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DEVELOPMENT OF QUALITY ASSURANCE PROGRAM FOR CONSTRUCTION IN OIL AND GAS COMPANY BY USING STATISTICAL QUALITY CONTROL AND SIX SIGMA

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Abstract:

Stripe Oil Indonesia operated in Sumatera with a production capacity of 200,000 barrels of oil per day and operated over 530 km of pipelines. Many pipelines have already exceeded their design life with some segments more than 50 years with high potential for leaks that have caused production loss. To extend the operating lifetime of existing pipelines, a pipeline repair project was started in 2019 with sleeve installation. Based on factual data, the project team has experienced a delay in the first 2 months of the project. One of the main contributions to the delay was the welding failure that occurred in January 2019. The welding failure has caused a fire incident due to burn-through in the existing pipeline. The root cause analysis of burn-through incidents has been done with the finding of poor welder performance to meet project requirements. The recommendation is to measure the welder's performance from heat input data records and analyze the rejection rate and capability index. This research demonstrates how Six Sigma methodology using the DMAIC process and Statistical Quality Control can be applied successfully in pipeline repair projects to address issues of reducing defective welds, improving quality performance, and achieving project milestones. The analysis result showed an improvement in quality performance where the defect rate continued to decline as well as the capability index of the welder continued to improve and completed sleeve installation above the target. The project team also managed to achieve the six sigma level. Improvements also occurred in safety performance which achieved zero incidents due to welding failure (burn-through) from February 2019 to December 2020. In terms of business, actual cost savings achieved 28% from the approved budget.

Keywords:

Burn-through, DMAIC, Pipeline Repair, Quality Program, Root Cause Analysis, Six Sigma, Statistical Quality Control

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Introduction

PT. Stripe Oil Indonesia (SOI) has produced around 200,000 barrels of oil per day. In Riau, Sumatra, SOI operates and maintains over 530 kilometers of oil shipping pipelines to transport crude oil to the terminal tank facility. Some of this pipeline infrastructure is near the end of its useful life. SOI's pipeline is typically made of carbon steel. Over time, the pipeline will gradually loss its strength due to corrosion. Many pipelines have already exceeded their design life with some sections have been operating for more than 50 years. This weakened pipeline has a high potential for leaks, which is a safety and environmental concern for SOI.

There are 12 segments of pipelines with total length of 325 km have already exceeded their design life with some sections have been operated for more than 50 years. Incidents of pipeline leaks have been occurred 29 times over decade with frequency of 1 to 6 leak incidents per year. Those pipeline leaks have caused production loss, cost of repair, risk of fire, potential harm to workers and community near the leak location, and risk to company's reputation (Costa, 2016). The impact of those aging and corroded pipeline can be seen in the production rate of crude oil in SOI that keep declining from 315 thousand barrels per day (MBD) in 2013 to 200 MBD in 2018. Without any massive repair of those corroded pipeline, the crude oil production is expected to further decline to below 100 MBD in 2021 when this block will be handed over to Indonesian state-owned oil and gas company.

To extend the operating lifetime of the existing pipeline, Comprehensive Pipeline Maintenance (CPM) program was launched to demonstrate SOI's commitment to the Government of Indonesia as a prudent operator with values of safe operation, minimizing any impact on the environment and delivering its targeted production. The main CPM's scope of work is sleeve installation as shown in Figure 1. Sleeve installation is the most common method for a short-term solution to improve pipeline integrity and reduce pipeline risk by using a metal wrap installed around the pipe for reinforcement (Shuai, 2021).

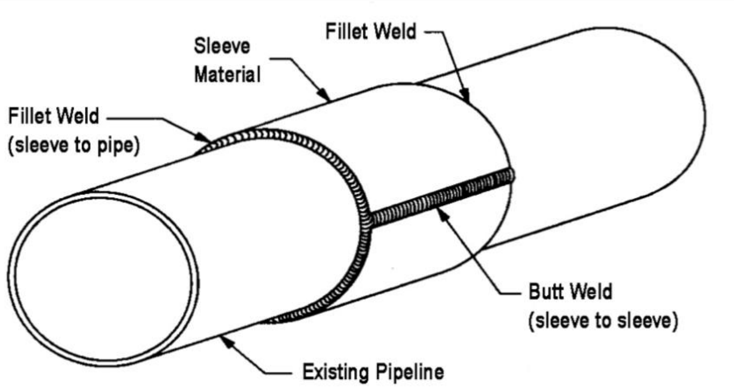

Figure 1: Pipeline Repair with Sleeve Installation

Sleeve installation is considered a high-risk activity due to requiring welding on the existing pipeline that contained hydrocarbon. Since welding work will be done on a live pipeline called "in-service welding" (API STD 1104, 2021), the risk is high. If the welding unintentionally penetrates the pipe and makes a hole, the welding sparks will come into contact with the hydrocarbon inside the pipeline and may lead to fire or explosion. The technical term for this incident is "burn-through" (Qian, 2018). To avoid burn-through risk during welding, the project team must develop and establish standard repair procedure for sleeve installation including tightening the quality control process to keep monitoring welding activities at the field in order to always comply with standards and procedures.

