welder skill, incorrect electrode, manipulation, Arc blow, Incorrect welding, current/voltage, incorrect travel speed, Incorrect inter-run cleaning. An imperfection at the toe or root of a weld caused by metal flowing on to the surface of the parent metal without fusing to it
- Overlap; Contamination, Slow travel speed, Incorrect welding technique, Current too low

Linear Volumetric Defects: Linear in length with volume

- Slag lines, • lack of fusion with associated slag, • piping.

Non-planar defects: rounded indications without significant length

- Slag inclusions, • gas pores/blow holes, • other metallic and non-metallic inclusions

Defects which may be detected by visual inspection can be grouped under five headings; Cracks, Lack of solid metals, Lack of fusion, Lack of smoothly blended surfaces, Miscellaneous.
Mechanical damage can be defined as any surface material damage cause during the manufacturing process. This can included damage caused by grinding, hammering, chiselling, chipping, breaking off welded attachments (torn surfaces), using needle guns to compress weld capping runs. A welding inspector should also inspect the parent material for any visible defects. A weld repair may be used to improve weld profiles or extensive metal removal, repairs to fabrication defects are generally easier than repairs to service failures because the repair procedure may be followed. The main problem with repairing a weld is the maintenance of mechanical properties, during the inspection of the removed area prior to welding the inspector must ensure that the defects have been totally removed and the original joint profile has been maintained as close as possible e.g[5].
All the types of defects noted average almost caused by man / welder travelled factor always appears as one of the causes. On the basis that the researcher decided to do improvement by replacing the Man (Welder Manual) using the Automatic Welding Machine SAW (Submerged Arc Welding).

Measurement

Measurement Variable;

1. Incomplete Penetration by Ultrasonic Test (UT),
2. Undercut by Penetrant test & Magnetic Particle Investigation (MPI),
3. Porosity, Crack, pinhole by Radiography Test (RT).

There are many optional tool for measurement using Non Destructive Test (NDT), in this research limitation of applied NDT referred to NDT requirement as per customer specification and standard examination required and approved by technical association in charge.

Table 1.1: Data Collection Plan

Data Collection Plan - Project							
Data		**Operational Definition**					
Metric	**Data Type**	**How Measured**	**Related Info to collect**	**Sampling**	**Date**	**How Recorded**	**Frequency**
1	VISUAL	**PENETRANT TEST**	ASME V NDT	100	2014	VISUAL CAPTURE	100
2	VISUAL	**MAGNETIC PARTICLE INVESTIGATION**	ASME V NDT	100	2014	DISPLAY CAPTURE	100
3	VISUAL	**ULTRASONIC TEST**	ASME V NDT	100	2014	DISPLAY CAPTURE	100
4	VISUAL	**RADIOGRAPHY TEST**	ASME V NDT	100	2014	FILM CAPTURE	100

Analyze

Process A (Manual) V/S Process B (Automatic)

Defect Ratio Average (Between Proses A & B), Defect Per Million Opportunity (DPMO A & B), Define Six Sigma Level A & B,

DPMO & Six Sigma Level Comparison

Table 1.2: DPMO & Z Level Value

PROSES - 1 (MANUAL WELDING GTAW+SMAW)

DPMO Calculator

This template calculates the DPMO using the number of defects.

Total number of units:	100
Number of defects:	26
Opportunities for Error in one unit:	5

DPMO = 52000 Sigma Level= 3.13

PROSES - 2 (AUTOMATIC WELDING GTAW+SAW)

DPMO Calculator

This template calculates the DPMO using the number of defects.

Total number of units:	100
Number of defects:	3
Opportunities for Error in one unit:	5

DPMO = 6000 Sigma Level= 4.00

The table assumes a 1.5 sigma shift because processes tend to exhibit instability of that magnitude over time. In other words, although statistical tables indicate that 3.4 defects / million is achieved when 4.5 process standard deviations (Sigma) are between the mean and the closest specification limit, the target is raised to 6.0 standard deviations to accommodate adverse process shifts over time and still produce only 3.4 defects per million opportunities.

