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Oluseye Michael Johnson

# UTILIZING LEAN SIX SIGMA MODEL FOR MANAGING PROJECTS IN THE OIL AND GAS PIPELINE INDUSTRY: A CASE STUDY OF SELECTED COMPANIES IN LAGOS STATE, NIGERIA

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**Author:** Oluseye Michael Johnson
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**ABSTRACT :**
The aim of this thesis is to investigate factors that cause project late delivery (delays)as a result of welding defects usually experienced during the oil and gas pipeline construction phase and proffer solutions for elimination through the Lean Six Sigma (LSS) model. Delays in projects do lead to cost and time overruns, construction repair, dissatisfied customers and a bad reputation for such organization. This model is able to manage these projects effectively by ensuring optimum welding quality through the various LSS tools and techniques, which form bases for identifying the root causes for welding defects usually experienced during the pipeline welding activities and present means for analysis for possible solutions for their elimination; these normally occur in the oil and gas pipeline construction phases in Nigeria.

This research revealed for instance, through the weld inspection report for one of the selected company, an average rate of 149120 weld defects per million opportunities (DPMO) at a sigma level of 2.55 of past pipeline projects undertaken. Thus, poses great concerns and desires an improvement mechanism for the reduction in weld defects. This falls under the capability of the LSS model.

This study deploys the use of appropriate literature on LSS, and both qualitative and quantitative research methods, where relevant data gathered through conducted interviews, weld inspection reports and submitted questionnaires with the relevant players in the oil and gas pipeline industry. Based on the issues stated above, the application of define, measure, analyze, improve and control (DMAIC) methodology phases of LSS was used as the empirical case study. This phase extensively utilized the collected data, starting with the weld inspection reports in shaping the definition of the research project, thus establishing the project charter, SIPOC. With the aid of other gathered data, the measure phase examines this critical principle of determinism, expressed mathematically as $Y=f(X)$, which gives insights into the factors or functions affecting pipeline welding quality through an environment, machine, materials and man. This formula guides this research in the analysis phase, in formulating a possible solution to ensure quality in the welding process and reduce defects through various statistical tests and charts, such as ANOVA, Cause and Effect, Fishbone, Pareto chart. Finally, improve and control phases, with the aid of FMEA and SPC chart, ensure continuous improvement and monitoring as a result of the evaluated solution, which ensures a reduction in weld defects and late delivery in the construction phase of the oil and gas pipeline operations.

**KEYWORDS:** Lean Six Sigma, continuous improvement, pipeline construction projects, improve weld quality

# TABLE OF CONTENT

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Johnson Oluseye Michael

## LIST OF TABLES

## LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| **AC** | Alternate Current |
| **ANSI** | American National Standards Institutes |
| **ANOVA** | Analysis of Variance |
| **API** | American Petroleum Institute |
| **ASTM** | American Society of Mechanical Engineers |
| **ASME** | American Society for Testing and Materials |
| **AWS** | American Welding Society |
| **Cp** | Process Capability |
| **Cpk** | Process Performance |
| **CTQ** | Critical to Quality |
| **CWS** | Certified Weld Inspector |
| **DC** | Direct current |
| **DET** | Detention |
| **DPMO** | Defects per million opportunities |
| **DPR** | Department of Petroleum Resources |
| **DMAIC** | Define, Measure, Analysis, Improve and Control |
| **EFQM** | European Foundation for Quality Management |
| **Eq.** | Equation |
| **FMEA** | Failure Mode and Effects Analysis |
| **HAZ** | Heat Affected Area |
| **HSE** | Health Safety Executive |
| **ISO** | International Organization for Standardization |
| **LCL** | Lower Control Limit |
| **LSL** | Lower Specification Limit |
| **LSS** | Lean Six Sigma |
| **MSS** | Manufacturers Standardization Society |
| **NDT** | Non-Destructive Testing |
| **OCC** | Occurrence |
| **OD** | Outer Diameter |

| | |
|---|---|
| **PPE** | Personal Protective Equipment |
| **PQR** | Procedure Qualification Record |
| **RPN** | Risk Priority Number |
| **SEV** | Severity |
| **SIPOC** | Suppliers, Inputs, Process, Outputs and Customers |
| **SME** | Small and Medium Enterprises |
| **SMAW** | Shield Metal Arc Welding |
| **SPC** | Statistical Process Control |
| **TQM** | Total Quality Management |
| **UCL** | Upper Control Limit |
| **USL** | Upper Specification Limit |
| **VOC** | Voice of the Customer |
| **VOE** | Voice of the Employee |
| **VOP** | Voice of the Process |
| **WPS** | Welding Procedure Specification |

# 1 INTRODUCTION

The significance of the oil and gas industry for a country plays great importance in terms of economic superiority, empowerment and political influence globally, as such not leaving out an oil and gas nation like Nigeria (Agi, 2016).

According to Parast and Adams (2012), both cited the influence of any successful operational performance improvement methodology of the oil and gas industry which does positively impact the economy of such nation, which also, eventually translates regionally and globally. However, complexities and uncertainties are abounding for organizations, as a result of globalization and an increased desire for satisfying customers in this ever-changing business environment (Timilsina, 2017: 1). Furthermore, Pekkola et al. (2016); Timilsina (2017) acknowledged that organizations must explore and adopt all possible performance strategies to survive, compete and grow from this environmental turbulence being experienced currently in this business world.

In the construction sector, many construction projects are undertaken by organizations often experiences late delivery or delays in one or several ways before their completion, contrary to the agreed or stipulated contract period (Aibinu and Jagboro, 2002; Marzouk and El-Rasas, 2014). This commonly occurs globally and as such, lots of research has taken place to unearth this phenomenon (Eizakshiri et al. 2011; Sweis et al. 2018). While, construction delays can be defined according to Marzouk and El-Rasas (2014), as time overruns that exceed the contract completion date or a planned date agreed by all relevant parties involved for the delivery of the project. These delays result in cost and time overruns, which can eventually make the planned project profit turn to project loss for the contractor, client or investor (Aibinu and Jagboro, 2002; Eizakshiri et al. 2011; Gluszak and Lesniak, 2015; The Council for Six Sigma Certification, 2018b: 643).

According to Aibinu and Jagboro (2002) citing the case of Nigeria, being a developing nation, experiences an "endemic" proportion in construction delays. Odeyinka and Yusif (1997) described the situation as having a 70% time overruns for general construction delays. While Hatmoko and Khasani (2019) mentioned that 37% of time overrun and having a standard deviation of 41% occurrence in the performances of projects in the Nigerian oil and gas industry.

As suggested by Ferdousi and Ahmed (2009); Dumitrescu and Dumitrache (2011); Umude-Igbru (2017), that for business organizations to compete favourably in this current global market, simultaneous effects must be made continuously to improve their quality, organizational and productivity processes. This, of course, falls under the capability of Lean Six Sigma (LSS).

Therefore, Antony (2004) emphasizes the importance of LSS as being a powerful business strategy that ensures causes of errors or defects are identified and eliminated in a given process, product or service through the disciplined procedure with the aid of statistical and non-statistical tools and techniques in a meticulous manner. Furthermore, explaining that LSS can also be referred to as a measure of quality that aims towards zero errors using appropriate statistical tool and technique, through several charts and graphs for interpretation from the collected data. And these errors or defects are noted as things which cause setback towards attaining customer satisfaction.

While Desai and Shrivastava (2008); Dumitrescu and Dumitrache (2011), equates LSS as a business performance improvement strategy or statistical quality objective which seeks to reduce the number of errors to less than 3.4 Defects per Million Opportunities (DPMO) in a given process, product or service, which is also equivalent to +/- 6 standard deviations from the mean.

Due to several weld defects usually experienced during the pipeline welding operations, to repair does consume more materials, energy, costs and time (Dennis, 2002). While Slack et al. (2010) further asserted that quality defects ensure an upsurge in work, inspection/test, surety, scrap costs, inventory and processing time.

Utilizing the Voice of the Process (VOP) through the obtained data from one of the selected oil and gas pipeline construction company situated in Lagos State, Nigeria, revealed in their weld inspection reports of several weld defects for some projects undertaken in the past twelve (12) months, an average rate of 160255 weld defects per million opportunities (DPMO) and 2.49 sigma level (ISIXSIGMA, 2020). Thus, translated into quality and sigma levels as “Quality level: 160255 DPMO” and “sigma level: 2.49 sigma” (Rumana and Desai, 2014; Yadav and Sukhwani, 2016). However, the company chose to remain anonyms and therefore, it’s referred as company A.

While the other selected company which will be referred as company B, showed in their weld inspection reports of several weld defects for some projects undertaken in the past fifteen (15) months, an average rate of 155199 weld defects per million opportunities (DPMO) and 2.52 sigma level (ISIXSIGMA, 2020). Thus, translated into quality and sigma levels as “Quality level: 155199 DPMO” and “sigma level: 2.52 sigma” (Rumana and Desai, 2014; Yadav and Sukhwani, 2016).

The above revelation of the two companies show similarities in terms of both having low sigma level and high DPMO. Thus, both seek improvement methodology to reduce their average rate of weld defect in their welding activities during the pipeline construction phase.

In the course of this research, the deployment of LSS problem-solving methodology: define measure, analyze, improve and control (DMAIC), which is a systematic five-step phase adopted to identify and solve problems (Rumana and Desai, 2014). Starting with the define phase, the project charter is defined in relation to the weld inspection report. Further data obtained from the submitted questionnaires and the conducted interviews form a basis in the measure phase for examining the principle of determinism, mathematically expressed as $Y=f(x)$ (Gygi, et al., 2012). Thus, extensive insights into factors or functions affecting pipeline welding quality through the welding environment, machine, materials and man appropriately considered.  Furthermore, this phase through the formula guides the research into the next phase, analyze phase, in formulating possible solutions in ensuring optimum weld quality in the welding process and thereby effecting a reduction in welding defects through various statistical tests and charts, such as ANOVA, Cause and Effect, Fishbone, FMEA, Pareto chart. Lastly, improve and control phases, with the aid of FMEA, SPC chart and DOE, ensure continuous improvement and monitoring as a result of the evaluated solution. Statistical software application such as Excel and Minitab will be deployed for use in this research.

In conclusion, the implementation and adoption of LSS in the oil and pipeline construction operations seek to ensure optimum welding quality in managing these projects effectively and thus leads to scheduled project delivery (Yadav and Sukhwani, 2016).

## 1.1 Background of Study

The performance expected from managing construction projects can be said to be of high optimism, but rather the case is contrary which even draws the global attention to this phenomenon called “project delay or late delivery” normally experienced in projects execution.

As opined by Agi (2017), the oil and gas industry which is noted for its uniqueness in terms of its high capital intensive nature globally, is not left out of this inherent problem, as such mentioning this peculiarity for Nigeria as well. Also, stating that lack of sufficient and economical operational activities in the country’s oil and gas sector portend this negative situation.

Despite the use of traditional quality management tools by many organizations, its effectiveness can be debatable, especially as it relates to the prevailing business demands experienced nowadays (Bisgaard, 2008; Umude-Igbru and Price, 2015). To address all these, the adoption and implementation of LSS globally as a reliable and continuous improvement initiative by organizations successfully lead to this research. This assertion was affirmed by Yadav and Sukhwani (2016), in their research, as it is the most powerful quality and process improvement management and tool to be used to achieve eminence in products, services and processes.

Given the varied nature of projects undertaken, the construction of these projects in the oil and gas industry usually require large investment (Capital and human resources), complex technology, direct and indirect investors/stakeholders, and environmental and social impact (Sweis et al., 2018; Thuyet et al., 2007). Pipeline construction projects are generally characterized as having a substantial number of repetitive sectors work; however, various forms of delays are experienced as well. As mentioned by Hatmoko and Khasani (2019); Orangi et al. (2011); Thuyet et al. (2007), in their findings on delays experienced by project contractors in pipeline infrastructure research work for the Victoria-based Australia, Vietnam and Middle East countries pipeline projects respectively, the following were summarily discovered as root causes for the delay:

- Modification / changes made from initial design
- Flaws detected in designs (obscurities and inconsistencies of specifications)
- Inadequate documentation / design submission delays
- Communication lapses between designers and contractors
- Communication lapses between client and project team
- Issues bordering customer / end-user concerns
- Insufficient geotechnical researches
- Issues bordering client / stakeholders approvals
- Poor relationship with government and relevant authorities
- Critical weather conditions
- Materials / equipment suppliers' delays
- Subcontractor issues
- Incompetent project team and poor site management practices
- Errors encounter in planning and scheduling stages
- Issues bordering on cultural and heritage management
- Construction repair/rework

Despite the successes recorded by various organizations for the implementation of LSS to tackle impediments for managing projects successfully, its adaptation in developing countries has received less attention (Albliwi et al., 2015). Umude-Igbru and Price (2015) further asserted, in their research work, the poor performance (35%) of implementation of LSS in Nigeria.

However, the research intends to introduce the use and implementation of LSS to tackle factors that necessitated construction rework, such as weld defects usually encountered during welding activities in pipeline construction operations.

In the course of pipeline welding operations, weld defects usually encountered after carrying out necessary Non-Destructive Testing (NDT) possesses great concern to the project managing team, as this normally leads to repair; cost and time overrun on the project, and thus prolong the delivery schedule (Shinde and Inamdar, 2014).

## 1.2 Problem Statement

Several effects and attempts by many stakeholders in the oil and gas pipeline industry in Nigeria in seeking ways to curb this ugly menace – late delivery – which usually occurs in several projects works. In a project life cycle, the construction phase tends to be a critical aspect that draws great concerns for stakeholders as a result of construction delays (Orangi, 2011). During pipeline construction operations, encountering welding defects in the course of welding activities tends to cause schedule delays, rework, cost and time overruns. As such, a continuous improvement and quality control process mechanism is sought to address this, which readily falls under the capability of Lean Six Sigma.

## 1.3 Objective of Study

The main objective of this thesis is to investigate and identify factors which cause project delays in the form of welding defects encountered during welding activities in the oil and gas pipeline construction operation, and proffer solutions for their elimination using the Lean Six Sigma model.

LSS successes can be traced to several articles and reports in the past, which highlighted the benefits of using LSS in various fields of businesses, institutions and organizations. The gained insights will highlight these organizations using LSS methodology in managing various projects successfully.

## 1.4 Research Questions

What are the roots causes for late delivery as a result of high weld defects occurrences and the possible elimination in the oil and gas pipeline projects because they serve as impediments to successfully manage these pipeline construction operations optimally?

### 1.4.1 Research Hypothesis

This research is being conducted with the help of an alternate hypothesis ($H_A$): There is a significant relationship between inadequate training of pipeline welders and a high level of weld defects.

## 1.5 Assumptions and Limitations

The study focused mainly in Lagos State, the western part of Nigeria, in contract to the initial players heavily involved in the oil and gas pipeline sector- Niger Delta and southern region of the country. Further research has to be conducted in the future to capture the generalized perception for delays in this peculiar sector. This limitation constrained the degree of generalization of the findings. Furthermore, the research encountered a lack of cooperation and mistrust especially from some large corporations and SME's respondents in this sector, this perception may arise in the context of not disclosing certain information which may expose their self-inadequacies or aggravate delays in their project operations. As such, the Nondisclosure Agreement (NDA) was acceded to with respondents whose responses played a vital role in the research.

Hence, the selected companies preferred to remain anonymous. The obtained document via the weld inspection report and the conducted survey via the questionnaire from these companies proved vital in accomplishing the objectives for the research.

Furthermore, this research centred on the construction phase of the oil and gas pipelines, where steel pipes have already been transported and stored at project site before commencement of welding activities. Furthermore, stringing of pipes commenced in preparation for joining various steel pipes and accessories together through welding processes. The finished welded joints tested through Non-destructive Testing (NDT) to ensure their quality. However, some welding defects occur after the tests which require repair and recheck.

Finally, the basis of assumption for this research rests on the positive responses received from the respondents – Voice of the Employee (VOE) – of the two case companies, through the conducted interviews (video and audio communication) and submitted questionnaires (electronic). Also, the received information was conveyed willingly and appropriately befitting the criteria set for this research work.

# 2 LITERATURE REVIEW

## 2.1 Introduction

This second chapter describes the overview of Lean and Six Sigma theoretically and carefully analyze past literature reviews, relating to the subject matter, to have general information and their possible effects toward managing project successfully.

### 2.1.1 The Concept of Lean

Lean can be described as a collection of tools that identify wastes in a product or process and proffer solution for their elimination so as to improve their quality, production time and cost (Rehman et al. 2013; Bae and Kim 2008; The Council for Six Sigma Certification 2018a). Rahman et al. (2013) affirmed that Lean ensures processes or products produced without waste. Further explaining, that these wastes could be anything other than the minimum requirement of equipment, parts, materials, resources and working time, which are essential in many processes, services or products production.

While Kadarova and Demecko (2016) described Lean as a collection of tools and methods to assist managers and employees to improve by means of identifying and removal of a bottleneck in work processes through systems redesign. In summary, as implied by Bae and Kim 2008, that lean tends to maximize value for an organization once wastes are eliminated.

As mentioned by Cancado et al. (2019); Kadarova and Demecko (2016), these wastes could be issues arising in any given products, services and process as a waste of manpower, transport cost, unnecessary inventory, human movement, waiting time, overprocessing, overproduction, defects and people talent.

### 2.1.2 The Concept of Six Sigma

The word “Sigma”, which is a Greek letter, σ, represents standard deviation. In statistics, the standard deviation can be defined as the degree of variation or dispersion for a given set of data or process (Dubey and Yadav, 2016). This was further explained by Dubey and Yadav (2016); Youssouf et al. (2014) that Six Sigma ensures for a process or product to be capable of maintaining the Six Sigma level, then its specification limits or tolerance, an interval must be at least 6σ from the mean or average point. Outside the tolerance interval is considered as wastes or defects.

In fact, “sigma” which is noted as a means of metric can be used as a means to reflect organizations’ products, services or processes within prescribed specification limits or within zero wastes (Abdelhamid, 2003).

As stated by Gygi et al. (2012), that sigma scale is a prevalent system for assessing pivotal characteristics of a process, product or service in comparison to the intended requirements. Further explaining the expected performance of any given process can be related to as having a higher sigma score or level with little or no flaws or defects. While a process having a poor or lower sigma score can be taken as having higher flaws. Table 1, illustrate the sigma level in terms of percentage of defects and outcome or opportunities.

The expected quality performance or target of any process, product or service is sigma level 6, which aims to have a defect rate of 3.4 defects per million opportunities or outcomes (Youssouf et al., 2014).

**Table 1.** Sigma level of business performance yield (Youssouf et al., 2014).

| S/N | Sigma Level (Score) | Defective (%) | Defects per Out-come/Opportunities (DPMO) |
|---|---|---|---|
| 1. | 1 | 69.10 | 691462 |
| 2. | 2 | 30.90 | 308538 |
| 3. | 3 | 6.7 | 66807 |
| 4. | 4 | 0.62 | 6210 |
| 5. | 5 | 0.023 | 233 |
| 6. | 6 | 0.00034 | 3.4 |

### 2.1.3 The Concept of Lean Six SIgma

The merger of these distinct quality management and business improvement methodologies evolved into an extensive management system which tends to promote high-quality principle, techniques, effective leadership, eliminate wastes and reduce variation, promote customer satisfaction and business values (Pamfilie et al., 2012; Enoch, 2013; Dumitrescu and Dumitrache, 2011).