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In January 2019, CPM project team has started the work of sleeve installation and completing only 341 pairs of sleeves from target 402 pairs in the first month of January.

In terms of quality performance, the project team found 2 defects during welding the sleeve on existing pipeline. The first welding defect has caused the burn through on existing pipeline which result to fire on the existing pipeline. Fortunately, the fire can be stop immediately with fire extinguisher by the safety man at the field without any injury to the workers. But in the worst-case scenario, this incident may lead to catastrophic consequences such as explosion of the pipeline with potential of serious injury or even fatality to the workers. The second defect has no safety issue but still required re-work to repair the defect.

Those 2 defects are the main cause of delay when the project started sleeve installation in January 2019. The project team has conducted Root Cause Analysis (RCA) for those 2 defects and found the gap related to QA/QC issue. In order to achieve zero defect and zero burn-through, the project team must develop the tool to measure the performance and capability of the welders based on the result during in-service welding.

The delay and burn-through incident happened in January 2019 has impacted the project team performance in the following month. In February, the project only delivered only 856 pairs of sleeve installation from target of 1,107 pairs of sleeves.

The objective of this research is to develop quality assurance program for construction that is specific for sleeve installation work in order to minimize welding defects, achieve zero burn-through during in-service welding, and ensure continuous improvement of quality performance from the company. Quality Assurance program is a process that consist of several routine activities aimed at achieving the required standard that defined by the company. Every oil and gas company requires to have a QA program to measure how well the project team comply with the standards and procedures, and to ensure continuous improvement in quality performance. A well-designed and properly executed QA program provides more benefits for a company and its business partners (Johnson, 2000).

The performance measurement will be analyzed by using Statistical Quality Control (SQC) to evaluate the capability index of the welders, and Six Sigma method to measure the defect rate or DPMO (Defects Per Million Opportunities) with DMAIC process (Define, Measure, Analyze, Improve, Control) as a data-driven technique to improve the process.

This research demonstrates how Six Sigma methodology using DMAIC process and SQC method can be applied successfully in oil and gas companies to address issues such as reducing defective welds, improving quality performance and achieving project milestones. The results are significant improvement in quality performance by reducing defect, improve the capability index of the welders, achieving six sigma level of 3.4 DPMO and avoiding high-risk incidents of burn through during in-service welding, and significant improvement of project progress by achieving the project milestone ahead of time with cost saving of 28% from the approved budget.

Literature Review

One of the important factors to complete sleeve installation work successfully is to implement Quality Management System (QMS). Quality is an integral part of work process execution and very important for construction works that directly impact safety, cost and schedule (Ponder,

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2002). Project Quality Management includes the processes for integrating the organization's quality policy about planning, managing, and monitoring product quality requirements in order to meet stakeholders' objectives. (PMBOK Guide, 2017)

Statistical Quality Control (SQC) is a number of different techniques designed to evaluate quality from a conformance view; that is, how well are we doing at meeting the specifications that have been set during the design of the parts or services we are providing? Managing quality performance using SQC techniques usually involves the periodic sampling of a process and analysis of these data using statistically derived performance criteria. SQC can be applied to construction work in oil and gas facilities especially for welding works at the existing pipelines (Jacobs, 2018).

The process capability index of the welders in January 2019 was measured by using SQC method with Minitab software. The result is shown in Figure 2 with Ppk = 0.88, still below 1.33 which means the process is not capable and need improvement.