Conversion Calculator

Sigma Conversion Table

DPMO	Sigma Level (With 1.5 Sigma Shift)*	Cpk (Sigma Level / 3) With 1.5 Sigma Shift*
933,200	0.000	0.000
915,450	0.125	0.042
894,400	0.250	0.083
869,700	0.375	0.125
841,300	0.500	0.167
809,200	0.625	0.208
773,400	0.750	0.250
734,050	0.875	0.292
691,500	1.000	0.333
645,650	1.125	0.375
598,700	1.250	0.417
549,750	1.375	0.458
500,000	1.500	0.500
450,250	1.625	0.542
401,300	1.750	0.583
354,350	1.875	0.625
308,500	2.000	0.667
265,950	2.125	0.708
226,600	2.250	0.750
190,800	2.375	0.792
158,700	2.500	0.833
130,300	2.625	0.875
105,600	2.750	0.917
84,550	2.875	0.958
66,800	3.000	1.000

Conversion Calculator

Sigma Conversion Table

DPMO	Sigma Level (With 1.5 Sigma Shift)*	Cpk (Sigma Level / 3) With 1.5 Sigma Shift*
52,100	3.125	1.042
40,100	3.250	1.083
30,400	3.375	1.125
22,700	3.500	1.167
16,800	3.625	1.208
12,200	3.750	1.250
8,800	3.875	1.292
6,200	4.000	1.333
4,350	4.125	1.375
3,000	4.250	1.417
2,050	4.375	1.458
1,300	4.500	1.500
900	4.625	1.542
600	4.750	1.583
400	4.875	1.625
230	5.000	1.667
180	5.125	1.708
130	5.250	1.750
80	5.375	1.792
30	5.500	1.833
23	5.625	1.875
17	5.750	1.917
10	5.875	1.958
3	6.000	2.000

Improve

Invest and use SAW automatic welding machine is the one of the technological innovation that researcher and enterprises approve and sponsored to applied and implementing the research. The financial benefit analysis especially in break event point analysis should be submitted and propose as an organization improvement approval.

Break Event Point (BEP) Analysis

Table 1.3: BEP Analysis

Before Automatic SAW (6 Months); (2nd Semester 2014)

Defect Rate = 25% and Cost of Rework Repair Average at 60% from Cost of Work
Selling Price / Unit = IDR 8.600.000 / Unit

```
Total Sales        = IDR 8.600.000, x 100 Unit                                   = IDR 860.000.000,
Cost       = Material + Work + OH
           = IDR 2.450.000, + IDR 1.850.000, + IDR 900.000, = IDR 5.200.000, / Unit
Total Cost = IDR 5.200.000, x 100 Unit                                           = IDR 520.000.000,-

Re-Work Cost       = 60% x (IDR 1.850.000, + IDR 900.000,) = IDR 1.650.000, / Unit
Total Rework Cost  = IDR 1.650.000, x 25 Unit                                    = IDR   41.250.000,

Rework/Month       = IDR 41.250.000, / 6bulan = IDR 6.875.000, / Month (Losses)

Gross Profit       = IDR 860.000.000, - IDR 520.000.000,                         = IDR 340.000.000,
Net Profit         = Total Sales – (Cost + Rework Cost)
                   = IDR 860.000.000, - (IDR 520.000.000, + IDR 41.250.000,)     = IDR 298.750.000,
ROI                = ( IDR 298.750.000 / IDR 561.250.000, ) x 100%               = 53.23%
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After Automatic SAW (6 Months); (1st Semester 2015)

Defect Rate = 3 % and Cost of Rework Repair Average in 60% from Cost of Work
Selling Price / Unit = IDR 8.600.000 / Unit

```
Total Sales        = IDR 8.600.000, x 100 Unit                                   = IDR 860.000.000,
Cost       = Material + Work + OH
           = IDR 2.450.000, + IDR 1.850.000, + IDR 900.000, = IDR 5.200.000, / Unit
Total Cost         = IDR 5.200.000, x 100 Unit                                   = IDR 520.000.000,-

Re-Work Cost       = 60% x (IDR 1.850.000, + IDR 900.000,) = IDR 1.650.000, / Unit
Total Rework       = IDR 1.650.000, x 3 Unit                                     = IDR     4.950.000,