Also, despite the successes recorded by some organization using Lean implementation, as reported by Cortes et al. (2016), that some decision-makers and managers of some organizations, who are yet to implement it, are not sufficiently convinced enough to invest their time and money for this improvement methodology. Further explaining that this was as a result of lack of accurate measurement, however, combined with Six Sigma, this is able to accurately measure and analyze with statistical methods (Cortes et al., 2016).

#### 2.1.3.1 Lean Six Sigma Targets

LSS aims in meeting the set target in order to achieve and maintain quality based on statistical control. Then, quality can be said to attain high performances with no or little variation. While, Gygi et al., (2012) stated that quality can be taken as attaining conformity with guarded specifications on products, processes or services. Further explaining that specifications are target performance values and outside these values, such performance is taken as flawed or rejected.

Furthermore, Gygi et al. (2012), averred the importance of specification as a means of meeting targets and not the limit. Ensuring that processes operating on target with few variations should be the target for performance enhancement and excess cost reduction.

Statistical metrics can be referred to, in any process or its characteristics, as a means of measurement of the inherent properties, which is categorized between the mean and standard deviation for the given process (Gygi et al., 2012). Further explaining that the performance of a process is subject to the degree of the variation, which in turn imparts the customer. As such, for a given process, it’s imperative to maintain control over the mean and variation of such process from time to time due to constant changes (Dumitrescu and Dumitrache, 2011).

With the aid of a normal dispersion as a statistical representation of a process, product or service, as depicted in Figure 1, the standard deviation (sigma) around the target (mean), measures the dispersion (tolerance interval) of a process between the upper and lower specification limit. And as a matter of facts, any value beyond these limits is considered as wastes or rejects (Youssouf et al., 2014). The tolerance interval is a scale from 1 to 6 standard deviation. The value closest to the target is scaled as 6 standard deviations. While farther from it is scaled as 1 standard deviation.

To attain quality in a process, getting the target, not limits is considered to be the most important part of a specification. This target encompasses utilizing specific characteristics for its operation, to maintain process improvement and excessive cost reduction with little fluctuation (Gygi et al., 2012).

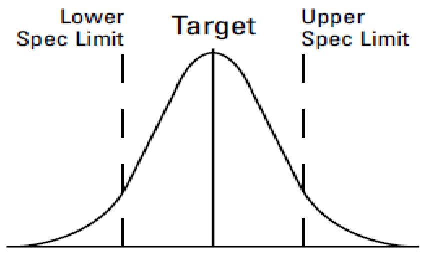


**Figure 1.** Statistical representation of a process, product or service (Youssouf et al., 2014).

## 2.2 Merits and demerits of Lean Six Sigma

Antony et al., (2007), highlighted extensively in a research paper, some merits and demerits of adopting LSS models by a business organization, which are as follows:

### 2.2.1 Merits of Lean Six Sigma

- Ensure reduction or elimination in organization products or processes defects, wastes and excessive variation.
- Business profitability can be said to be guaranteed based on past success story recorded by some business organization.
- Elimination of cost incurred with poor quality, such as costs incurred in late delivery.
- Cross-functional teamwork in organization is effectively harmonized to improve service delivery or productivity.
- Effectively improve service and process efficiency in terms of time management and lead time in an organization.
- Ensure improvement in customer satifaction, commitment or loyalty for services or products of an organization.
- Decision making by management is greatly enhanced as a result of availability of reliable data and information which all came about with the aid of LSS tools and techniques.
- Existing organizational cuture or practices tend to transform positvely to new levels and achievement.

- In any business service delivery, non-value added factors which tends to slow delivery usually exists, however, LSS ensures substantial reduction or elimination of these factors for overall faster service delivery.
- Substantial benefits or rewards, such as monetary incestive for employees of an organization practicing LSS.

### 2.2.2 Demerits of Lean Six Sigma

- Lack of awareness or strategic planning techniques for LSS adoptability in organization.
- Difficulties in dismantling old organizational cultures and practices to adopt to change.
- Lack of management to commit resources to embrace changes, and also, consumes time which are all essential requirement for adopting LSS.
- Irrespective of successful stories recorded by some organization, however, some business organization recorded substantial negative impact practising LSS.

## 2.3 Literature review of Lean Six Sigma for the Oil and Gas Industry

In this chapter, an overview of Lean and Six Sigma will carefully be analyzed from past literature reviews to have general information and their possible effects toward managing the project successfully.

According to Chan and Chan (2004), acknowledged the fact that organizations always seek project success as the end goal for every project through various project improvement management mechanisms. To achieve that, organizations changed from what was been practiced before to embrace the LSS methodology, which offered continuous and effective improvement mechanisms and cost reduction (Krisnnaswamy et al., 2012; Wang and Chen, 2010).

Despite the successes recorded by some organization using Lean, as reported by Cortes et al. (2016), that some decision-makers and managers of some organizations, who are yet to implement it, are not sufficiently convinced enough to invest their time and money for this improvement methodology.

Uzochukwu and Ossai (2016) posit that oil and gas industries are having difficulties being competitive in the global market as a result of effects being made to meet customers demand and the dwindling prices of their products. Further explaining that this trend affects a lot of Nigerian oil and gas companies as well, and based on these challenges, great effects are continuously being made to overcome these situations.

In order for business organization to remain globally competitive some oil and gas companies in Nigeria have been practicing Lean or Six Sigma due to the fierce competitions as a result of the rapid globalization of businesses in the country.

The oil and gas industry is known to be immensely lucrative and is been played in a highly competitive environment in which the big players or the multinational organizations have large stake (Tsiga et al. 2017).

Mohammed and Suliman (2019) conducted research using linear regression modelling for delay prediction models to investigate circumstances leading to pipeline construction projects delays in the oil and gas sector in Bahrain. Their finding, with the aid of some statistical tools through this statistical software, SPSS, was able to acknowledge significant effects between project scope variation and delays in outlining groundwork for the project in anticipating project duration delays. Irrespective of capturing only 34.3% of the variations in project duration delays, their analysis still asserts these five delay factors such as "*poor site management and supervision; inefficient and poor performance of contractors/subcontractors; contractor's lack of planning at preconstruction; rework due to errors, mistakes and defective works during construction; and delay in drawing* *preparation of the projects*" as having a substantial outcome in anticipating the cost of delay.

## 2.4 Overview of Oil and Gas Pipelines Construction

Pipelines are series of joint individual tubular conduit through which fluid – crude oil, petroleum, diesel, hot steam, petrochemicals, natural gas, water, etc. – is transmitted under considerable pressure from a source of origin to various destinations for use (Sharma and Maheshwari, 2017; Biose, 2019). These cylindrical-shaped conduits are made of metal /steel or plastics having various sizes and lengths. Based on the area of interest for this research, the consideration centred on the steel pipes and the joints or welds used for them and the various attached fittings. The attached pipe fittings include elbows, flanges, bends, reducers, tees, weldolets, etc. (ASME, 2002).

According to Sharma and Maheshwari (2017), stating that welded pipes and fittings bear internal fluid pressure once in use constantly, as such, the high strength pipeline materials and the quality of welding, in terms of appropriate standards and techniques, play a vital role in ensuring reliability and profitability overtime for the construction of these oil and gas pipelines. Further explaining the increase in demand and discovery of new locations for natural resources, transportation of these products through the pipelines could span up to thousands of kilometres and hence, the overall weldability involved for the various joints encountered presents enormous challenges to pipeline engineers.

The oil and gas pipelines and fittings are manufactured following the worldwide standard and specifications, such as the American National Standards Institute (ANSI) American Petroleum Institute (API), American Society of Mechanical Engineers (ASME), American Society for Testing and Materials (ASTM), Manufacturers Standardization Society (MSS) (Biose, 2019; ASME, 2002; API, 2013). These pipes and fittings are manufactured according to various ranges of specified outside diameters sizes and wall thickness.
These specifications are classified by grades, according to Biose (2019), the material grade denotes the designed and manufactured thickness or internal thickness of the

pipelines and fittings to withstand operational stresses and internal corrosion during their design life span. The standards and specifications of these materials depend on the chemical composition and mechanical properties each material is designated to operate within the intended use (API, 2013).

As a result of the high-pressure application involved in onshore, offshore or underground or surface pipelines network, which usually occurs in the form of the large variation of the ambient condition. Hence, oil and gas pipelines materials of the carbon steel grades quality conform to the worldwide standards: ASTM A 106 Grade B or API 5L Grade B for low-pressure range and high working pressure or large diameter size, and also, including the type API 5LX range, based on designs for the working pressure (DPR, 1992; Sharma and Maheshwari, 2017).

The delivered pipes at sites, including the fittings, are usually laid aligned along the pipeline route in series, referred to as pipe stringing, in preparation for welding procedure and the testing of the welded joints. The testing includes Nondestructive testing (NDT) and Hydrostatic (DPR, 1992). Both tests ensure the integrity of the welded pipeline network joints. To guide against corrosion, the certified joints must be sealed with the recommended painting and coating, such as epoxy resin, polyurethane, coal tar enamel, asphalt enamel, mastic asphalt and polyethylene wrapper (DPR, 1992; Samimi and Zarinabadi, 2012).

According to DPR (1992); ASME (2002), the hydrostatic test or leak test involves using pressurized water to test, usually in the range of 1.25 to 1.4 multiple the maximum designed working pressure for a section or the whole closed pipeline network under specified time frame. Once the integrity of the pipeline network is certified capable of operational use, the water is expunged before the introduction of the intended fluid.

DPR is the statutory regulatory body responsible for monitoring and ensuring compliance of the Oil and Gas industry in the country for the sole objective of maintaining approved standards in all activities involved in the industry (DPR, 1992).

### 2.4.1 Welding Procedure

Welding is the process of fusing two or more item of the same or dissimilar materials to become a coalescence body (Prasanna and Rao, 2016). While Sidhu and Chatha (2012) defined welding as a process of joining two steel pieces together by applying heat which melts them together forming molten filler material and solidify after cooling to form a single continuous item (Sidhu and Chatha, 2012). Furthermore, explaining that the process which depicts the strength of weldment of the joined piece largely depends on the materials metallurgy, engaged welding process and the welder skills and techniques. It can be used in different environments such as in earth atmosphere, underwater and outer space, and as such, applicable in several sector of industry – construction, oil & gas, aircraft, transportation, machine manufacturing, etc.

Prasanna and Rao (2016) affirmed that welding process is categorized into two: liquid state (fusion) and solid state (pressure), according to the condition of base material. Fusion welding involves heating of two separate materials of similar composition to melting point to fuse, with or without the addition of a filler metal between the joint gaps. Examples of fusion welding include arc welding, oxy-fuel gas welding, submerged arc welding and resistance welding. While, the solid state welding involves joining surfaces of similar or dissimilar materials together through the application of pressure rather than heat, and no filler metal is required (Cronje, 2005; Prasanna and Rao, 2016). Examples of solid-state welding include cold welding, forge welding, friction welding and ultrasonic welding.

This welding operation done manually is used by metalworkers in the fabrication, maintenance and repair works, adequately ensures reliability through the mechanical and chemical properties of materials, and achieves water and air tightness and appropriate joining efficiency and strength (Alam, 2005; Sidhu and Chatha, 2012).

As stipulated by DPR (1992), affirming the welding quality standards for all pipelines and fittings in accordance with the API 1104/1107. For enhancing the welding quality through the arc welding method, thorough consideration over the following welding parameters is put into practice by the welding team, such as welding current, welding slot types, electrode diameter size, welding timing and speed, electrode angle position and direction, arc length to the workpiece, etc. (Soy et al., 2011).

However, welding exhibit several side effects associated with the welded structures in the form of distortion, misalignment, destabilize the state, lack of penetration, residual strain etc. which invariably lower the structural integrity and lassitude crack propagation life around the heat affected area (HAZ) of welded structure (Alam, 2005; Zeinoddini et al., 2013). The resultant side effect is referred to as “weld defect”. While Sharma and Maheshwari (2016) further explained that unsuitable environmental conditions and erroneous welding designs or procedures do lead to weld defect. Both citing instances where hydrogen embrittlement or corrosion as a result of improper welding, and adverse weather condition and thermal heat during welding activities.

Based on a general guide as provided by AWS (2015), listed in Table 2, suggesting the adaptation of the sequence of welding and inspection operations involving the preparations, during, and aftermath of the welding procedure. The given sequence of activity, however, depends on the weldment type, method of execution, and the stipulated project contract terms. Before the commencement of welding operations, a tack weld is normally done to hold the workpieces together in correct alignment, creating a gap to be filled by the weld metal/ solidified weld (ASME, 2002).

**Table 2.** Welding and inspection operations sequence (AWS, 2015).

**Sequence of Welding and Inspection Operations**

| Prior to Welding | During Welding | After Welding |
|---|---|---|
| • Material Identification<br>— Chemical analysis<br>— Mechanical properties<br>• Base Metal Conditions<br>— Freedom from internal and surface discontinuities<br>— Flatness, straightness, dimensional accuracy<br>• Joint Condition<br>— Edge Shape<br>— Dimensional accuracy<br>— Cleanliness<br>— Root opening<br>— Alignment<br>— Backing<br>— Tack welds<br>• Special Assembly/Fabrication Practice<br>— Adequacy and accuracy of jigging, bracing, or fixturing<br>— Application and accuracy of pre-stressing or precambering | • Preheat and interpass temperatures<br>— Controls<br>— Measurement methods<br>• Filler Metal<br>— Identification<br>— Control<br>— Handling<br>• Root Pass<br>— Contour<br>— Soundness<br>• Root preparation prior to welding second side<br>• Cleaning between passes<br>• Appearance of passes (sometimes in comparison with workmanship standard)<br>• In-process NDE as required or specified<br>• Conformance to approved welding procedure | • Postheat treatment requirements<br>• Acceptance inspection<br>• Method of cleaning for inspection<br>• Nondestructive examination<br>— Visual examination<br>— Surface contour and finish of welds<br>— Conformity of welds with drawings<br>— Magnetic particle<br>— Liquid penetrant examination<br>— Radiographic examination<br>— Ultrasonic examination<br>— Proof testing<br>— Other suitable methods<br>• Destructive testing<br>— Chemical<br>— Mechanical<br>— Metallographic<br>• Marking for acceptance or rejection<br>• Repairs<br>• Inspection after repair |

### 2.4.2 Shield Metal Arc Welding Process

Based on this research, shield metal arc welding (SMAW), also known as stick welding or manual metal arc welding, is considered due to its major use in the country oil and gas pipeline construction, maintenance and repair operations. The SMAW is categorized under arc welding which uses a consumable stick or electrode - filler metal rod coated with chemicals – to form an electric arc when placed in close contact with a base metal for the purpose of achieving fusion (Soy et al., 2011).

Welding commences when a generated electric arc is struck by the contact between the tip of an electrode and the workpiece or base metal to be welded. The arc melts both electrode and the metal surfaces to be welded to form a weld pool of molten metal, with aid of the chemical coatings (flux), slag and gas is formed to protect the weld pool from the surrounding atmosphere. Hence, the final solidified weld cleaned to remove the slag coverings by chipping or wire brushing (Cronje, 2005; Genculu, 2012).

An electric current, either alternating (AC) or direct current (DC), is used to generate the welding power supply in order to maintain constant welding, usually set between 30 to 300 Amperes and voltage supply between 15 to 45 volts depending on electrode type (Cronje, 2005; electrical exam, 2018). The workpiece is grounded as shown in Figure 2.

However, prior to the commencement of welding activities, preheating may be necessary to raise the temperature to a desired minimum level of the workpiece based on applicable welding procedure specifications. The applied minimum temperature specifications consider the grade and thickness of the base metal and weldment size. Preheating involves using oxyfuel torches, resistance elements and induction coils to heat up the welding surface area of the base metal before commencing welding. The risk of crack is greatly reduced with appropriate preheating, interpass temperature heating and post-heating (AWS, 2015).

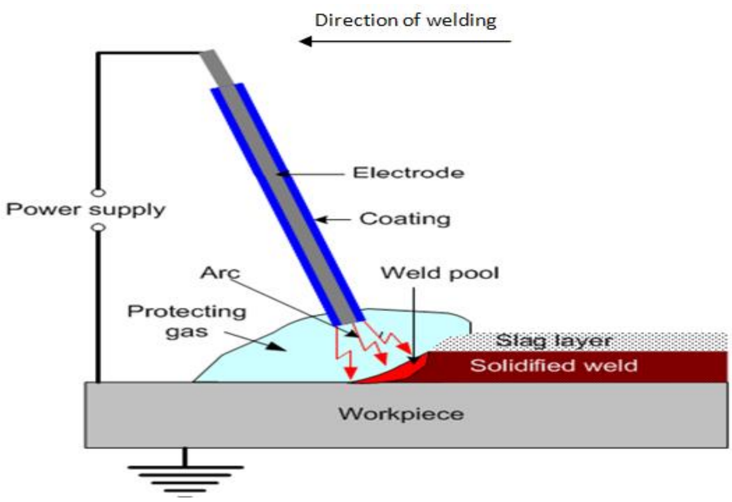


**Figure 2.** Schematic welding process of SMAW (Soy et al., 2011).

The use of SMAW in the construction industry is based on the fact that it dominates other welding processes due to its reliability, low cost, versatility, simplicity and portable welding equipment - which can be used both indoors or in situ.

#### 2.4.2.1 Welding Equipment

The ideal welding equipment used for SMAW consists of welding cables, electrode holder, grinding tools, cleaning tools, PPE, ground clamp and an uninterrupted welding power supply generating set, as depicted in Figure 3. Depending on the type of electrode to use and desired properties of the weld, the polarity of the welding cables is interchanged. For the DC operated welding machine, the direct current with a negatively charged electrode (DCEN) heat up the electrode to achieve increasing the melting rate but causes a decrease in weld depth. To achieve the best penetration and bead profile, so swapping the polarity of the welding cable of the electrode to positively charge (DCEP) and the negative charge to base metal (becomes hotter), thus, ensures an increase in penetration of the welding and welding speed (Sidhu and Chatha, 2012).

The welding machine is generally built to reduce the incoming voltage source and increase the amount of current for welding through the step-down transformer (Sidhu and Chatha, 2012).

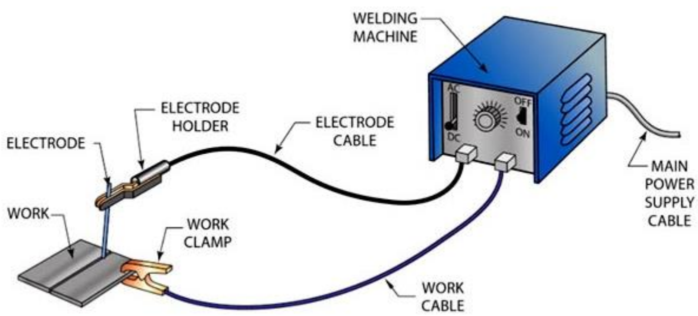


**Figure 3.** Shield metal arc welding equipment (electrical exam, 2018).

#### 2.4.2.2 Welding Materials

Electrodes or consumables are the essential materials used to achieve fusion in the welding process for SMAW. Based on the purpose of welding and the SMAW, the two main group types used are the joining and filler welding electrodes. The solidified molten compose both forming the arc and filling the welding area. The diameter of electrodes varies but the most used sizes are 2.50 mm, 3.25 mm and 4.00 mm, and having lengths of 20 cm to 45 cm (Soy et al., 2011).