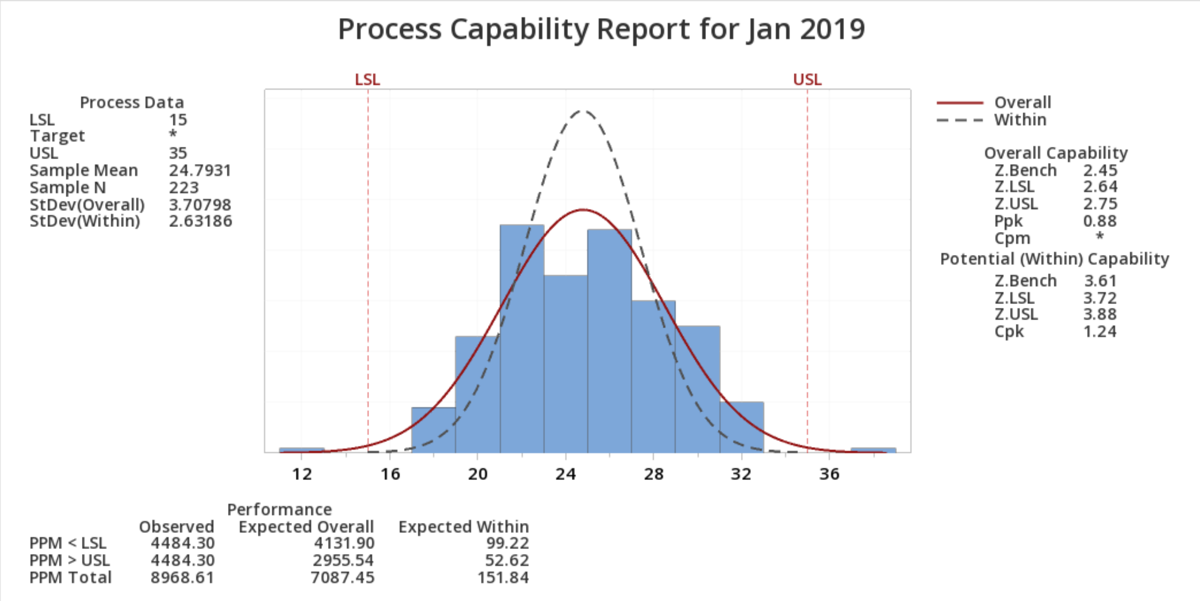

Figure 2. Process Capability and Six Sigma Result in January 2019 with Minitab

Six Sigma is the set of practices to systematically improve the process by eliminating defects. The term Six Sigma refers to a highly capable process that can produce products within specifications. The process that achieves Six Sigma levels produces only 3.4 defective products per million opportunities. The main focus of Six Sigma is to improve key process of in-service welding and takes quality as a function of processes capability to produce a result within specification (Jacobs, 2018). The Six Sigma measurement focuses on customer satisfaction, data-driven management, and improvement of the business process (Przekop, 2006). The method of Six Sigma includes many of the statistical tools that were used in other quality activities, using a systematic project-oriented technique through the define, measure, analyze, improve, and control (DMAIC) cycles. The main focus of the methodology is understanding and achieving what the company wants, because that is seen as key to achieving project milestones (Jacobs, 2018).

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The Six Sigma result in January 2019 that is shown in Figure 2 with DPMO value of 7087 is very high or far from Six Sigma level target of 3.4 DPMO. The welder performance needs to be improved in order to reduce the welding defect rate.

Methodology

The methodology used in this research is Six Sigma with DMAIC process (Define, Measure, Analyze, Improve, and Control) to ensure performance improvements with proper data processing, and combined with SQC (Statistical Quality Control) that used as indicator of improvement efforts done by the project team. The Six Sigma measurement focuses on customer satisfaction, data-driven management, and improvement of the business process (Przekop, 2006).

Data Collection

Data collection of this research use actual data of heat input from the welders during in-service welding on existing pipeline. The data is collected every day from the welders for 2 years starting from 1st January 2019 when pipeline repair project was started until 31st December 2020 when the project was completed. There were around 60 welders from various contractors working for this project in various locations of existing pipeline around Minas – Duri – Dumai area. The project team expected to receive around 210 data of heat input every month or total around 2,500 data per year from various welders depending on project progress and field condition.