Rework/Month       = IDR 4.950.000, / 6 bulan = IDR 825.000, / Month (Losses)

Gross Profit       = IDR 860.000.000, - IDR 520.000.000,                         = IDR 340.000.000,
Net Profit         = Total Sales – (Modal + Rework)
                   = IDR. 860.000.000, - (IDR 520.000.000, + IDR 4.950.000,)     = IDR 335.050.000,
ROI                = ( IDR 335.050.000 / IDR 524.950.000, ) x 100%               = 63.83%
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SAW Investment ;

```
SAW Machine complete with Orbital Rotator assy (Krisbow) Total Price                    = IDR 64.800.000,
Gap Profit After-before Improvement = IDR 335.050.000, - IDR 298.750.000, = IDR 39.300.000,(6 Months) = IDR 6.550.000,/Month
BEP Investment     = Investment Cost / Benefit per Month
                   = IDR 64.800.000, / IDR 6.550.000,) = 9.9 Months      = 10 Months Without Additional Expenses
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It mean that the Investment Pay by Benefit of Defect Ratio reduce,

After Month 11th get enjoyment time from benefit of Quality Improvement Value IDR 6.550.000,/Month and Get SAW Machine Value IDR 64.800.000 minus time depreciation cost

Control

To sustaining the quality performance of the process and product it very important have to implementing control strategy and planning also maintenance activity to prevent and sustain the reliability and availability of the equipment and operating procedure standard.

At any point in the course of welding tacking, root pass, filler pass or capping pass, but particularly for the root and cap, a detailed inspection may be required. British Standard BS EN 970 (BS 5289:1976) gives guidance on tools and responsibilities together with sketches of typical defects.

The inspector at this point must:

a. Observe, identify and perhaps record (measure) the features of the weld.

b. Decide whether the weld is acceptable in terms of the particular levels that are permitted; defect levels may be ‘in-house’ or national codes of practice.

When the defect size is in excess of the permitted level then either a concession must be applied for (from a competent person), or the weld rejected.
To create a control plan we should define the process mapping and grouping the task and requirement as per table below;

Table 1.4 : Process Mapping & Control Cycles Plan Requirement

No	Process Mapping & Control Cycles Plan Description	Referred	OTHERS
I.	**DESIGN Phase** ; - Define and Collecting Voice of Customer, - Quality Function Deployment & Failure Mode & Effect Analysis (Confidential), - Design Feature, Design Data and Mechanical Calculation of thickness Under Pressure, - Inspection Test Plan and Measurement Methode Requirement, - Drafting / Drawing in CAD, - Cost & Pricing analysis,	14 Deming's - ASME IX Div.I UG.27-28 ASME V Metric Projection	NFPA 14
II.	**APPROVAL Phase ;** - Vendor Drawing Approval, - Listing & Prepare of Document (SKT legal, Drawing, Material/Mill Certificate, WPS-PQR, Welder Certificate), Kemenaker PNK3 / Skk Migas / EBTKE as per Requirement/Goverment Drawing Approval (Pengesahan Gambar)	NA Government Requirement	
III.	**MATERIAL Requirement Planning ;** - Drawing Analysis and Cutting Plan, - Bill Of material Review, - Spesification code & Requirement Review, - Material Supplier Assesment,	- - ASTM / ASME Sect. I A KPI	API 5L
IV.	**MATERIAL Order ;** - Inquiry (Request For Quotation / RFQ), - Catalog / Certificate document Check, - Price Comparison Analysis, - Negotiation & Purchase Order,	Form ASTM SCM SCM	
V.	**INCOMING Material ;** - Certificate & heat Number Check, - Visual Check (Sharp Edge, Critical Defect, Crack, etc) - Dimension Check (Length, Width, Daigonal, Diameter Outside/Inside, Wall Thickness), - Document Acceptance,	ASTM ASTM ASTM -	ASME B46 ASME B36 ASME B16
VI.	**TOOL PREPARATION ;** - Cutting Tool - Welding Machine - Consumable - Safety Equipment - Welding Rotator Jig	- - ASME Section II C - -	P&F Num.