It consists of flux coated core wire stick and its classified by the tensile strength of the coating type, specified welding position, deposited weld material, specified current and polarity, as depicted in Table 3. Furthermore, the choice of the type of electrode to be used depends on the thickness of workpiece material, type of welded material, welding position, recommended welding current and welding slot type (IAEA, 2001; Soy et al., 2011). The recommended worldwide standard electrode for SMAW comply with AWS S5.1 and ISO 2560.

**Table 3.** Classification of types of electrodes with strength capability (IAEA, 2001).

| Electrode classification | Minimum tensile strength | | Minimum yield strength | |
|---|---|---|---|---|
| X = a variable | MPa | ksi | MPa | ksi |
| E60XX or E43XX | 425 | 60 | 345 | 48 |
| E70XX or E48 XX | 485 | 70 | 395 | 58 |
| E80XX | 550 | 80 | 460 | |
| E90XX | 620 | 90 | 530 | |
| E100XX | 690 | 100 | 600 | |
| E110XX | 760 | 110 | 655 | |
| E120XX | 825 | 120 | 740 | |

### 2.4.3 Non-Destructive Testing (NDT)

For safety and reliability of welded joints, importance is normally placed with Inspection of welds. Hence, the NDT is considered highly significant due to techniques deployed to test material welded joints through the internal flaws or visible surface flaws without interfering with its suitability for the intended purpose (Valavanis and Kosmoloulos, 2010).

According to AWS (2015) defined non-destructive tests as proof testing the design, materials and manufacturing methods of the welded joints in meeting the stipulated design requirements to guard against joint weakness or failure once in operation.

AWS (2015); DPR (2001), both listed the different methods used for NDT in evaluating materials and welds: radiographic inspection, ultrasonic testing, visual inspection, magnetic particle testing. These methods reveal weld defects in the form of discontinuity based on the applied test signal, through visual observation by Certified Weld Inspectors (CWI). These CWI can recognize the various types of defects and demands for repairs for the affected joints before been certified non-defective through the weld inspection reports (Valavanis and Kosmoloulos, 2010; AWS, 2015).

This test may include a visual examination of welded joints to verify correct size and location as specified through the design drawings. Penetrant or magnetic particle testing may be initiated to check crack free welds or the machined section of the involved material does not indicate grinding cracks. Volumetric tests such as ultrasonic or radiography (x-ray) of welded joints may also be deployed to check for cracks, incomplete joint penetration, intemperate porosity and incomplete coalescence (AWS, 2015; IAEA, 2001). A review of the material test reports may also be considered for verification purposes to ascertain the correct use of material. Repairs of the total or defective section of the welds must be initiated once it fails to meet the design criteria standards.

### 2.4.4 Weld Defects and Repairs

Weld defects can be regarded as discontinuities or imperfections that sometimes occur in welded materials' joints which leads to rejection based on integrity conducted test and eventually repair or replace (ASME, 2002; IAEA, 2001). Once weld defects detected in any joint lengths –either partial or full - repairs are initiated by grinding the weld metal away with an angle grinder and its removal verified by inspection to commence re-welding according to the Welding Procedure Specification (WPS), such as API 1104, API RP 1107 and API RP 1111 (ASME, 2002; DPR, 1992; Zeinoddini et al., 2013). Furthermore, another NDT on the repaired joint is conducted to verify the zero-defect status according to the welding procedure specifications.

However, Alam (2005) argued, through a doctoral research paper, the negative effect of weld repair on welded materials in terms of loss of mechanical properties, fatigue crack, microstructure alteration of the HAZ and redistribution of weld residual stresses in the HAZ. The research revealed, using three specimen metal plates: unwelded, welded and weld-repaired, that the weld-repaired plate showed much lower fatigue life compared to the welded and unwelded plates. Thus, concluding the cracks in the HAZ of weld-repaired plate joints exhibited much larger defects and other side effects (Alam, 2005).

Zeinoddini et al. (2013), showed in a research publication, in Table 4, the partial repair weld of length 350 mm of an offshore pipeline based on the approved welding parameters - Procedure Qualification Record (PQR) and WPS. A test sample of the pipe of grade API 5L X52 steel with OD of 203.2 mm (8 inches) size and thickness of 15 mm. The repair was carried out with a qualified welder using the SMAW (Zeinoddini et al., 2013).

**Table 4.** Welding parameters for a partial repair welding (Zeinoddini et al., 2013).

| | | PASS 1 | PASS 2 | PASS 3 | PASS 4 |
|---|---|---|---|---|---|
| Electrode AWS class. | | E7016G | E7016G | E7016G | E7016G |
| Electrode dia. | mm | 4 | 4 | 3.2 | 3.2 |
| Current & polarity | | AC | AC | AC | AC |
| Avg. current | A | 138 | 144 | 104 | 109 |
| Avg. voltage | V | 25 | 24 | 21 | 22 |
| Avg. travel speed | mm/s | 9.2 | 8.1 | 11.1 | 9.8 |
| Inter pass temp. | °C | 52 | 87 | 168 | 203 |

This investigation explains the adverse effect of transverse tensile residual stresses on the weld area of a partially repaired section of steel plate compared to the initial welding. While a preheating treatment of temperature of 600 degrees Celsius for 1 hour was necessitated and subsequent cooling to ambient temperature with a furnace.

Weld imperfections have several characteristics and remedies, which tends to occur at the weld toe or weld termination, as described by Alam (2005), thus, highlighting these different weld imperfections.

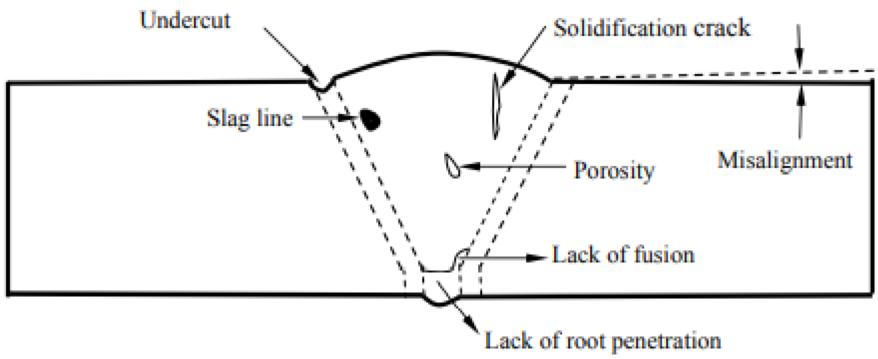


**Figure 4.** Various weld imperfections in butt weld joints (Alam, 2005).

As highlighted by Alam (2005), the typical weld imperfections in Figure 4, displays positional occurrences of several types of weld defects in a cross-sectional piece of metal. While, in Table 5, the possible causes and remedies of these different types of weld defects as presented.

**Table 5.** Types of welding defects and remedies (Welder Porter, 2020).

| S/N | Types of Welding Defects | Causes | Corrective Measures |
|---|---|---|---|
| 1. | **Porosity**<br><br>This is due to weld metal contamination. Bubble-filled weld occurs that weakens overtime as a result of trapped gases. | • Contaminated welding surfaces, such as rust, paint, oil/grease<br>• Wrong surface treatment<br>• High moisture content at surrounding<br>• Too long arc<br>• Insufficient electrode deoxidant | • Proper cleaning of welding surfaces<br>• Correct arc length<br>• Appropriate weld speed<br>• Use appropriately stored &dry electrode<br>• Proper weld technique |
| 2. | **Incomplete Fusion** | • Too much weld speed usage<br>• Overflowing weld pool | • Proper cleaning of welding surfaces<br>• Prevent overflowing weld pool |

| | | | |
|---|---|---|---|
| | This occurs as a result of improper fusion between weld bead and base metal. | • Contaminated welding surfaces, such as rust, paint, oil/grease<br>• Wrong electrode angle position<br>• Inappropriate electrode type for base metal<br>• Insufficient heat input | • Reduce deposition rate |
| **3.** | **Incomplete Penetration**<br><br>This occurs as a result of incomplete filling of the grove depth & creating void at the joint depth. | • Insufficient heat input<br>• Overflowing weld pool<br>• Contaminated welding surfaces, such as rust, paint, oil/grease<br>• Wrong electrode angle position<br>• Inappropriate electrode type for base metal | • Proper cleaning of welding surfaces<br>• Prevent overflowing weld pool<br>• Reduce deposition rate |
| **4.** | **Slag Inclusion**<br><br>This occurs when slag is formed from the flux coating during welding and mixes with weld metal. | • Too much weld speed usage<br>• Improper cleaning of each weld pass before the next pass<br>• Too low weld current usage<br>• Insufficient cleaning<br>• Faster cooling of weld pool | • Use correct weld current<br>• Use proper electrode angle<br>• Ensure appropriate cooling of weld pool<br>• Removal of slag regularly by wire brushing<br>• Appropriate weld speed |
| **5.** | **Spatter**<br><br>This occurs as tiny solidified particles from the weld | • Too high weld current usage<br>• Too low voltage usage<br>• Contaminated surface<br>• Unstable wire feeding<br>• Too long arc usage | • Proper cleaning of welding surface<br>• Use proper electrode angle<br>• Correct polarity usage |

| | | | |
|---|---|---|---|
| | pool scattering along the weld path. | • Wrong electrode angle position<br>• Wrong polarity usage | • Correct arc length<br>• Appropriate current & voltage |
| **6.** | **Undercut**<br><br>This occurs as groove formation at the edges of the width of welds or weld toe and left unfilled by weld metal. | • Too much weld speed usage<br>• Wrong filler metal<br>• Too high weld current usage<br>• Inappropriate weld technique<br>• Too long electrode usage<br>• Wrong electrode angle position | • Use appropriate welding technique<br>• Use proper electrode angle<br>• Appropriate current usage<br>• Correct arc length<br>• Appropriate weld speed |

# 3 RESEARCH METHODOLOGY

This chapter might be regarded as the core essence of this research. This arises from the fact that the research methodology adopted ensures clarity to the research topic. The contents of the previous chapters, especially the literature review, formed the basal structure for the research methodology.

The central point of interest for this research methodology lies in the data analysis, where the gathered data is further split into two main sections in order to recommend a possible resolution to the problems. The first part (Section 1) centers on the analysis of the primary data through the returned survey questionnaire. While the second part (Section 2) focuses on the DMAIC of Lean Six Sigma.

The importance of research methodology according to Remenyi et al. (1998), explaining that research methodology seeks ways research problem is confronted and usually involves the procedure selected towards theories, research techniques, data gathering and analysis scheme. While, Umude-Igbru (2017), affirmed the significance of research methodology adaptation by a researcher as high dependence on the type of research problems and the solutions it seeks to obtain.

The integrity of the adopted methodology is critical to the reliability and validity of the study and its subsequent findings. Thus, the essence of this chapter will shed light on the methods, techniques and tools selected towards achieving the research goals.

## 3.1 Research Methodology Flowchart

The flowchart depicts the overall flow of the research, which encompasses the three stages – starting from the initial research consideration to the final research resolution, as depicted in Figure 5.

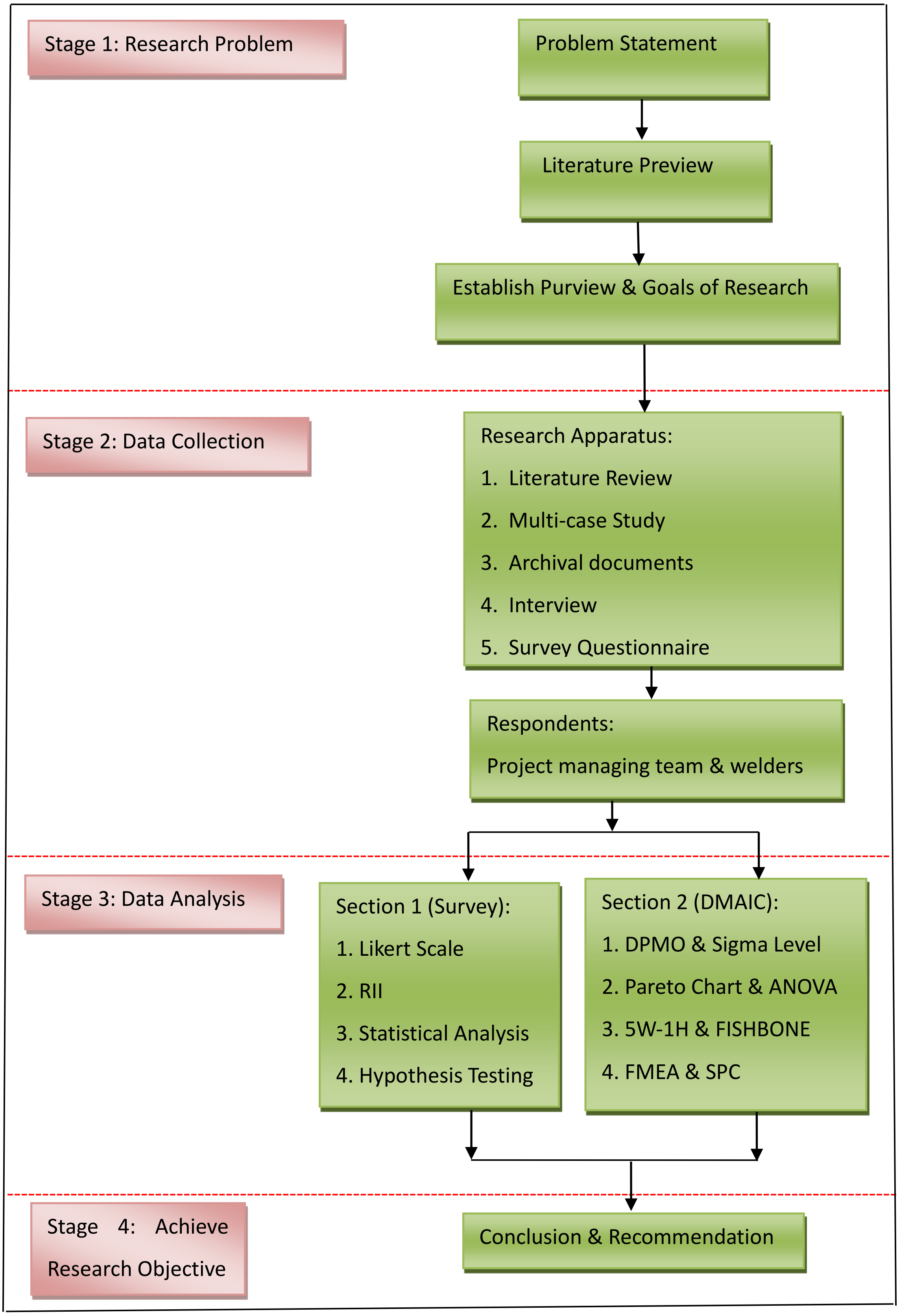


**Figure 5.** Research methodology flowchart.

## 3.2 Research Strategy

For this research to thoroughly review and understand the subject matter, an appropriate design and strategy must be adopted that utilizes the in-depth research phenomenon to tackle the research problem.

Research strategy can be described as the utilization of appropriate tools to tackle peculiar research problems by the researcher (Umude-Igbru (2017). Further stating that selection of these strategies by the researcher is prone to the philosophical atmosphere surrounding the given research. Hence, the qualitative and quantitative approaches ensure effective utilization of the obtained data through the adopted survey and case studies research strategy as deem appropriate in attaining the objective of the research.

## 3.3 Research Sampling

### 3.3.1 Study Population

The target study population for Lagos State consisting of fifty-one (51) oil and gas pipeline construction firms operating and registered with the Department of Petroleum Resources, the government regulatory body responsible for the oil and gas industry (DPR, 2018; Occhiali, 2018; Aigboduwa and Oisamoje, 2013). However, the study eventually selected two (2) companies with a valid response to this research, which is 4% of the target population.

### 3.3.2 Sample Size

To instil statistical confidence in any available data, an appropriate magnitude of sample size is ensured for data analysis and interpretation (Zadeh et al., 2014). As a result of the two combined companies used for the research, the population size of interest involving the project team members in administrating and controlling the pipeline construction operations is sixty-four (64). This comprises the project managers, project engineers, site engineers, welders and fitters. So the expected sample size of respondents is fiftyfive (55) based on the sample size formula, with a 90% Confidence Level and +/-7% Margin of Error (Lohr, 1999).

## 3.4 Research Methods

The research methods adopted both quantitative and qualitative research methodologies. The adopted selection depends on the researcher and the criteria involved for the research designs, as such targeting the data collection and analysis (Umude-Igbru, 2017). According to Amaratunga et al. (2002), stating that using both methods, referred to as "mixed-method research", and based on strong suggestion within the research community that they effectively complement each other in any research work. While, Obiajunwa (2010), further stating that the adaptation of both quantitative and quantitative promotes better understanding and aid in drawing appropriate conclusions for the research works.

The research methods employed for this research involves the mixture of interviews, questionnaire surveys and case study. All this method ensures adequate data collection.

### 3.4.1 Case Study

Utilizing a case study approach enables a researcher to have a clear understanding of any organizations' natural settings of various entities under investigation such as contemporary phenomenon, for the purpose of data gathering from active participants within such entities and unrestricted controls or boundaries (Hartley, 2004). While Umude-Igbru (2017), states the importance of a case study to a researcher in the form of noting the various diverse aspects of the contemporary phenomenon and explore any possible relationship of any given process conducted within a natural context.

Case study research entails single or multiple case studies. For the sake of this research, multiple case studies were adopted, which considers more than one or multiple companies for any possibility of comparing and understanding any contemporary phenomenon involved among them (Eisenhardt and Graebner, 2007).

Hence, the first case, referred to as Company A, situated in Lagos State, Nigeria, has been heavily involved in the engineering and construction of oil and gas pipeline for the past 16 years, and as such, encountered quality weld defects during its operations.

While the second company, referred to as Company B, is also located in Lagos State, Nigeria, is a fully integrated engineering, procurement and construction company, mostly in the oil and gas industry in the past 12 years.

### 3.4.2 Interviews

Interviews can be regarded as an essential means of qualitative research to collect data for the purpose of acquiring information, opinions, in-depth understanding, experiences and perspectives of key actors involved in the day to day operations of an event or organization.

For this research, semi-structured and unstructured interviews were adopted and were conducted over the phone with the pipeline project managing team, includes the project managers, project engineers, quality engineers, site engineers, mechanical engineers, technicians, welders and fitters. Several interactions, discussions and questioning ensued, which shed light on the selection of the four influencing factors or groups associated with pipeline welding quality – environment, machine, materials and man.

### 3.4.3 Quesionnaire Survey

The questionnaire ensures the passage about information of respondents' knowledge and opinions to the research work. According to Mohamed et al. (2019); Saunders et al.

(2009), explaining the essence of a questionnaire as a means for conducting explanatory and descriptive research phenomena of cause-effect relationships or the involved trait and impression by a researcher. The obtained data tends to be reliable based on the direct sources knowledge and opinions readily availability. Thus, taking the data as the primary data.