Statistical Quality Control (SQC)

SQC is a number of different techniques designed to evaluate quality from a conformance view; that is, how well are we doing at meeting the specifications that have been set during the design of the parts or services we are providing? Managing quality performance using SQC techniques usually involves periodic sampling of a process and analysis of these data using statistically derived performance criteria. SQC can be applied to construction work in oil and gas facility especially for welding works at the existing pipelines. (Jacobs, 2018)

When performing welding on existing pipeline, heat input can be measured and recorded. Heat input is the amount of electrical energy supplied by a welding arc to a base metal, in this case to existing pipeline. Refer to Standard Repair Procedure that released by the company and refer to American Society of Mechanical Engineers (ASME) Section IX QW-409.1 (Houle, 2010), the amount of heat input (measured in kJ per inch) is only allowed between 15 to 35 kJ/inch. If the heat input result during welding below 15 kJ/inch, it will increase potential of poor-quality welds that has to be reworked. But if the heat input result above 35 kJ/inch, it will create hole on the pipeline surface (burn-through) that may lead to fire or explosion.
The heat input limit becomes upper specification limit (USL) and lower specification limit (LSL):

- Upper Specification Limit (USL): 35 kJ/inch
- Lower Specification Limit (LSL): 15 kJ/inch

CPM project team has instructed QC inspector crew at the field to record all heat input reading during in-service welding pipeline. The record of heat input every month to be calculated and analyzed using SQC method to measure the capability index.

The capability index will show how well the welders performance result fit into the range specified by the design specification limits.

Capability Index (Cpk) formula:

$$C_{pk} = \min\left[\frac{\overline{\overline{X}} - \text{LSL}}{3\sigma} \text{ or } \frac{\text{USL} - \overline{\overline{X}}}{3\sigma}\right]$$

where:

$\overline{X}$ = mean or average value of heat input every month
LSL = Lower Specification Limit (15 kJ/inch)
USL = Upper Specification Limit (35 kJ/inch)
σ = Standard deviation

Cpk result analysis:

- If Cpk ≥ 1.33 → the process is capable
- If Cpk < 1.33 → the process is not capable (need improvement)

Six Sigma

A defect is simply any component that does not fall within the company's specification limits. Each step or activity in a company represents an opportunity for defects to occurs, and Six Sigma programs seek to reduce the variation in the processes that lead to these defects. Six Sigma is the set of practices to systematically improve process by eliminating defects. The term Six Sigma refers to a highly capable process that can produce products within specifications. Process that achieves Six Sigma levels produces only 3.4 defective products per million opportunities (Moosa, 2010). Main focus of Six Sigma is to improve key process of in-service welding and takes quality as a function of processes capability to produce result within specification.

One of the benefits of Six Sigma is that it allows the project team to readily describe the performance of a process in terms of its variability and to compare different processes using a common metric. This metric is defects per million opportunities (DPMO).

The calculation of Six Sigma or sigma level and DPMO will use statistical theory of Z test. A Z-test is a statistical test for which the distribution of the test statistic can be approximated by a normal distribution.

In this case, the formula for Z test are as follows:

$Z \text{ left} = (LSL - \overline{X}) / \sigma$
$Z \text{ right} = (USL - \overline{X}) / \sigma$

where:

$\overline{X}$ = mean or average value of heat input every month
LSL = Lower Specification Limit (15 kJ/inch)
USL = Upper Specification Limit (35 kJ/inch)
σ = Standard deviation

DMAIC Process

The method of Six Sigma includes many of the statistical tools that were used in other quality activities, using a systematic project-oriented technique through the define, measure, analyze, improve, and control (DMAIC) cycles (Kumar, 2008). The main focus of the methodology is

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understanding and achieving what the company wants, because that is seen as key to achieve project milestone. (Jacobs, 2018)

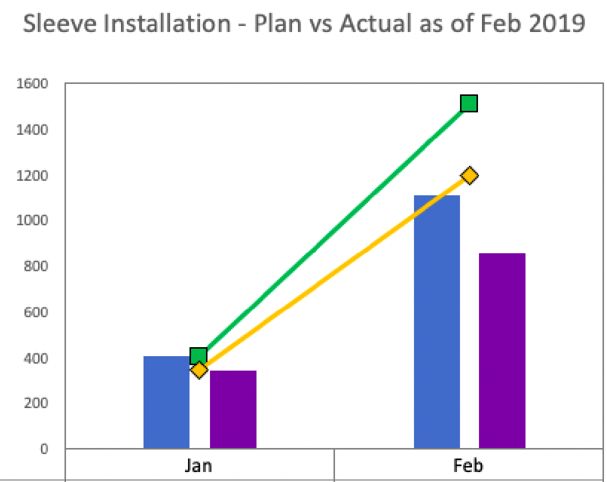
DMAIC refers to a data-driven quality approach for continuous improvement process. The DMAIC process is designed to allow for flexibility and iterative work. The DMAIC process of this research are as follows:

- Define: improve capability of the welders to minimize welding rework and avoid high risk incident due to burn through in order to meet project milestone of sleeve installation project.
- Measure: measure the welder capability index and defect rate using SQC and Six Sigma method to identify how well the welder performance.
- Analyze: determine the root cause of welding defects and provide recommendation to the project team as follow-up action for improvement and identify the key variables that most likely to create process variation.
- Improve: remove the causes of defects that are identified from RCA result and update the tools to improve the process.
- Control: Achieve the metric result as targeted by the project team, and ensure continuous improvement will sustain

Findings And Arguments

Pipeline repair project was started in January 2019 with target to complete total 14,000 pairs of sleeves in 2019. In the first 2 months (January and February 2019), the project team has experienced delay with target sleeve installed for each month.