VII.	**BRAINSTORMING ;** - Meeting & Briefing of Process Plan, - Safety Induction, - Time Schedule and Achieving target, - START Collect Material from Inventory warehouse & Tool preparation on working area,	- - - -	- - - -
VIII	**CUTTING ;** - Marking Material as per Plan Drawing of Cutting Plan dimension, - Cutting Torch check, LPG-O2 Gas Check, Fire Protection check, Safety	Dwg -	- -

	tool Check, clearing area check,	-	-
	- Cutting Process,	-	-
	- Chipping, deburring & grinding sharp edge,	-	-
	- Deliver WIP to next Process,	-	-
	- Cleaning cutting area,		
	SETTING PREPARATION ;		
IX.	- Grinding & Bevelling (Pipe, Cap, Flange & other Fitting),	ASME IX	WPS
	- Deliver WIP to Setting Area,	-	-
	SETTING ;		
	- Assy Main StandPipe to Cap setting to Weld,	ASME IX	WPS
	- Assy Base WNRF Flange setting to Weld,	ASME IX	WPS
X.	- Assy Outlet Pipe to SOFR Flange setting to Weld,	ASME IX	WPS
	- Assy Outlet Pipe to Main standpipe setting to Weld,	ASME IX	WPS
	- Deliver to Welding Area,	ASME IX	WPS
	- Cleaning Setting area,	-	-
	WELDING ;		
	- Weld Main StandPipe to Cap (RFC),	ASME IX	WPS
	- Weld Base WNRF Flange (RFC),	ASME IX	WPS
XI.	- Weld Outlet Pipe to SOFR Flange (RFC),	ASME IX	WPS
	- Weld Outlet Pipe to Main standpipe (RFC),	ASME IX	WPS
	- Finishing and cleaning HAZ & Cleaning Preheater,	ASME IX	WPS
	- Deliver to Inspection & Testing ,	-	-
	- Cleaning Welding area,	-	-
	INSPECTION & TESTING – NON DESTRUCTIVE TEST ;		
	- Visual Check & Re-check final dimension overall,	ASME V	-
	- Liquid Penetrant Test,	ASME V	-
XII.	- Radiography Test,	ASME V	-
	- Report Analysis & Defect review,	ASME V	DMAIC
	- Defect Repair & Re-test after accepted,	ASME V	DPMO
	- Delivered to Hydrotesting area,	-	-
	HYDROTESTING ;		
	- Tool Preparation (Test Pump, Pressure gauge, Valve, Fitting, Water	ASME V	-
	Storage, Pressure Recorder),	ASME V	-
	- Install Outlet Valve to blind outlet side or Blind use Blind Flange+Gasket,	ASME V	-
XII	- Connecting Inlet Side to Water Pipe Header,	ASME V	-
I	- Water Suply to header,	ASME V	-
	- Pressure test to Test Pressure requirement on plan Design, Dwelling	-	-
	pressure time, and decrease pressure after testing acceptance,	ASME V	-
	- Review & Repair if any Leak and Re-test,	-	-
	- Delivered to Painting Area,		

Conclusion

The result of this research were create an innovation technology that measured by financial investment analysis which supporting to the business cost and benefit of the technological improvement. It shown in the result that resume the break event point analysis, after month of 11th the investment calculation were get enjoyment time from benefit of quality improvement in value of IDR 6.550.000,/month and get SAW machine in value of IDR 64.800.000 minus time depreciation cost, it proved that quality improvement not only create an investment cost but also reduce cost and could upgrade product quality performance, it mean that quality improvement linier to reducing cost.

This typical research model could be implement in several type of improvement depend on goal and resources capacity and organization policy. The financial performance especially in BEP analysis could help to measure and become an indicator to compare the value added before and after improvement.

Human factor in defect analysis are the most critical issued that affecting to process and product quality. It shown in defect ratio report and root defect caused analysis. Qualified welder would make high quality product even though low in consistency to make continuous in quality because of humanity factor and others affecting caused. This problem countermeasure and solved by enhancing and implementing innovation and technology of automatic Submerged Arc Welding (SAW) machine.

This technological improvement help Small and Medium Industry to compete, sustain and stay in their business and motivate to create more improvement especially in technological improvement to increase quality of product and in the end increase sustainability and business opportunity.

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