The formulation of the questionnaire came primarily from the plethora of literature sources and extensive conducted interviews. Using this approach ensure wide coverage of various possibilities of causes for pipeline weld quality. The respondents of the survey questionnaires target the companies' project managers, project engineers, quality engineers, site engineers, mechanical engineers, technicians, welders and fitters. With the use of VOE, the collected survey results ensure appropriate feedback in terms of technical and in-depth knowledge regarding pipeline construction operations.

The questionnaires are administrated through electronic mail and a web-based link, which directs respondents with the provided link. Prior phone calls were made before sending the questionnaires to explain the essence and permission to respondents of the two case companies. The questionnaire composed of open-ended and closed-ended questions. The open-ended questions, being a qualitative approach, validate the data collection by ensuring the inputs of the respondents are of their own words and opinions rather than an imposition of predetermined responses notably with the closed-ended questions been used as a quantitative approach (Denni-Fiberesima and Rani, 2011).

The questionnaire is divided into three main parts. SECTION ONE relates to general information for both companies' respondents. SECTION TWO relates to the pipeline project managing personnel responding to questions relating to the four dependent influencing factors or categories associated with pipeline welding quality – environment, machine, materials and man. And SECTION THREE relates to the pipeline welders.

In the closed-ended questions, respondents must select their opinions or level of effect in each of the numbered questions and statements of the questionnaire appropriately. Each of the four dependent factors has pertinent questions and statements followed by a six-point Likert scale. The scale ranged from (1), represents “No opinion”; (2), represents “Does not affect”; (3), represents “Slightly affect”; (4), represents “Affect”; (5), represents “Strongly affect”; and (6), represents “Extremely affect”.

To ensure validity and reliability of the questionnaire, the “No opinion” option entails respondents are not boxed in answering questions they do not know rather than leaving blank unanswered questions or invalid feedback. Also, further effects are made to respondents on how to go about the questionnaire process through further information, explanation of terminology and motivation to promptly complete the questionnaire through further reminders by email and phone follow-ups (Denni-Fiberesima and Rani, 2011). Otherwise, according to Russell (1994), respondents giving invalid feedback occur when participants are unskilled or misunderstood the importance of questionnaires (Russell, 1994).

## 3.5 Data Collection

As a means to ascertain the facts and reliability for research work, the researcher must ensure appropriate methods are effectively deployed to obtain correct data in the course of its gathering. This affirmation is based on Umude-Igbru (2017), stating in a doctoral publication, that data collection involves systematic methods and techniques employed by a researcher to acquire and analyze data correctly in a structured and reliable means which aims to achieve the research purpose and its validity.

Primary and secondary data sources formed a critical role in the research. This multiple data approach ensures optimum use in terms of richness and depth of knowledge to any research work (Inkoom and Biney, 2010).

The obtained primary data comprises:

- Questionnaire submitted to the project team
- In-depth interviews among project team
- Observation of welding processes
- Archival data through both companies' weld inspection report for the year 2019

The obtained secondary data comprise the literature review. The obtained academic sources formed the theoretical framework by providing pertinent information and guides for the research, especially in the peculiar area of interest.

### 3.5.1 Survey Response Rate

For the purpose of data collection, out of a total of 64 questionnaires distributed to both companies, the returned and properly filled questionnaires were 59 respondents, which shows 92% of response rate for analysis. This number exceeded the calculated sample size of 55 respondents. While each case company questionnaire response rate shows 91% for company A, and company B shows 93%, as depicted in Table 6.

The respondents were informed of the survey commencement through various emails, text messages and calls, while the period of collection of questionnaire span 5 weeks. All the returned questionnaires came through the provided web-based link and my college email.

**Table 6.** Workforce and survey response rate of case companies' pipeline construction team (Survey, 2020).

| Case companies | Company sector | Employees | Workforce involved in pipeline welding operations | Respondents involved in the questionnaire survey |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **Company A** | Project management team | 35 | 24 | 21 |
| | Welding team (certified) | | 11 | 11 |
| **Company B** | Project management team | 29 | 20 | 19 |
| | Welding team (certified) | | 9 | 8 |

## 3.6 DMAIC Model

The research utilizes the DMAIC model of the LSS. This ensures the step-by-step procedure of the LSS methodology is followed in order to critically examine the associated problem of the weld quality and to arrive at an appropriate solution.

The essence for using LSS improvement mechanism is based on optimization of processes in which the relationship between vital process inputs ($X_S$) and the eventual process output(Y) are critically examined to achieve desired objectives or reset the inputs if required appropriately (Abdelhamid, 2003; Munro et al., 2008).

$$Y = f(X_1, X_2, X_3, X_4). \quad (1)$$

*Where inputs are denoted by function of X, and output by Y.*

Using the deterministic approach for measurement, as expressed mathematically in the above formula (Eq. 1) and the survey questionnaire as the measurement instrument for data in ranking the responses, effectively ensure the possibility for quantifying the behaviour of the “Xs” and “Ys” and the inherent relationships between the inputs, processes and outputs (Gygi et al., 2012).

This research scenario's outcome represents the Y in this equation, being noted as the quality of the weld, which seeks to achieve satisfaction through the requirement of VOC and VOP. Anything short of attaining this satisfactory equilibrium, such as high weld defects in any given pipeline project, tends to cause dissatisfaction with VOC and VOP.

In furtherance of the above mentioned paragraph, Gygi et al. (2018); Desai and Shrivastava (2008), stated that for organizations to desire performance improvement in processes, the characteristics for output(s), referred as Y or Quality of weld, must be thoroughly examined to identify these critical inputs, referred as "$X_S$": $X_1$ = environment, $X_2$ = machine, $X_3$ = materials, $X_4$ = man. Note, these inputs are regarded as key process input variables (KPIV). Thus, understanding and addressing these inputs effectively facilitate resolutions and therefore, enhance the output, as depicted in Figure 6.

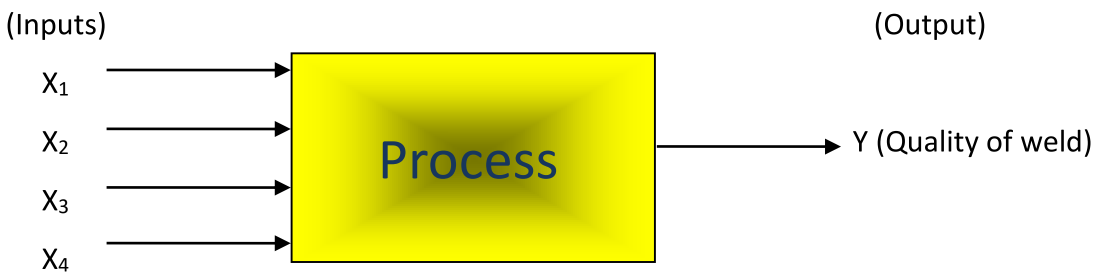


**Figure 6.** Categories of inputs, process and output (Gygi et al., 2018).

Gygi et al. (2018), eventually summarizes that appropriate utilization of the measured data tends to position the researcher toward greater efficiency with the capabilities of Six Sigma vis-à-vis the DMAIC model. Hence, the following sub-divisions practically illustrate the application of DMAIC model in a sequential phase for the purpose of process improvement and problem-solving of weld defects encountered in the pipeline construction operation.

### 3.6.1 Define Phase

This is the first stage of the DMAIC model, which seeks to determine the project's scope and boundary, VOC requirements and the projects overall objectives (Jirasukprasert et al. 2012). The evaluation of the current scenario for the organization is holistically considered to commence an extensive investigation, and utilize collected data for comparisons quantitatively and statistically.

The following LSS tools and techniques, commonly used in these phases, ensure general understanding and clarity of the situation at hand for use by subsequent phases:

#### 3.6.1.1 Project Charter

The project charter, which is a tool used in LSS, ensures a given project's problem, objective, scope, structure, boundary and team involved to be clearly displayed as a form of project documentation procedure (Jirasukprasert et al., 2014; Srinivasan et al., 2014). It defines any given project's overall information structure, illustrated in Table 7.

**Table 7.** Project charter for both companies.

| | |
|---|---|
| **Project charter** | Company A/B: Pipeline Construction Operation |
| **Problem Statement** | Weld defects in pipeline welding operation causes schedule delays, rework, cost and time overruns |
| **Goal Statement** | To reduce the weld defect encountered during welding operations by the application of Lean Six Sigma methodology |
| **Project boundary** | Focusing on welding activities |
| **Voice of the customer (VOC)** | Welding quality |

| | |
|---|---|
| **Business case and expected benefits** | Defects occurances cause rework, incur extra expenses and |
| **Expected customer benefits** | Attain customer satisfaction and positive perception towards construction firms |
| **Team members** | Project student, project supervisors and employees of the concerned companies |

#### 3.6.1.2 Critical To Quality (CTQ)

A critical requirement of customers or end-users expectations from any product, process or service is a satisfaction that is expressed through the Voice Of Customer (VOC). As such, this requirement can also be expressed through the CTQ (Dumitrescu and Dumitrache, 2011; Mamatha et al., 2014). Therefore, the developed CTQ relies on two drivers: welders and the project management team.

To meet customer satisfaction, critical drivers must ensure all project processes work adequately in terms of qualified and competent personnel; use of approved and standard equipment and materials; meeting project time delivery as agreed and high quality of completed project without flaws, as depicted in Figure 7.

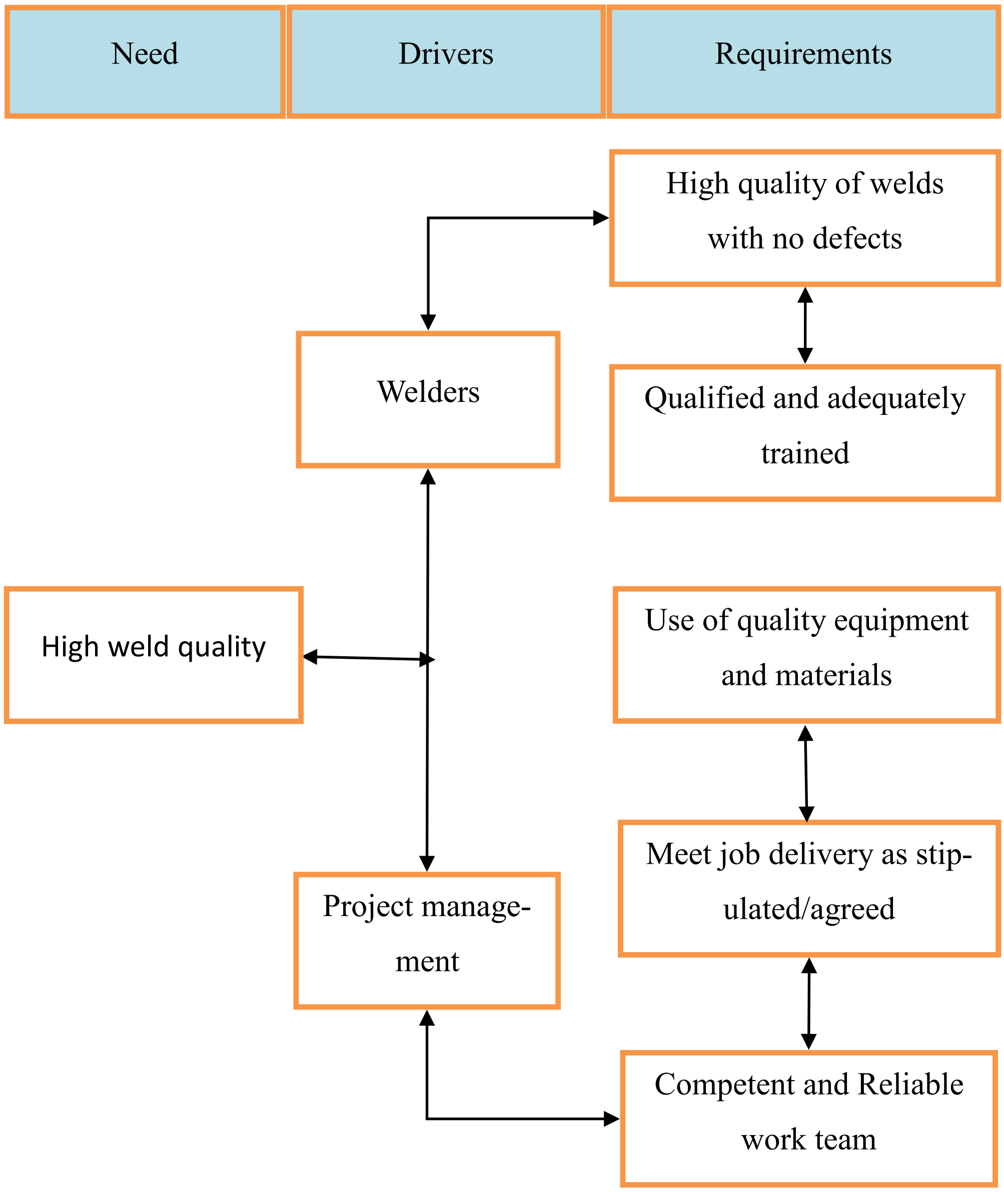


**Figure 7.** CTQ diagram for attaining high quality of welds.

### 3.6.1.3 SIPOC

To understand the involved problems, a LSS process mapping tool, such as SIPOC – Suppliers, Inputs, Process, Outputs, and Customers – is used to gain an in-depth understanding of the welding procedures along with the associated elements involved (Anderson and Kovach, 2014). Table 8, shows the SIPOC project's pipeline journey starting from delivery to site to the eventual use by end-users. While Tenera and Pinto

(2014), explained its relevance in terms of having a better view of the involved project activities and stakeholders to easily identify areas of interests.

**Table 8.** SIPOC process for construction of pipeline system (Anderson and Kovach, 2014).

| Suppliers | Inputs | Process | Outputs | Customers |
|---|---|---|---|---|
| Pipe & fitting suppliers, Welding electrodes, welding materials, Welding equipment, Water, Air compressor, Nitrogen cylinders | Pipe Fittings, Welders, Pipe fitters, Project drawings, Project specifications, Weld procedure, Weld machine, Pressure test, Weld inspection test & devices | Certified materials, Cut & fit pipes, Cut & fit fittings, Tack weld, Make weld, Inspect weld, Repair weld, Certied pipeline system | Weld inspection reports, Pressure test reports, Pipeline system approval for use | Facilities, End users |

### 3.6.1.4 Process Flowchart

The process flowchart ensures, according to Jirasukprasert et al. (2014), a comprehensive understanding in the form of graphical illustration of any given processes' flow sequence to assess the various stages involved and tackle possible problematic areas.

The sequence of the pipeline welding process as shown in Figure 8, depicts the different stages involved such as the delivery of the pipelines to the site, inspection for quality products, preparation for welding activities, setting welding parameters, actual welding and numbering the various welds, NDT conducting on the welds and certification of the approved welded ones. However, disapproval for use of pipes or welds is systematically embedded along the process for outright rejection or repair once incapable of not meeting approved standards.

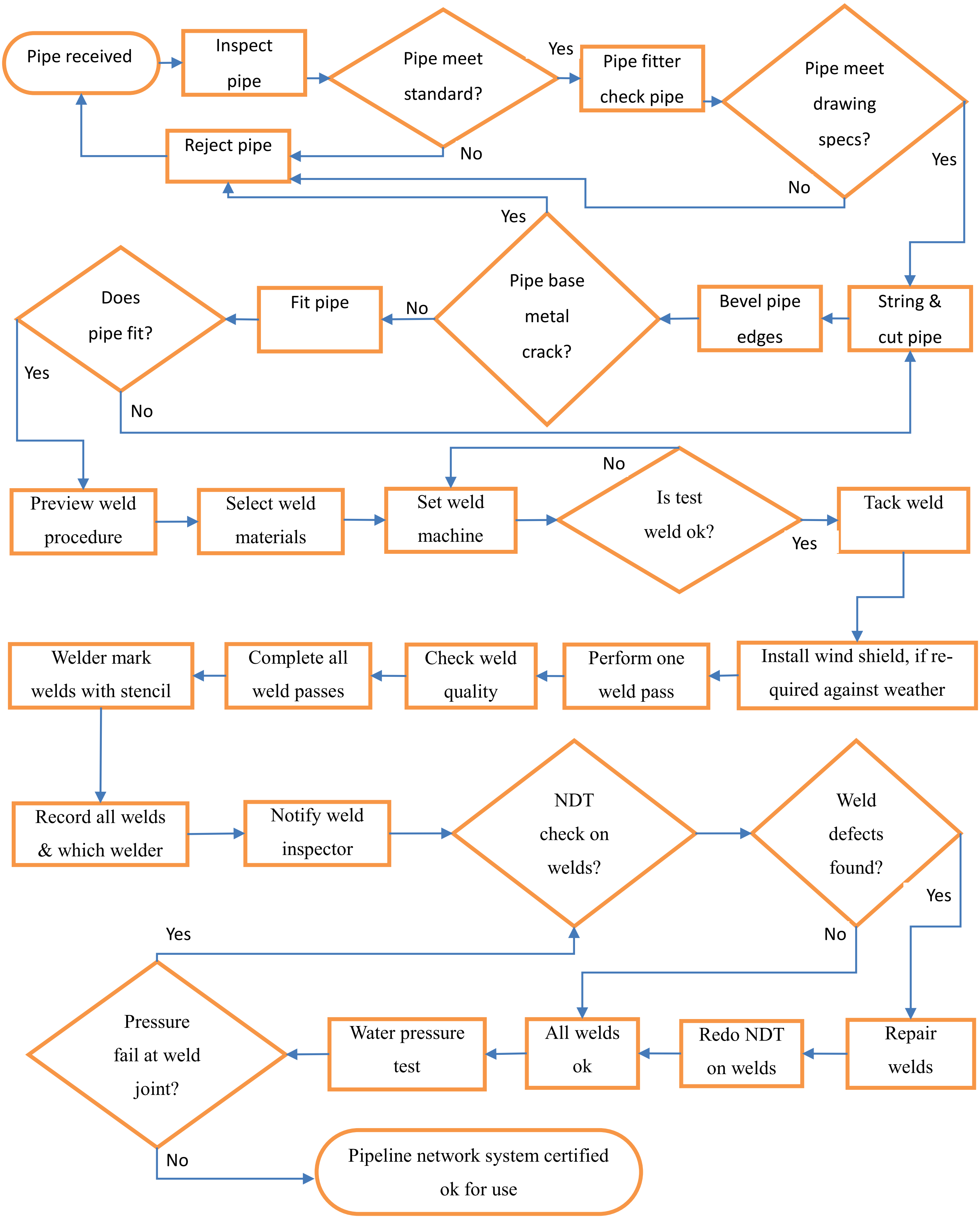


**Figure 8.** Flowchart of the pipeline network construction process.

### 3.6.2 Measure Phase

The measure phase entails appropriate data utilization of the given problem, that is, based on the acquired knowledge of the process, such as the general knowledge, data collection, verification of the aquired data, and assessing the possible variability to the process to effectuate positive outcome (Yadav and Sukhwani, 2016). The adoption of appropriate and reliable metrics for use to clarify the measurement and monitoring of the intended data will form the basis for analysis later on.

Through the collected data – weld defects and survey questionnaire – significant measurement performed with the help of LSS tools, coupled with substantial brainstorming ensures addressing the critical to quality in the welding operation.