From Figure 3, the project team only installed 341 pairs sleeve from target 402 pairs sleeve (delay 15.2% from plan). The delay continues to February 2019, with actual sleeve installed only 856 pairs from target 1,107 pairs (delay 22.7% from plan). If the project team did not do any improvement, they will not achieve the milestone of 14,000 pairs sleeve installation by the end of 2019.



	Jan	Feb
Plan	402	1,107
Actual	341	856
Cum.Plan	402	1,509
Cum.Actual	341	1,197

Figure 3. Progress Status of Sleeve Installation as of February 2019

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One of the main factors that caused delay was the welding defect occurred in January 2019. Refer to heat input data in January 2019 collected from welders during in-service welding, there were 2 defects occurred as shown in Figure 4.

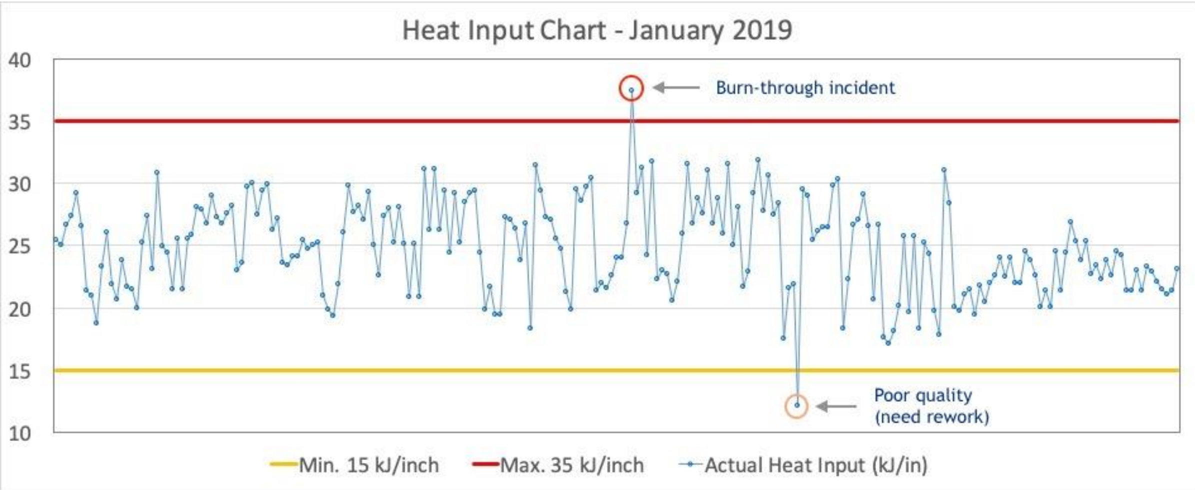

Figure 4. Heat Input Chart in January 2019

Define Phase

The project priority is to improve capability of the welders to minimize welding rework and avoid safety incident of burn through in order to achieve project milestone of sleeve installation by completing total 14,000 pairs of sleeve installed by the end of 2019. The ultimate target is to reach six sigma level of weld defect rate. The heat input result from the welders must meet project specification with acceptable range between 15 to 35 kJ/inch.

Measure Phase

From data collection of the welders that was collected starting from January to December 2019, the project team performed measurement of total number of defects, process capability index, and defect rate (DPMO). The measurement of welder performance is completed by using Minitab software for process capability index and defect rate.

Table 1. Welder Performance Measurement Result in 2019

Year 2019	Total Number of Defects (Target = 0)	Process Capability Index (Target > 1.33)	Defect Rate DPMO (Target < 3.4)
January	2	0.88	7087
February	0	0.87	6608
March	0	0.92	2870
April	0	1.03	1007
May	0	1.10	768
June	0	1.13	434
July	0	1.40	18.5
August	0	1.30	55.9
September	0	1.40	24.7
October	0	1.54	2.35
November	0	1.50	3.44
December	0	1.52	2.78

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Analysis Phase

Root Cause Analysis is a proven method for improving processes by investigating and evaluating events and near misses. To prevent recurrence, we must understand the root cause and implement appropriate corrective actions. Cause and effect with fishbone diagram show the connection between problems and possible causes as shown in Figure 5.