#### 3.6.2.1 DPMO and Process Sigma Level

The Defect per Million Opportunities (DPMO) and the Sigma Level helps in evaluating the current performance or yield quality of a given process, service or product. For such a process to yield high value or quality (99.9997 %), the calculated DPMO must be 3.4 million opportunities or output with a value of 6 for the sigma Level (Youssouf et al., 2014. This simply means the process has zero defects or flaws to hinder the process performance.

By employing these two important metrics: calculation of the DPMO and sigma level, this indicates the situation of welding quality pipelines based on past weld defects records from both companies. Table 9, shows the process yield (%) as it relates to obtaining the values of the DPMO and Sigma Level for any given process:

**Table 9.** DPMO and sigma level for process, product & service (Youssouf et al., 2014).

| Process Sigma Level | DPMO | Process Yield (%) |
|---|---|---|
| 1 | 691462 | 30.90 |
| 2 | 308538 | 69.10 |
| 3 | 66807 | 93.30 |
| 4 | 6210 | 99.38 |
| 5 | 233 | 99.977 |
| 6 | 3.4 | 99.9997 |

From the weld inspection reports, initially obtained data, revealed the low quality of weld through DPMO and the Process Sigma Level (PSL) of the multiple case studies (Yadav and Sukhwani, 2016; ISIXSIGMA, 2020), as depicted in Table 10. The calculation is based as follows (Eq. 2 and 3):

$$DPMO = (Defects * 10^6 / (Opportunities * units). \qquad (2)$$

$$PSL = 0.8406 + \{SQRT\ [29.37-2.221 * Ln\ (DPMO))\}. \qquad (3)$$

*Where Ln is Natural logarithm*.

**Table 10.** Summary of DPMO and sigma level of both companies.

| Case Companies | DPMO | Process Sigma level |
|---|---|---|
| Company A | 160255 | 2.499627 |
| Company B | 155199 | 2.520951 |

#### 3.6.2.2 Process Capability

Process capability can be defined as the relationship between the voice of the process (VOP) and the voice of customer (VOC). This simply means the measurement of compatibility of the process performance to that of meeting or satisfying the expectation of customers (Gygi et al., 2012). While, Dumitrescu and Dumitrache (2011), defined process capability as a means of statistical measurement of a process targeting specific characteristics, which usually falls within customer expectation.

Based on the DMAIC model, the essence of computation of the process capability lies with the amount of the relationship between the process and the performance characteristics, subject to the intended requirements (Gygi et al., 2012). This ensures the involved metrics in focusing on the essential area for improvement of a set control. As such, the control limits are within boundaries or specification limits, thus, signifying that the process is considered to meet the expectations.

For the VOP, the desirable process thresholds lie within the lower control limit (LCL) and upper control limit (UCL). While the VOC, the desirable process thresholds lie within the lower specification limit (LSL) and upper specification limit (USL). Values outside these controls or specifications are considered as variations. The overall objective of LSS in a process is to reduce or eliminate variation to attain a sigma level of 6 or process yield of 99.9997% of the outputs within the controls or specifications.

Finally, the two main metrics for analyzing the process capability are the ”Cp” referred to as process capability and the ”Cpk” referred to as process performance. Dumitrescu and Dumitrache (2011), explained that the Cp value indicates how the process is performing within desired specification or outputs without considering the target, and the Cpk is how close the mean value is to the target value. These two measurements played important roles in analyzing the obtained data of the case companies in the next chapter (Statistical Process Control).

### 3.6.3 Analyze Phase

This phase critically analyzed the potential causes for the weld defects, with the aid of brainstorming, significant progress made in ensuring the identification of these causes, then analyzed and profer for solution for their elimination (Jirasukprasert et al. 2014). To achieve this phase, analysis of the data through appropriate investigation to ascertain and discern the readings or root causes of the weld defects.

#### 3.6.3.1 Pareto Chart

With the aid of the Pareto chart, identification of the highest sets of weld defects fell on slag inclusion and incomplete fusion, as a result of the main causes of the weld defects occurring in the pipeline welding operations of both companies.

Figure 9, shows for company A, the Pareto chart for the weld defects which occurred in an individual Project 7, while the other graph, Figure 10, showed the Pareto chart for all 10 recorded combined projects.

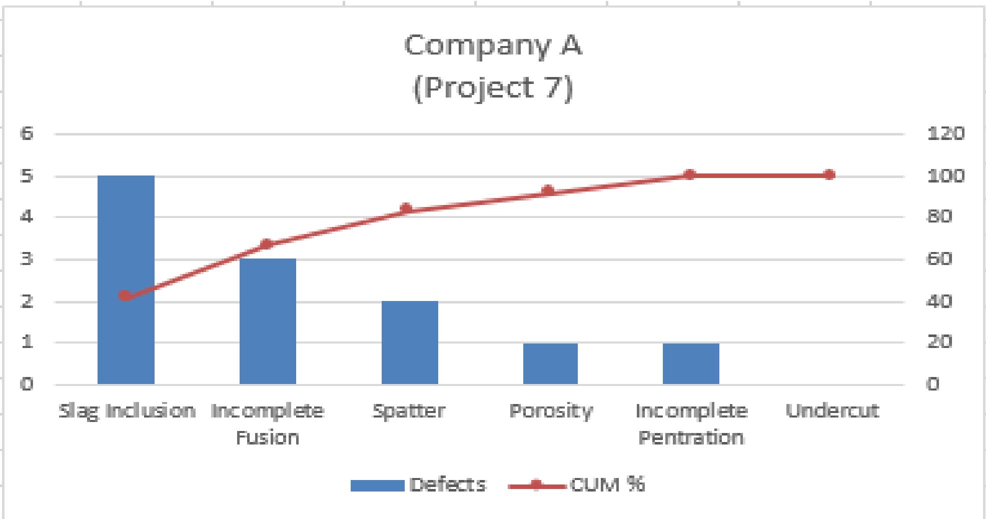


**Figure 9.** Pareto chart for Project 7 of company A.

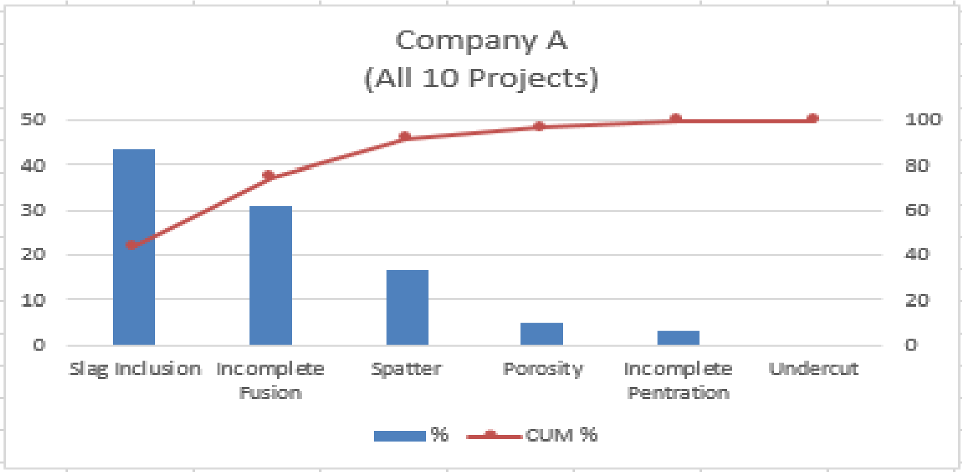


**Figure 10.** Pareto chart of all combined 10 projects of company A.

While in company B, in Figure 11, revealed the Pareto chart for the weld defects which occurred in an individual Project 5, while the other graph, Figure 12, showed the Pareto chart for all 6 recorded combined projects.

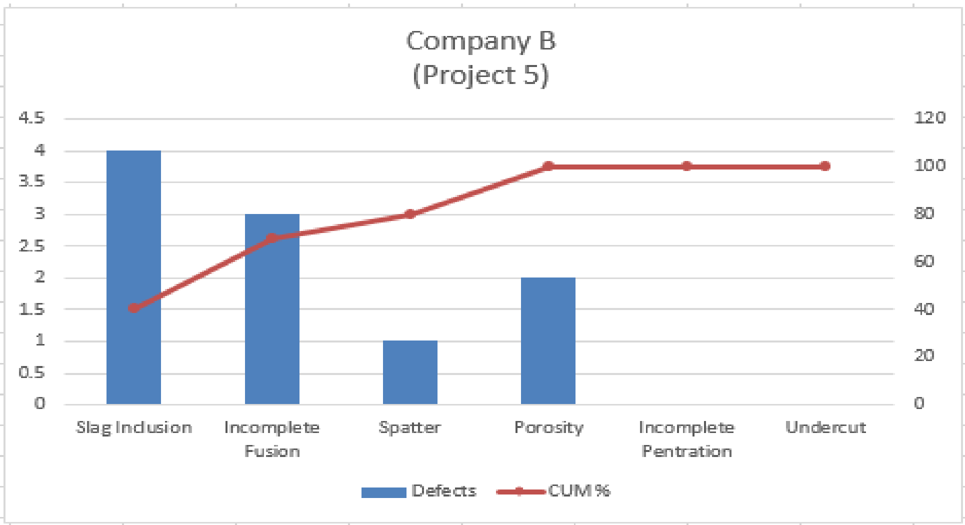


**Figure 11.** Pareto chart for Project 5 of company B.

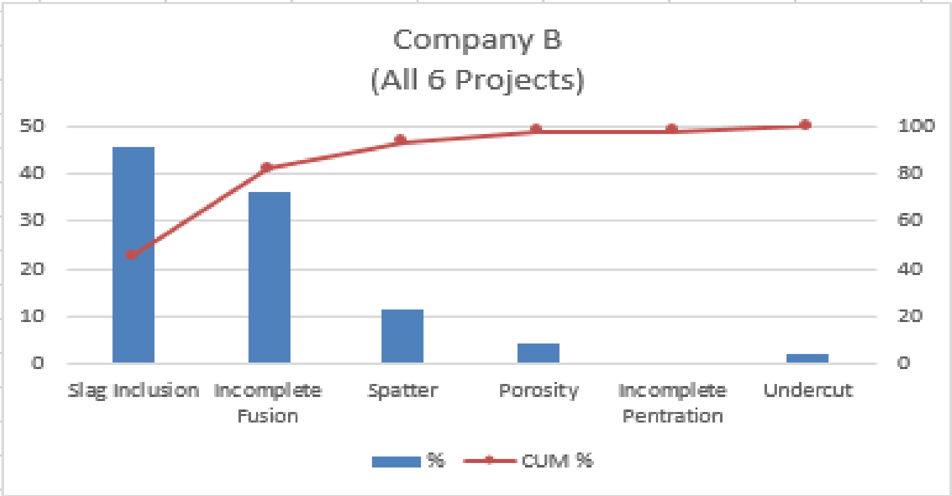


**Figure 12.** Pareto chart of all combined 6 projects of company B.

### 3.6.3.2 Fishbone Analysis

The fishbone analysis can be referred to as a ”cause and effect diagram” which helps to narrow down the focus in the form of segmenting the four various factors – equipment, machine, material and man. The cause and effect diagram (Figure 13) consisting the four main factors “Xs” with the subdivided influencing factors, which simultaneously have overall effects, “Y”, causing weld quality or defects.

These highlighted influencing factors were carefully investigated, after extensive brainstorming, to arrive at these points, that is, if adequately pursued conclusively to remove any form of bottlenecks or undermining problems in the welding operations, then the overall quality of weld will improve.

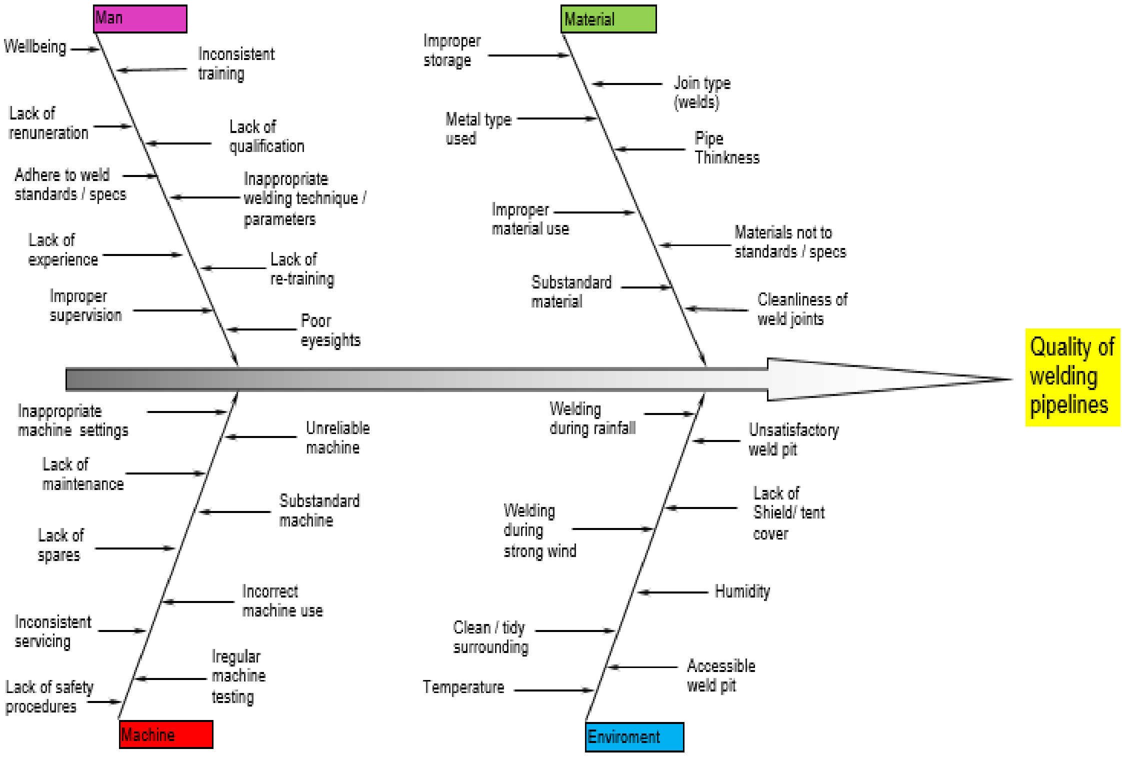


**Figure 13.** Fishbone diagram highlighting factors affecting weld quality (Anderson and Kovach, 2014).

### 3.6.3.3 5W - 1H Analysis

By utilizing 5 Whys and 1 How, a critical understanding of various questions usually been asked regarding problematic situations, such as what, why, where, who, where and how certain problem persist in any peculiar scenario, circumstances, products and services to find solutions or resolutions through the removal of such hindrances. Finding answers to these questions does aid in understanding and proffering solution to problems, as outlined in Table 11.

The four influencing factors or categories involved in effecting the welding outcomes or quality in the construction operations. Theses categories are Machine, Equipment, Man and Environment.

**Table 11.** 5W-1H Analysis for weld defect occurrences in welding activities (Kifta, 2018).

| Category under review | 5W-1H Technique | Explanation |
|---|---|---|
| **Machine** | What | Welding machine |
| | Why | Inconsistent voltage/current output |
| | Who | Pipeline managing team /Machine repair personnel |
| | Where | During use at site |
| | How | Insufficient maintenance |
| **Equipment** | What | Welding equipment/accessories |
| | Why | Defective condition |
| | Who | Pipeline managing team |
| | Where | During use at site/storage |
| | How | Check condition before/after use |
| **Man** | What | Welding activities |
| | Why | Inadequate training |
| | Who | Welders |
| | Where | Open site without shield cover |
| | How | Assess welding procedures |
| **Environment** | What | Welding activities |
| | Why | Insufficient illumination and windy condition |
| | Who | Pipeline managing team/welders |
| | Where | Open site |
| | How | Check light source adequacy /shield cover |

### 3.6.3.4 ANOVA

Using Analysis of Variance (ANOVA) ensures appropriate identification of the level of significance between the main effect and interacting factors as a result of multiple responses among them (Srinivasan et al., 2014).

The earlier calculated result (Table 18 and 19) using the weld defect rate (%) value involving ten projects of both companies gave the following results as shown below in Table 12. As observed, the first variance (company A), **5.509467778**, is smaller than the second variance (company B), **14.59059556**. Furthermore, the F value (**0.128895614**) is lesser than the F critical (**4.413873419**). So therefore the null hypothesis is taken as ”fail to reject”, implying that the defect rates of both companies are not statistically significant.

**Table 12.** ANOVA result of the weld defect rate of both companies.

**ANOVA - Single Factor**

Alpha 0.05

| Groups | Count | Sum | Mean | Variance | | |
|---|---|---|---|---|---|---|
| Column 1 | 10 | 160.27 | 16.027 | 5.509467778 | | |
| Column 2 | 10 | 155.18 | 15.518 | 14.59059556 | | |
| | | | | | | |
| Source of Variation | SS | df | MS | F | P-value | F critical |
| Between Groups | 1.295405 | 1 | 1.295405 | 0.128895614 | 0.723756708 | 4.413873419 |
| Within Groups | 180.90057 | 18 | 10.05003167 | | | |
| Total | 182.195975 | 19 | | | | |

### 3.6.3.5 Correlation and Linear Regression Analysis

The correlation between the weld defect rate of company A and company B, gives the value, **0.204312848**. This implies less relationship between company A and company B, meaning a high level of independence between them (not related) in any statistical relationship. While the linear regression analysis further supports this through the value of R Square of **0.04174374**.

While the correlation between the weld defects and total weld joints in the various given projects for company A shows a value of **0.9722**. And also, the correlation between the weld defects and total weld joints in the various given projects for company B shows a value of **0.8173**. This implies a strong relationship between weld defects and total weld joints for each of the company.

From Figure 14, the linear regression analysis for company A, between the weld defects and total weld joints in the various given projects, the R Square indicate a value of **0.945236718**, displaying the p-value and significance F values as less than 0.05. This implies a reliable data analysis and a positive correlation.

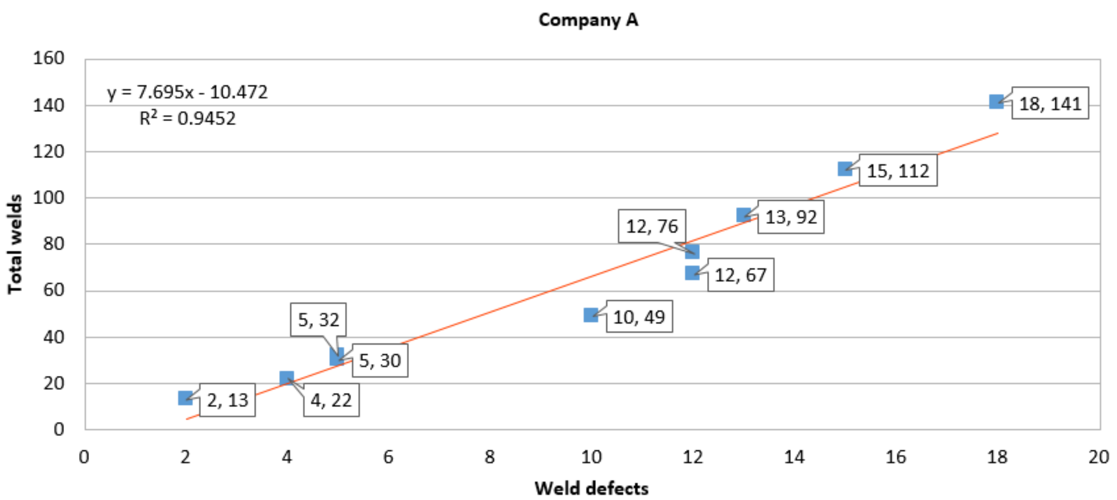


**Figure 14.** The positive correlation and linear regression analysis for company A.

Also, in Figure 15, the linear regression analysis for company B, between the weld defects and total weld joints in the various given projects, the R Square indicate a value of **0.668034843**, displaying the p-value and significance F values as less than 0.05. This implies a reliable data analysis and a positive correlation.

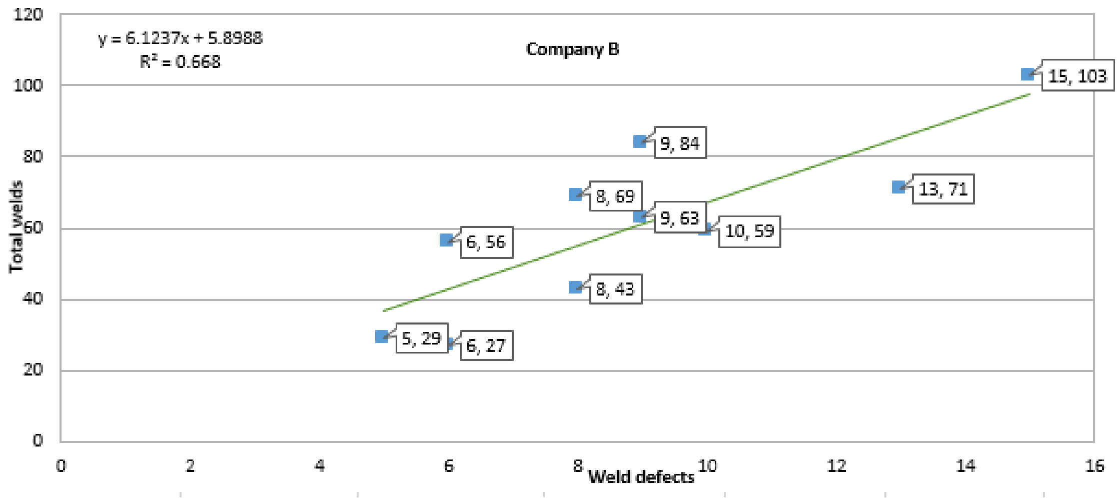


**Figure 15.** The positive correlation and linear regression analysis for company B.

### 3.6.3.6 Statistical Hypothesis Testing

Hypothesis testing can be explained as a predictive statement in a scientific research study to test the possible or expected outcome through comparing the differences or relationships between variables or groups of a sample or population (Denni-Fiberesima and Rani, 2014; Gunduz, 2004). Furthermore, a researcher usually proposes this assumption with an intent to establish truth or collection of truths in an investigation. Hypotheses can be established to be accepted or rejected, even if it eventually disproved, some new idea about a phenomenon may be established for future scientific investigation (Denni-Fiberesima and Rani, 2014).

Two hypotheses are developed – the null hypothesis ($H_O$) and the alternate hypothesis ($H_A$). Using two groups from a sample, for example, their means are used to compare if they are significantly different or not. The test statistic (t test) available in Microsoft Excel is employed to test the hypothesis to determine the significant relationship for any given assumption. That is, the null hypothesis is established as being rejected in favour of an alternate hypothesis or otherwise.

In addition, the p-value is further used to compare the significance level if the null hypothesis is established as rejected in favour of the alternate hypothesis. The p-value can be taken as 5%, usually common in research works.

Based on the empirical evidence presented in this research, the returned survey questionnaire from both companies (pipeline project management personnel), which indicate irregular re-training of pipeline welders as being ranked highest by the RII.

The two hypotheses created for this research are as follows:

- $H_O$ = There is no significant relationship between irregular and inadequate training of pipeline welders and high level of weld defects.

- $H_A$ = There is significant relationship between irregular and inadequate training of pipeline welders and high level of weld defects.

### 3.6.4 Improve Phase

After having reviewed and identify the root causes for these weld defects in the previous phase, thus, this phase ensures developing appropriate solutions in tackling these problems (Anderson and Kovach, 2014; Jirasukprasert et al., 2014).

Besides, the development of pertinent recommendation ensued after extensive brainstorming and aided with the use of the various adopted literature.

The research had to conduct a simulation to achieve the objective, of the reduction of the rate of weld defect in the pipeline construction operation. The result enables this research to conclude in terms of improvement in the yield process for implementation by the case companies.

#### 3.6.4.1 Implement New DPMO And Sigma Level

Upon implementation of the improve phase, the rate of defective weld in both companies will reduce and hence, the resultant process sigma level increases, and also, reduction in DPMO. As depicted in Table 13, making use of Equ. 2 and 3, the new DPMO and process sigma level for both companies.

**Table 13.** The summary of DPMO and sigma level of both companies.

| Case Companies | DPMO | Process Sigma level |
|---|---|---|
| Company A | 10936 | 3.792722 |
| Company B | 10071 | 3.823575 |

Based on the calculated sigma level, as depicted graphically in Figure 16, the clear result of the new (**3.79**) and old (**2.49**) process sigma level for company A. And also, Figure 17, indicate graphically the clear result of the new (**3.82**) and old (**2.52**) process sigma level for company B.

In addition, the new calculated average process yield for company A indicate a value of 98.91% against the previous value of 83.97%. While for company B, the new calculated average process yield for company B indicate a value of 98.99% against the previous value of 84.48%.

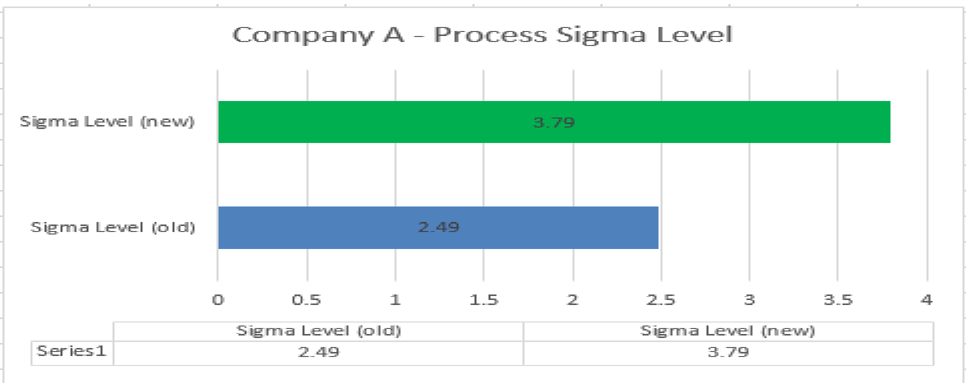


**Figure 16.** Displays old and new process sigma level for company A.

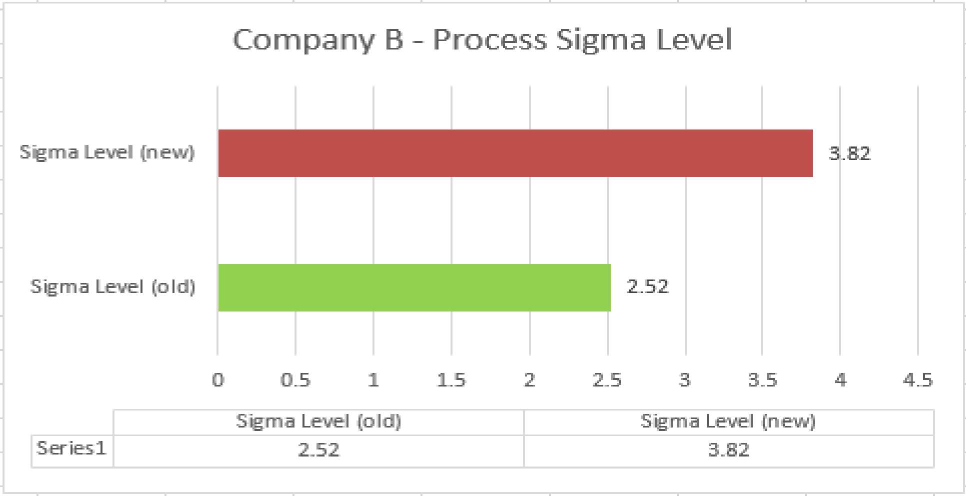


**Figure 17.** Displays old and new process sigma level for company B.

#### 3.6.4.2 Failure Mode And Effects Analysis (FMEA)

Failure mode and effects analysis (FMEA) is an important tool used to distinguish, appraise and prioritize potential failures or problems in an existing process for the purpose of tackling and removing risks (Anderson and Kovach, 2014; Gygi et al., 2012). This tool ensures the evaluation of the types of failures encountered in a process, such as pipeline weld defects and seeks elimination.

A rating scale of 1-10 points is allocated for evaluating factors such as severity (SEV), detention (DET) and occurrence (OCC) of effects of each noticeable problem, while a score of 1 denotes as ”weak effect”, and progressing in scale until getting to a score of 10, denoting as ”strong effect”. And also, the risk priority number (RPN), which is a product of the ratings of SEV, DET and OCC.  The RPN denotes ranking order of the highest value of risk of failures, thus signifying the highest risk o causing defective welds. Moreover, brainstorming helped in arriving at the FMEA scoring.

As illustrated in Table 13, the FMEA table shows both case companies’ effects and causes: severity, detention and occurrence of weld defects and the applicable solution to effect positive change. The light green coloured column (left side) depicts the problems (obtained from the survey questionnaire data) and, the light blue coloured column (right side) depicts the solution for eliminating defective welds in the pipeline construction.

Finally, as interpreted in Table 14, the light green coloured column, the RPN value indicts the highest value of 448, clearly showing the problem of inadequate training of the welders, which is before implementation of the LSS model. But also, the light blue coloured column shows the highest RPN value indicting the solution for eliminating defective weld through a strategy for ensuring satisfactory and effective periodic training for the welders.

**Table 14.** FMEA tabulation for weld defects in both companies.

| Key Process Step or Input | Potential Failure Mode | Potential Failure Effects | SEV | Potential Causes | OCC | Current Controls | DET | RPN | Actions Recommended | Resp. | Actions Taken | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| What is the Process Step or Input? | In what ways can the Process Step or Input fail? | What is the impact on the Key Output Variables once it fails (customer or internal requirements)? | How Severe is the effect to the customer? | What causes the Key Input to go wrong? | How often does cause or FM occur? | What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode? | How well can you detect the Cause or the Failure Mode? | | What are the actions for reducing the occurrence of the cause, or improving detection? | Who is Responsible for the recommended action? | Note the actions taken. Include dates of completion. | | | | |
| Man | Welders' lack of sufficient training | High weld defects | 8 | Management deficiency | 8 | N/A | 7 | 448 | Proper plans to ensure satisfactory training periodically | Project management members & welders | Periodic assessment | 3 | 3 | 2 | 18 |
| Man | Welders' lack of incentives/motivation | Low morale to work | 7 | Management not responding appropriately | 8 | N/A | 6 | 336 | Mangement should address this critically | Project management members | Periodic assessment | 2 | 3 | 2 | 12 |
| Man | Welders' lack of proper vision (eyes) | Difficulties to work effectively | 6 | Management not responding appropriately | 7 | N/A | 5 | 210 | Mangement should monitor this critically | Project management members & welders | Periodic assessment | 2 | 2 | 2 | 8 |
| Man | Management lack of effective communication practices | Difficulties to work effectively | 5 | Management lack of effective project management | 7 | N/A | 6 | 210 | Effective communication practices | Project management members & welders | Daily assessment | 1 | 2 | 1 | 2 |
| Machine | Lack of spares & equipment | Inability to meet customers request | 6 | Aging machines & maintenance | 7 | N/A | 6 | 252 | Purchase new machines & spares | Project management members | Daily assessment | 3 | 2 | 3 | 18 |
| Materials | Improper use of materials | Inability to meet customers request | 6 | Management Lack of quality controls | 6 | N/A | 7 | 252 | Mangement should monitor this critically | Project management members & welders | Daily assessment | 1 | 1 | 1 | 1 |
| Materials | Materials not meeting specifications | Inability to meet customers request | 6 | Management Lack of quality controls | 5 | N/A | 6 | 180 | Mangement should adhere to standards always | Project management members & welders | Daily assessment | 1 | 1 | 1 | 1 |

### 3.6.5 Control Phase

This final phase of the DMAIC model ensures constant monitoring of all the implemented improvement controls already set in place for the process to continue to produce the desired result and work correctly (Zadeh et al., 2014). Furthermore, Desai and Shrivastava (2008) highlighted this phase as a means of sustaining the gains that occurred – process improvement – and constantly review the results under strict adherence.

#### 3.6.5.1 Implement Controls And Documentation

In the course of sustaining overall improvements in an organization, standard procedural controls and record-keeping through strict documentation should be adhered to continuously monitor implemented controls (Gijo et al., 2014; Jirasukprasert et al., 2014). These controls with the aid of standard tools and techniques ensure complete guidance for monitoring for the benefit of making effective changes to the established controls if getting out of control. The following tools and techniques are used in this phase:

- Establishment of standard operating procedures (SOPs), which ensure step-by-step instructions as requirements for effective practices or operational procedures. These involve a checklist of tasks, responsibilities and outcome performances for any given process, and is constantly updated.
- The use of control charts for the benefit of monitoring any given process can be established, along with effective control plans to tackle any identified variations. The type of control chart to be used is the *p* chart or *np* chart, which is specifically for monitoring processes' defective substances.
- Sufficient training must be given to management and employees involved in these peculiar processes to enhance awareness of the established operational methods.

# 4 ANALYSIS AND RESULTS

In this chapter, all the previous findings will undergo extensive analysis to gravitate towards or arrive at substantive conclusion for this research. Also, the obtained survey questionnaire data stands as a means to support the findings recorded in the previous chapters.

Both closed-ended and open-ended questionnaire were adopted in this research to give candid information and unique insights from the respondents' perspective. Analysing the data obtained from the survey, which serves as a means of support for the research, along with previous obtained data.

## 4.1 Data Analysis

Both descriptive and inferential statistics played vital roles in ensuring appropriate analysis of the gathered data.

### 4.1.1 Reliability and Validity Test

As suggested by Antony et al. (2019), stating the importance of goodness of measure, as it relates to ensuring measurement of quality for any data analysis. Also, this emphasizes reliability in the act of ensuring steadiness, uniformity, accuracy and compatibility of data. Thus, utilizing the internal consistency analysis method as one of the ways of achieving measurement of quality.

To ensure reliability and validity, the most widely used reliability indicator for internal consistency is the Cronbach's Alpha test, for use to process the ordinal data obtained in the questionnaire survey.

### 4.1.2 Hypotheses Analysis

Using Excel (Anova: Two-Factor Without Replication), Cronbach's alpha calculated the approximate value for the survey questionnaire by respondents' opinion for company A as **0.82**, and for company B as **0.50**. These values can be said to be fairly acceptable, greater than (> 0.6), as a threshold value (Antony et al., 2019). This can be seen in Table 15 and 16.

**Table 15.** Cronbach's alpha value for company A.

| | | COMPANY A | | | | |
|---|---|---|---|---|---|---|
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Rows | 86.9784 | 10 | 8.69784 | 5.47466 | 3.5E-07 | 1.87828 |
| Columns | 32.632 | 20 | 1.6316 | 1.02698 | 0.43214 | 1.62331 |
| Error | 317.749 | 200 | 1.58874 | | | |
| | | | | | | |
| Total | 437.359 | 230 | | | | |
| | | | 0.81734 | | | |

**Table 16.** Cronbach's alpha value for company B.

| | | COMPANY B | | | | |
|---|---|---|---|---|---|---|
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Rows | 29.311 | 10 | 2.9311 | 1.99465 | 0.03625 | 1.88362 |
| Columns | 16.9665 | 18 | 0.94258 | 0.64144 | 0.86326 | 1.66143 |
| Error | 264.507 | 180 | 1.46948 | | | |
| | | | | | | |
| Total | 310.785 | 208 | | | | |
| | | | 0.49866 | | | |

While the Content Validity testing is considered for this research, as is not subjected to numerical evaluation but rather subjectively assessed by the researcher. Antony et al. (2007), averred that content validity testing rests on a researcher to develop measurement components that covers entire aspects of the variable being measured.

In this research, the adopted instrument evolved from extensive literature review and brainstorming with experts in Lean Six Sigma and worldwide recognized Quality Management systems, such as EFQM, TQM and ISO 9000 models. Furthermore, the adopted survey questionnaire had inputs from published prominent literature of leading Six Sigma professionals and academicians recognized globally (Antony et al., 2007).

Using both companies' responses from the pipeline project management personnel obtained in the form of Likert scale, thus the two-way ANOVA gives:

**Table 17.** Two-way ANOVA result of the respondents of both companies.

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *Company A* | *Company B* |
| Mean | 5.523809524 | 4.52631579 |
| Variance | 0.261904762 | 1.37426901 |
| Observations | 21 | 19 |
| Hypothesized Mean Difference | 0 | |
| df | 18 | |
| t Stat | 3.052260462 | |
| P(T<=t) one-tail | 0.003429272 | |
| t Critical one-tail | 1.734063607 | |
| P(T<=t) two-tail | 0.006858544 | |
| t Critical two-tail | 2.10092204 | |

From Table 17, the t-Stat (**3.052260462**) is larger than the t-Critical two-tail (**2.10092204**). So I would reject the Hull Hypothesis and accept the alternate hypothesis. This means that there is a significant relationship between irregular or inadequate training of pipeline welder and a high level of weld defects.

Also, assuming the the alpha (**0.05**), so the p-value (**0.006858544**) is smaller than alpha (**0.05**). So I reject the null hypothesis and accept the alternate hypothesis. This means that a statistical relationship exists between irregular or inadequate training of pipeline welder and a high level of weld defects.

Finally, to check the accuracy of the hypothesis result, and using the same respondents' data, a Cronbach's Alpha value of **0.81429**, was obtained. This signifies a value greater than 0.7.

### 4.1.3 Weld Inspection Report Analysis

The report revealed the evaluation of the quality of weld for welded joints through the NDT conducted by the weld inspector to declare partial or full rejection or eventual acceptance following the stipulated standards (Anderson and Kovach, 2014; API, 2013; AWS, 2015; DPR, 1992). The obtained report showed the number of defects encountered during various pipeline construction operations of both case companies.

Access to the weld inspection reports revealed the low quality of weld through DPMO and Process Sigma Level for each of the companies, as depicted in Table 18 and 19.