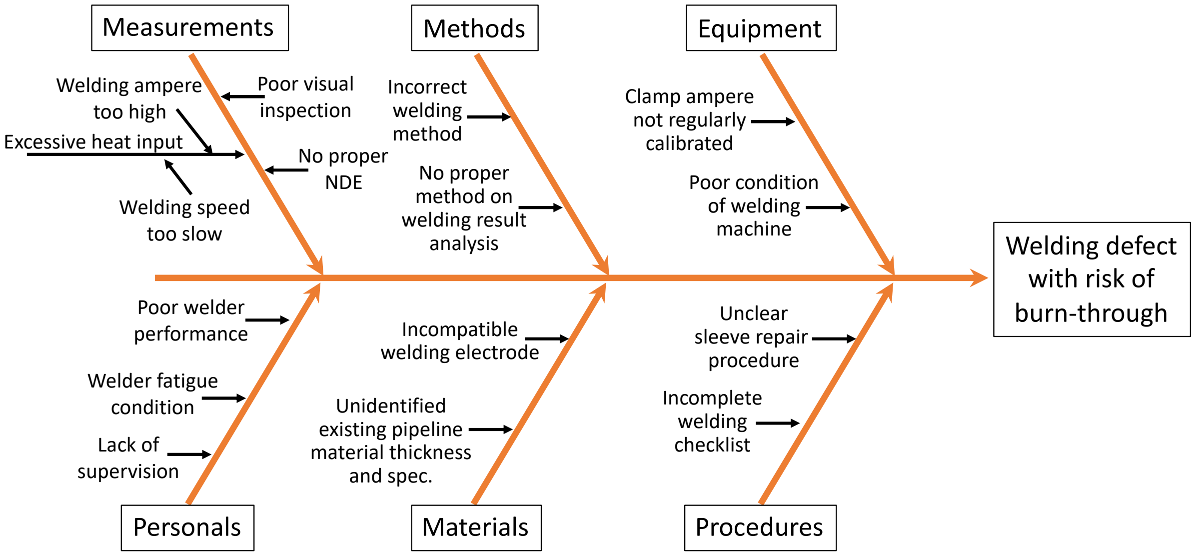

Figure 5. Cause and Effect Fishbone Diagram of Welding Defect

One of the tools that use in Six Sigma project is failure mode and effect analysis (FMEA). The FMEA indicates a recommendation to reduce and eliminate the failure by allocating a personnel or project team to resolve the failure by updating the system, design, and process (Olesik, 2018)

By using Pareto chart from FMEA result to find the root cause of the problem as shown in Figure 6.