**Table 18.** DPMO calculation for completed projects in company A.

| Projects | Total welds (Qty) | Weld defects (Qty) | Defect Rate (%) | Yield (%) | DPMO |
|---|---|---|---|---|---|
| 1. | 112 | 15 | 13.39 | 86.61 | 133929 |
| 2. | 67 | 12 | 17.91 | 82.09 | 179104 |
| 3. | 141 | 18 | 12.77 | 87.23 | 127660 |
| 4. | 92 | 13 | 14.13 | 85.87 | 141304 |
| 5. | 30 | 5 | 16.67 | 83.33 | 166667 |
| 6. | 22 | 4 | 18.18 | 81.82 | 181818 |
| 7. | 76 | 12 | 15.79 | 84.21 | 157895 |
| 8. | 32 | 5 | 15.63 | 84.38 | 156250 |
| 9. | 13 | 2 | 15.38 | 84.62 | 153846 |
| 10. | 49 | 10 | 20.41 | 79.59 | 204082 |
| MEAN | | | | | 160255 |
| PROCESS SIGMA LEVEL | | | | | 2.499627 |

**Table 19.** DPMO calculation for completed projects in company B.

| Projects | Total welds (Qty) | Weld defects (Qty) | Defect Rate (%) | Yield (%) | DPMO |
|---|---|---|---|---|---|
| 1. | 29 | 5 | 17.24 | 82.76 | 172414 |
| 2. | 43 | 8 | 18.60 | 81.40 | 186047 |
| 3. | 84 | 9 | 10.71 | 89.29 | 107143 |
| 4. | 56 | 6 | 10.71 | 89.29 | 107143 |
| 5. | 71 | 13 | 18.31 | 81.69 | 183099 |
| 6. | 103 | 15 | 14.56 | 85.44 | 145631 |
| 7. | 69 | 8 | 11.59 | 88.41 | 115942 |
| 8. | 59 | 10 | 16.95 | 83.05 | 169492 |
| 9. | 27 | 6 | 22.22 | 77.78 | 222222 |
| 10. | 63 | 9 | 14.29 | 85.71 | 142857 |
| MEAN | | | | | 155199 |
| PROCESS SIGMA LEVEL | | | | | 2.520951 |

### 4.1.4 Statistical Process Control Analysis

The Statistical Process Control (SPC) is employed in the research to ensure effective use of statistical techniques for measuring and controlling the quality of a product or process is achieved (Gygi et al., 2012). The primary tool of SPC is the control chart. The control chart is essentially used to track the performance of a process input or output over time.

The rate of pipeline weld defect is the given data for this research which are classified as attribute data. Thus, the p chart (proportion nonconforming) is the basis of the graphical analysis for interpretation.

Besides, the capability analysis, earlier mentioned in the previous chapter, is also considered along with the control chart for proper understanding of the case companies.

#### 4.1.4.1 Control Chart And Capability Analysis of Company A

The control chart, Figure 18, indicates the rate of weld defects in the ten projects of company A. Based on this, it is observed that process seems within the specifications, but the sigma Z score of **0.505322**, signify that the significant areas of the tail ends of the distribution tend to extend beyond the range or specification limit. This signifies that the process seems to have a high defect rate, so it is incapable of meeting the expected requirements.

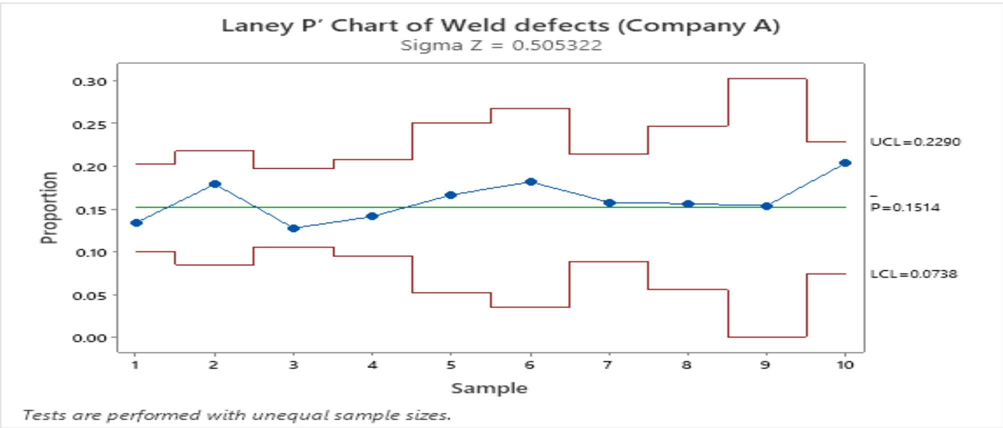


**Figure 18.** Displays p chart analysis for company A.

While the process capability chart, Figure 19, indicate the rate of weld defects in the ten projects of company A. Based on this, it is observed that the process is outside the range or specification, which supports the fact that the rate of defect is noticeably high.

The Cp or Pp value (0.54) and the Cpk or Ppk (**0.48**) are less than 1, which means the process is not capable of meeting the requirements. So the rate of weld defect is high for this pipeline construction welding expectations or requirements. This can be enhanced by reducing the variations which tend to cause a high rate of weld defects.

Also, the PPM value is **108544.30**, and this indicates that 108544.30 out of 1 million opportunities or outcome do not meet the specifications.

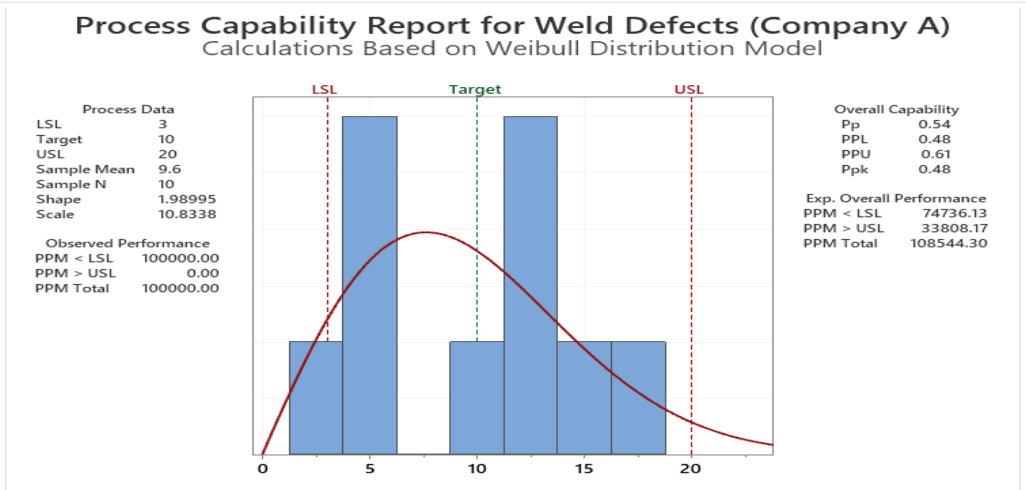


**Figure 19.** Process capability analysis for company A.

#### 4.1.4.2 Control Chart And Capability Analysis of Company B

The control chart, Figure 20, indicates the rate of weld defects in the ten projects of company B. Based on this, it is observed that process seems within the specifications, but the sigma Z score of **0.846906** signify that the significant areas of the tail ends of the distribution tend to extend beyond the range or specification limit. This signifies that the process seems to have a high defect rate, so it is incapable of meeting the expected requirements. With this result, it seems this process is slightly better compared to company A (**0.505322**), but both still have a high rate of weld defects.

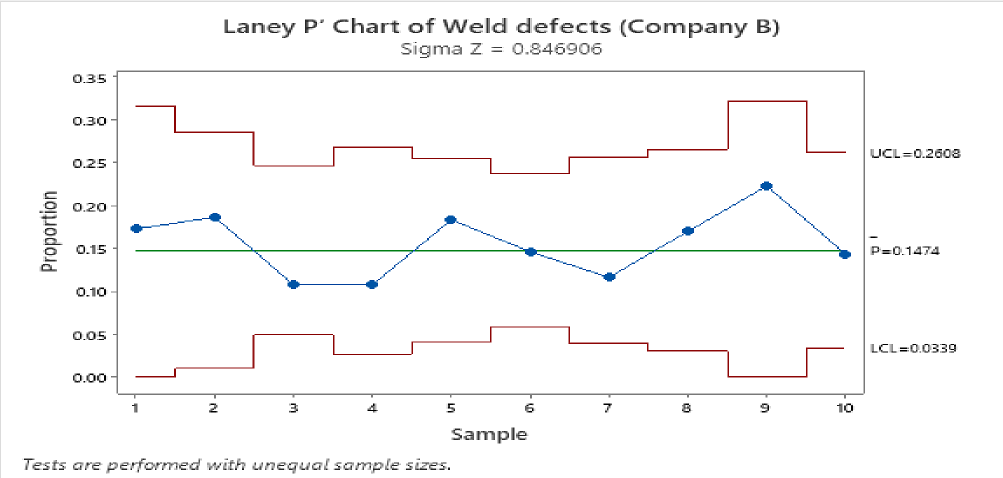


**Figure 20.** Displays p chart analysis for company B.

For the process capability chart, Figure 21, indicate the rate of weld defects in the ten projects of company B. Based on this, it is observed that the process is outside the range or specification, which supports the fact that the rate of defect is noticeably high.

The Cp or Pp value (**0.53**) and the Cpk or Ppk (**0.31**) are less than 1, which means the process is not capable of meeting the requirements. So the rate of weld defect is high for this pipeline construction welding expectations or requirements. This can be enhanced by reducing the variations which tend to cause a high rate of weld defects.

Also, the PPM value is (**190925.98**), this indicates that 190925.98 out of 1 million opportunities or outcome do not meet the specifications.

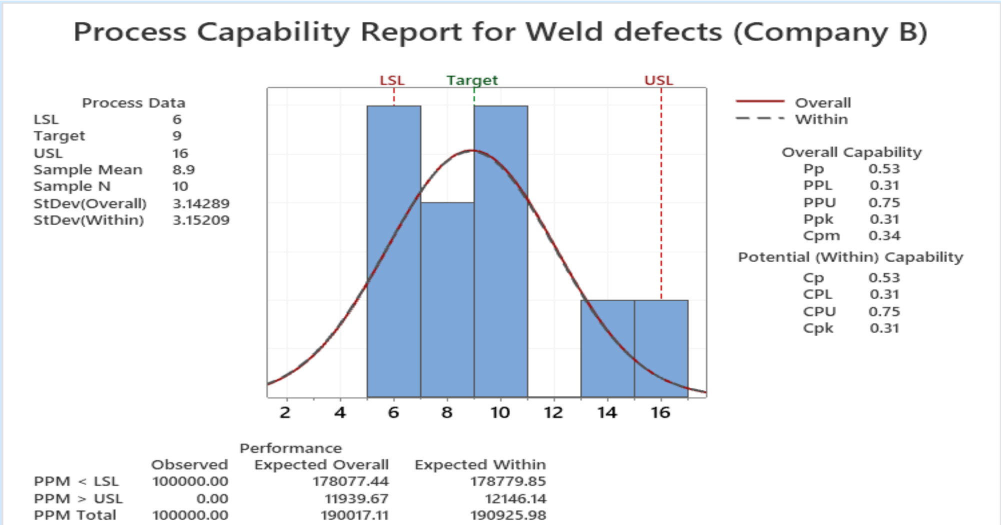


**Figure 21.** Process capability analysis for company B.

### 4.1.5 Survey Quesionnaire Analysis

Both descriptive and inferential statistics also played vital roles in ensuring appropriate analysis of the returned questionnaires with the aid of SPSS and Excel. Furthermore, the relative importance index (RII).

The Relative importance index enables the ranking of relative importance of various causes for weld defects within the four influencing categories or groups associated with pipeline welding quality to be determined. Also, the questionnaire adopts the Likert scale type, ranging from 1 – 6. According to Sweis et al. (2018), adoptability of the relative importance index (RII) for each factor ensure factor ranking, which is expressed by the given equation (Eq. 4):

$$RII = \sum (W) / A * N. \tag{4}$$

*Where RII is relative importance index. W is weight assigned to each question factor by the respondent (range 1-6), A is highest scale score (which is 6), N = sample size (respondents total).*

#### 4.1.5.1 Factors Contributing to Pipeline Construction Problems

With the use of Microsoft Excel, and based on the calculation of RII ranking used for the survey questionnaire on the two main target area of interest: project management team and the welding team respectively (Table 20 and 21). The data obtained from the respondents in project management, Table 20, showed the top 3 highest ranking of critical causes for weld defects, ranging with highest (**0.920635**) and the lowest (**0.793651**) for company A. These causes are distributed within the 4 main categories: Man; Machine; Materials and Environment.

**Table 20.** The 3 top ranking of project management respondents of Company A.

| ID | Category | Causes for weld defects | RII | Rank |
|---|---|---|---|---|
| 2.1.7 | Man | Irregular re-training of welders | 0.920635 | 1 |
| 2.1.11 | Man | Lack of welder competence & skills | 0.849206 | 2 |
| 2.3.2 | Materials | Materials not match drawing specification | 0.793651 | 3 |

**Table 21.** The 3 top ranking of welders/fitters respondents of Company A.

| ID | Category | Causes for weld defects | RII | Rank |
|---|---|---|---|---|
| 3.1.3 | Man | Irregular re-training | 0.863636 | 1 |
| 3.1.10 | Man | Non provision of incentives/motivation | 0.818182 | 2 |
| 3.1.4 | Man | Irregular eye test check-up | 0.787879 | 3 |

While Table 22 and 23, comprising company B and using, for instance, the welding team respondents, Table 23, revealed the top 3 highest ranking of critical causes for weld defects ranging with highest (**0.807018**) and lowest of (**0.789474**). These causes are distributed within the 4 main categories: Man; Machine; Materials and Environment.

**Table 22.** The 3 top ranking of project management respondents for Company B.

| ID | Category | Causes of weld defects | RII | Rank |
|---|---|---|---|---|
| 2.1.1 | Man | Ineffective communication practices | 0.807018 | 1 |
| 2.1.11 | Man | Lack of welder competence & skills | 0.789474 | 2 |
| 2.3.3 | Materials | Improper use of materials | 0.789474 | 2 |

**Table 23.** The 3 top ranking of welders/fitters respondents for Company B.

| ID | Category | Causes of weld defects | RII | Rank |
|---|---|---|---|---|
| 3.1.7 | Man | Possess inadequate welder/fitter certification | 0.875000 | 1 |
| 3.2.1 | Machine | Unavailability of spares & equipment | 0.812500 | 2 |
| 3.3.4 | Materials | Provision of wrong material | 0.812500 | 2 |

## 4.2 Demographic Analysis of Survey Respondents

To investigate the characteristics of the survey respondents, descriptive statistics was adopted in this research as a means to analyse the demographic variables. Each of the case studies have substantial relevant disciplines and work experience directly involved in the oil & gas pipeline construction.

### 4.2.1 Respondents Profile of Company A

The survey revealed that 82% of pipeline welders in company A, of 11 respondents, have been working between 5 to 15 years as certified welders, and also, 55% possesses Diploma qualifications from polytechnic educational institutions and the remaining 45% have certificates from vocational and technical colleges. While only one-third of the welders have Higher Diploma qualifications in Welding and Fabrication Technology/Engineering in the few available polytechnic institutions offering the course. Advanced course in this field is not available in the country but outside – mostly in Europe, America or Asia/Middle East – which is expensive for many to afford.

However, conceited effects for the localized skilled and competent workforce in this field are being made through the Nigerian Local Content Development Act initiative since 2010 (Ayonmike and Okeke, 2015).

While the pipeline project management team of company A, comprising 21 respondents, have mostly 52% work experience between 5 to 15 years and 33% between 16 to 25 years of work experience. Also, 57% possesses Bachelor degrees and 29% have Diploma qualifications in pipeline construction-related careers, such as mechanical engineering, pipeline engineering. Only 19% have further certified training and qualifications in pipeline construction and inspection – CWI and AWS certifications. These pieces of training at the intermediates level include Dye Penetrant Inspection, Radiographic Film Interpretation, Ultrasonic Testing Inspection, Visual Inspection. Two members of the project management team possess a Master's degree.

### 4.2.2 Respondents Profile of Company B

Company B, having 8 respondents, the survey data showed that 63% of pipeline welders have been working between 5 to 15 years, 25% between 16 to 25 years working experience as certified welders. While 50% possesses Diploma qualifications from polytechnic educational institutions and the remaining have certificates from vocational and technical colleges. While only one-quarter of the welders have Higher Diploma qualifications in Welding and Fabrication Technology/Engineering.

From the 19 respondents of the pipeline project management team of company B, 37% have work experience between 1 to 4 years, 26% have worked between 5 to 15 years and also, 26% between 16 to 25 years of work experience. Furthermore, 63% possesses

Bachelor degrees and 32% have Diploma qualifications in pipeline construction-related careers, such as mechanical engineering, pipeline engineering. Only 21% have further certified training and qualifications in pipeline construction and inspection – CWI and AWS certifications. These pieces of training at the intermediates level include Dye Penetrant Inspection, Radiographic Film Interpretation, Ultrasonic Testing Inspection, Visual Inspection. One member of the project management team possesses a Master's degree.

### 4.2.3 Weld Defect Range of Occurance

Data obtained from the respondents (welders) in the survey questionnaire revealed pertinent information regarding the percentage of occurrence of weld defect and the common types of weld defects associated with the case companies.

Each of the companies indicates the same weld defect range (0 – 20) % of mostly occurring cases during various welding activities for the past 2 years as shown in Figure 22 and 23.

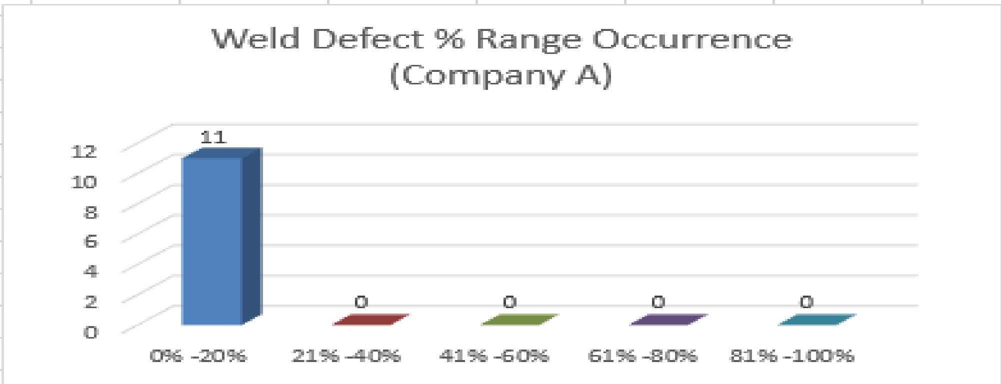


**Figure 22.** Weld defect range occurrence (%) in company A (Survey, 2020).

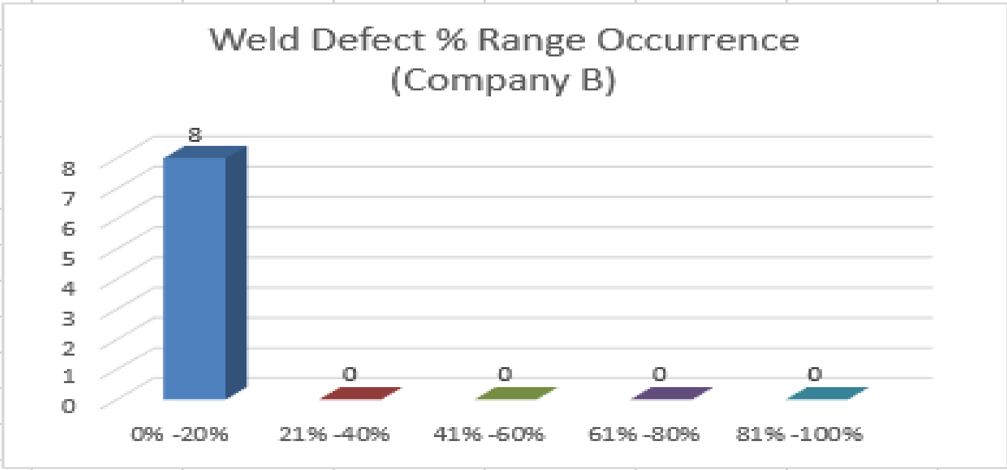


**Figure 23.** Weld defect range occurrence (%) in company B (Survey, 2020).

#### 4.2.3.1 Types of Welding Parameters

Welding parameters requirement play vital importance in fulfilling welding quality. These parameters include arc length, welding angle, welding current, welding speed and welding voltage. All these parameters must be set and maintained by the welders before, during and after the welding process to meet the stipulated and required standard for welding pipelines.