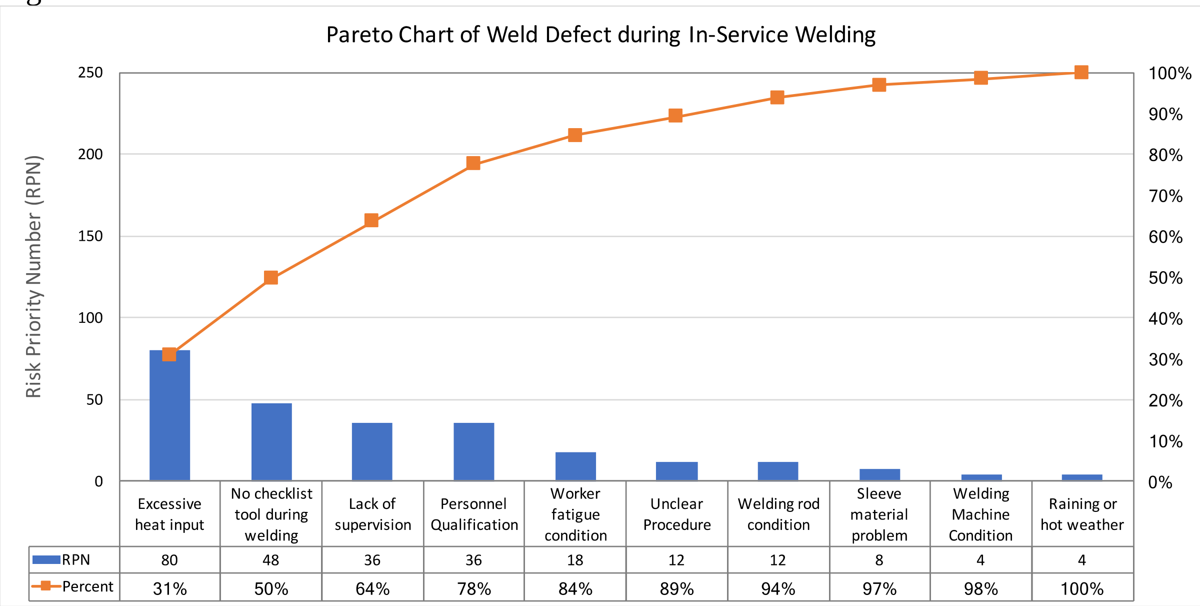

Figure 6. Pareto Chart of Welding Defect

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Improve Phase

To improve quality performance of the welders, there are several efforts have been done:

- Conduct training to all welders to increase welder's awareness and understanding that in-service welding is a high-risk work and remind the welders to always follow the procedures.
- Develop welding checklist in detail to ensure all requirements are fulfilled before conducting in-service welding on existing live pipeline.
- Update inspection testing plan by adding hold point during fit-up and in-service welding to ensure QC inspector must present to witness and supervise the welding process.
- Modify the welding process by adding trial sampling for welding before conducting in-service welding to give more confidence to the welders to avoid burn through incident.

The continuous improvement of the welders is shown in Figure 7 that indicate the defect rate of DPMO is getting better every month and achieved six sigma level of 3.4 DPMO, and the process capability index of the welder is also improving every month by increasing the Cpk value above 1.33.

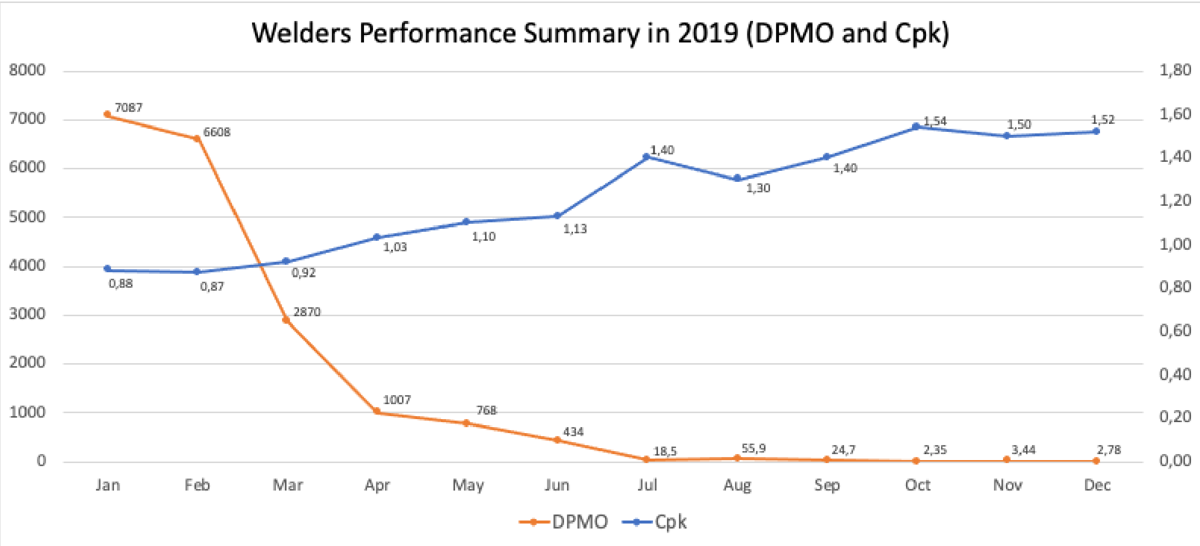

Figure 7. Improvement of Welder Performance in 2019

Control Phase

The last phase of DMAIC process is control, that ensure to achieve the target and maintain the performance. From the result of welder performance in 2019, the control phase started in October 2019 where the target of defect rate and process capability index were achieved. The tools that used in control phase are in-service welding checklist, update procedures, and inspection plan.

Conclusions

Quality Assurance (QA) program is a process that consist of several routine activities aimed at achieving the required standard that defined by the company. Every company's project team requires a QA program to not only measure how well the project team comply with company's standards and procedures, but also to ensure their continuous improvement (ISO 9001, 2015). A well-designed and properly executed QA program provides several benefits for a company

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and its business partners. This research shows that the QA program implemented by the project team with detail methodology has improved the quality performance as well as the overall project performance.

The development of Quality Assurance Program for Construction consists of:

- Roles and responsibilities of quality personnel
- Quality control data and reporting
- Performance measurement
- Corrective action for non-conformances
- Training program
- Socialization event and discussion forum
- Quality audit

This research demonstrates how Six Sigma methodology using DMAIC process and SQC method can be applied effectively in oil and gas company to measure and improve quality performance of the welders. The use of corrective action approach helped the project team to improve the quality performance of the welders.

By reducing the rejection rate of welding and achieve six sigma level, the project team has benefit of minimizing rework and optimizing production of the welders. These advantages have improved the project schedule by achieving project milestone to complete installed 17,124 pairs of sleeves by end of 2019 from target 14,000 pairs of sleeves.

The impact on business also brings more profit to the company and Government of Indonesia with significant project cost saving for the last 2 years. From the cost summary (approved budget vs actual cost) of CPM project in year 2019 and 2020 as shown in Table 2 below, shows that for sleeve installation scope, the project team managed to achieve cost saving of USD 6,513,637 or 28.29% from approved budget. For overall scopes, the cost saving is USD 22,128,672 or 36.20% from approved budget.

Table 2. Cost Summary of CPM Project

Project Scope	Approved Budget (USD)	Actual Cost (USD)	Cost Saving
Sleeve Installation	23,021,849	16,508,212	28.29%
Road Crossing	11,763,386	10,430,479	11.33%
Coating	8,957,821	3,428,779	61.72%
Sectional Repair	7,251,455	2,899,109	60.02%
Engineering	2,361,289	426,856	81.92%
Supervision	7,766,706	5,300,399	31.75%
Total	**61,122,506**	**38,993,834**	**36.20%**

The timeline of Quality Assurance Program implementation plan is shown in Figure 8. Since the CPM project started on 1st January 2019 and finished by end of December 2020, the timeline of process improvement for CPM QA Program started in the 1st Quarter 2019 until 3rd Quarter 2019. The control stage started in 4th Quarter 2019 when the defect rate of welding achieved Six Sigma level of 3.4 DPMO and maintain the performance until project completion by end of December 2020. For new project in 2021, the same cycle of QA Program will be implemented.

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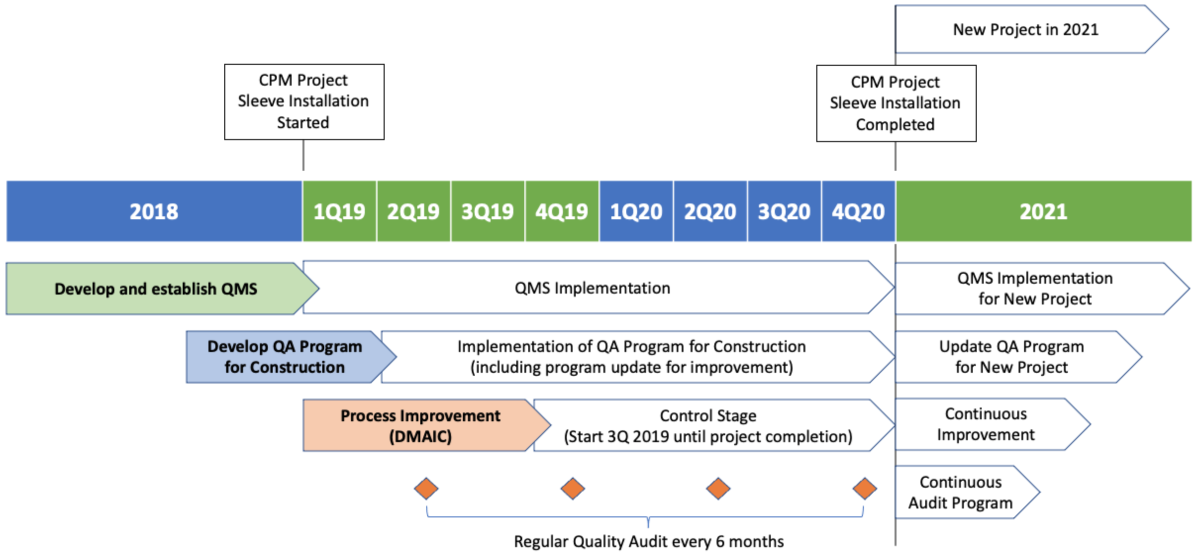

Figure 8. Quality Assurance Program Implementation Plan

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