Based on the obtained survey result, Figure 24, both case companies adhered to ensuring 100% utilization of these 5 welding parameters.

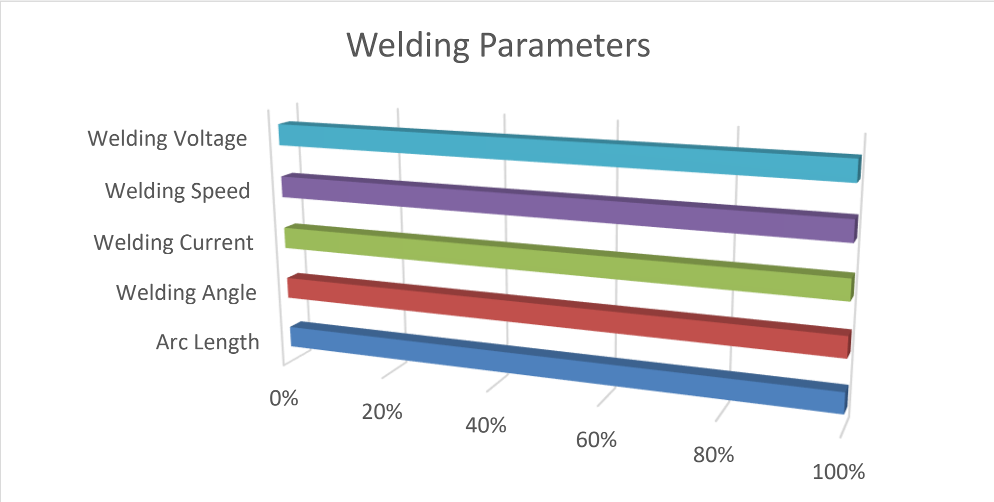


**Figure 24.** The used welding parameter applicable in both companies (Survey, 2020).

Also, the earlier mentioned welding parameters are all important routines applicable to the Shield Metal Arc Welding (SMAW), hence, the survey further investigated the different types of welding processes commonly used by the case companies.

As revealed in Table 24, the SMAW is mostly used by welders based on the ranking in both companies.

**Table 24.** Ranking of mostly used welding processes in both companies.

| S/N | Types of welding | Ranking |
|---|---|---|
| 1 | SMAW | 1 |
| 2 | Gas Welding | 2 |
| 3 | TIG Welding | 3 |
| 4 | MIG Welding | 4 |
| 5 | Plasma Arc Welding | 5 |

As revealed in Figure 25, showing the most commonly used welding processes in company A. This clearly showed that SMAW is mostly used by the welders during the pipeline welding operations.

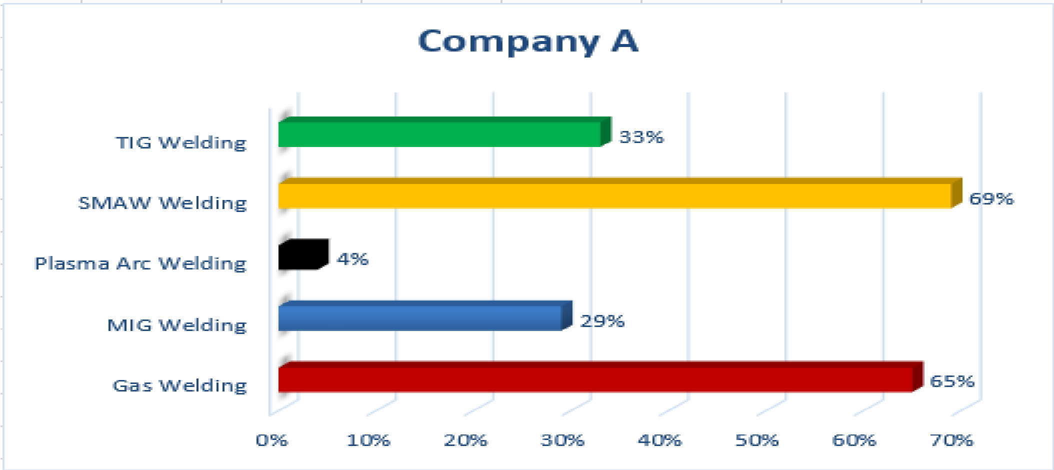


**Figure 25.** The used welding processes applicable in company A (Survey, 2020).

While Figure 26, revealed the most commonly used welding processes in company B. This clearly showed that SMAW is mostly used by the welders during the pipeline welding operations.

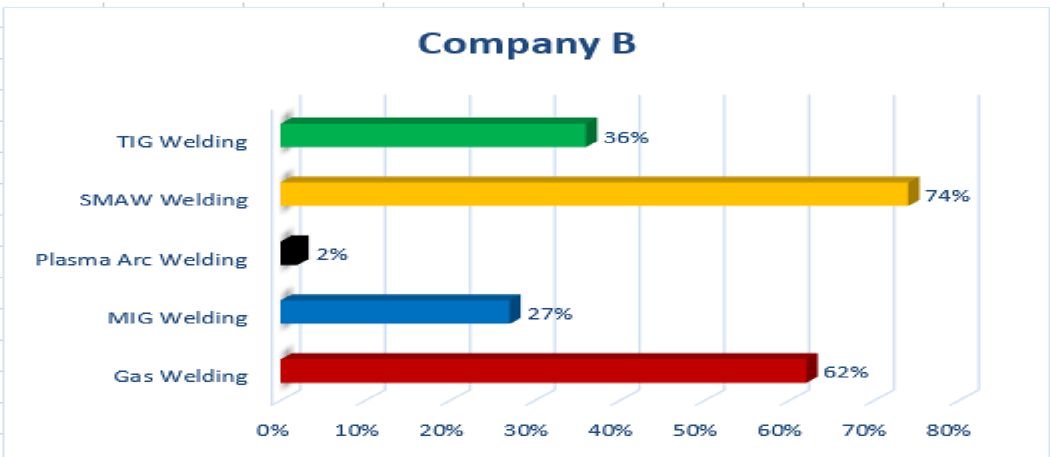


**Figure 26.** The used welding processes applicable in company B (Survey, 2020).

#### 4.2.3.2 Weld Defects of Case Studies

During each project, the recorded types of weld defects occurring were highlighted by the weld inspection personnel by conducting the necessary NDT on the various pipes sizes and fittings, and thus, made the mandatory weld inspection reports for necessary repairs and corrections. Also, note that once repairs made, another NDT must be conducted on the repaired weld to ascertain a final approval and certified for eventual use by the Oil and Gas regulatory body.

The case companies' revealed the various types of weld defects encountered during the pipeline construction phase in past projects. As shown in Table 25, displays the previous 10 projects for company A, and the various types of weld defects recorded, scheduled for repairs during the pipeline welding operations.

**Table 25.** Types of weld defects occurrence in projects of company A.

| Projects | Total welds in projects | Weld defects | Types of weld defects | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Slag Inclusion | Incomplete Fusion | Spatter | Porosity | Incomplete Penetration | Undercut |
| 1. | 13 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| 2. | 22 | 4 | 1 | 3 | 0 | 0 | 0 | 0 |
| 3. | 30 | 5 | 2 | 2 | 1 | 0 | 0 | 0 |
| 4. | 32 | 5 | 3 | 1 | 1 | 0 | 0 | 0 |
| 5. | 49 | 10 | 4 | 4 | 1 | 1 | 0 | 0 |
| 6. | 67 | 12 | 6 | 3 | 3 | 0 | 0 | 0 |
| 7. | 76 | 12 | 5 | 3 | 2 | 1 | 1 | 0 |
| 8. | 92 | 13 | 5 | 4 | 2 | 2 | 0 | 0 |
| 9. | 112 | 15 | 7 | 3 | 4 | 0 | 1 | 0 |
| 10. | 141 | 18 | 9 | 5 | 2 | 1 | 1 | 0 |

Also, as depicted in Table 26, displays the previous 10 projects for company B, and the various types of weld defects recorded, scheduled for repairs during the pipeline welding operations.

**Table 26.** Types of weld defects occurrence in projects of company B.

| Projects | Total welds in projects | Weld defects | Types of weld defects | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Slag Inclusion | Incomplete Fusion | Spatter | Porosity | Incomplete Penetration | Undercut |
| 1. | 27 | 6 | 2 | 3 | 1 | 0 | 0 | 0 |
| 2. | 29 | 5 | 1 | 2 | 2 | 0 | 0 | 0 |
| 3. | 43 | 8 | 4 | 4 | 0 | 0 | 0 | 0 |
| 4. | 56 | 6 | 2 | 4 | 0 | 0 | 0 | 0 |
| 5. | 59 | 10 | 4 | 3 | 1 | 2 | 0 | 0 |
| 6. | 63 | 9 | 7 | 0 | 1 | 0 | 0 | 1 |

#### 4.2.3.3 Analyzing Types of Weld Defects in Case Companies

The survey revealed the various types of weld defects which commonly occurs after every welding operation completed and the necessary NDT is carried out to test the weld integrity by a certified weld inspector. Once the faults or types of weld defects are reported, the appropriate repair is conducted and the weld integrity is retested afterwards.

It was observed for company A, in Figure 27, that the most common weld defect, in terms of ranking (Table 27), showed Slag Inclusion, Incomplete Fusion and Spatter as the top three.

**Table 27.** Ranking of most common weld defect occurring in company A.

| S/N | Types of weld defects | Ranking |
|---|---|---|
| 1 | Slag Inclusion | 1 |
| 2 | Incomplete Fusion | 2 |
| 3 | Spatter | 3 |

| | | |
|---|---|---|
| 4 | Porosity | 4 |
| 5 | Incomplete Penetration | 5 |
| 6 | Undercut | 6 |

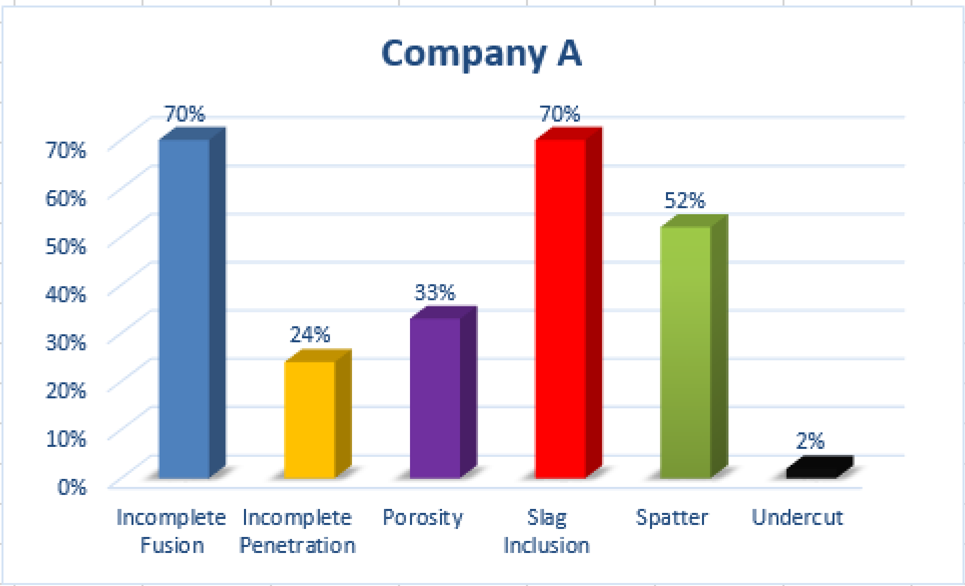


**Figure 27.** The most weld defect occurrence in company A (Survey, 2020).

Also, for company B, as shown in Figure 28, the most common weld defect occurring, and in terms of ranking (Table 28), showed Incomplete Fusion, Slag Inclusion and Spatter as the top three.

**Table 28.** Ranking of most common weld defect occurring in Company B.

| S/N | Types of weld defects | Ranking |
|---|---|---|
| 1 | Incomplete Fusion | 1 |
| 2 | Slag Inclusion | 2 |
| 3 | Spatter | 3 |
| 4 | Porosity | 4 |
| 5 | Incomplete Penetration | 5 |
| 6 | Undercut | 6 |

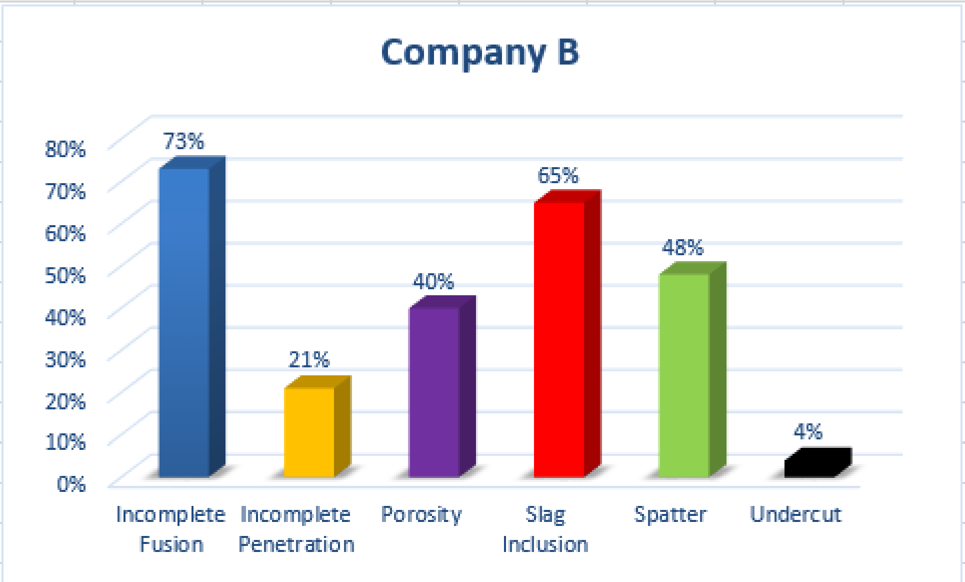


**Figure 28.** The most weld defect occurrence in company B (Survey).

## 4.3 Recommendation for Process Improvement

Based on the conducted research to resolve the problems encountered in the pipeline welding activities which having been identified as root causes leading to the obtained weld defects. It is imperative to thoroughly understand the causes of these weld defects and recommend solutions for their removal.

With the aid of LSS, the identified main types of weld defects noticed in both companies include: Incomplete fusion, slag inclusion and spatter. Table 29, revealed the causes and recommended remedies for these weld defects.

**Table 29.** Types of weld defects: causes & remedies (AWS, 2015; Welder Porter, 2020).

| S/N | Types of Weld defects | Causes | Corrective Measures |
|---|---|---|---|
| 1. | **Incomplete Fusion** | • Too much weld speed usage | • Proper cleaning of welding surfaces |

| | | | |
|---|---|---|---|
| | This occurs as a result of improper fusion between weld bead and base metal. | • Overflowing weld pool<br>• Contaminated welding surfaces, such as rust, paint, oil/grease<br>• Wrong electrode angle position<br>• Inappropriate electrode type for base metal<br>Insufficient heat input | • Prevent overflowing weld pool<br>• Reduce deposition rate |
| 2. | **Slag Inclusion**<br><br>This occurs when slag is formed from the flux coating during welding and mixes with weld metal. | • Too much weld speed usage<br>• Improper cleaning of each weld pass before the next pass<br>• Too low weld current usage<br>• Insufficient cleaning<br>• Faster cooling of weld pool | • Use correct weld current<br>• Use proper electrode angle<br>• Ensure appropriate cooling of weld pool<br>• Removal of slag regularly by wire brushing<br>• Appropriate weld speed |

| | | | |
|---|---|---|---|
| 3. | **Spatter**<br><br>This occurs as tiny solidified particles from the weld pool scattering along the weld path. | • Too high weld current usage<br>• Too low voltage usage<br>• Contaminated surface<br>• Unstable wire feeding<br>• Too long arc usage<br>• Wrong electrode angle position<br>• Wrong polarity usage | • Proper cleaning of welding surface<br>• Use proper electrode angle<br>• Correct polarity usage<br>• Correct arc length<br>• Appropriate current & voltage |

Finally, the given recommendation must be followed thoroughly to eliminate the identified weld defects. Thus, adhering to the corrective measures during welding operation as specified by complying to international welding standards.

Also, further consideration for the following factors must be established in these companies to improve pipeline construction operation performances for the overall objective of process, cost and time delivery efficiency:

- Adequate and periodic training for the welders/fillers and project managing team.
- Welders' proficiency must be adequately examined to ensure compliance to recognized international welding standards, specifications and procedures.
- Satisfactory and adequate incentives and enumerations should be appropriately administered to the welders/fitters.

# 5 CONCLUSION

This research work extensively focused on Lean Six Sigma methodology and its application for addressing problematic situations, such as eliminating or reducing defective welds encountered during welding operations in the oil and gas pipeline construction industry. The successful outcome of this methodology, based on past attestation by various business organization, encouraged appropriate investigation for its use and its ability to decipher problems in case studies scenario.

This assertion can be traced to the global publicity of LSS as an effective systematic mechanism driven through data acquisition for process delivery to tackle quality-related issues and achieve customer satisfaction. Besides, this approach is reported to improve organization profitability, achieve process operational excellence and ensure continuous process improvement with the aid of statistical tools and techniques. Utilizing the DMAIC improvement model of LSS ensure strategical usage of various steps or phases as a process road map to holistically address issues.

This adopted action research approach coupled with LSS methodology ensured this project work reflects on what was discovered or gathered (data) in each phase and, utilize the results (analysis) forming a guide for subsequent phase until arriving at the overall conclusions.

Furthermore, the conducted survey questionnaire – obtained from case companies employees – serves as a support for this research, and gives a holistic view in ensuring the problems are within reach by the management. Also, not to fail to mention the role played by the used literature reviews which formed enormous benefit for actualizing the overall objective for all possible solutions to the encountered problems.

The measure of process performance and operation of LSS is targeted at a quality yield (99.9997%) of 6 sigma level with a defect rate of 3.4 million opportunities for any project. However, each case companies' current sigma level ratings stands at 2.6, which reflects the high rate of defective welds in the welding operations during the pipeline construction. With the use of the define phase of the DMAIC model, which seeks to understand the project scope and aims to resolve the weld defects. This phase further identifies the project's charter, CTQ characteristics, SIPOC and flowchart.

The next is the measure phase, which entails the identification of key internal processes which influence the CTQ characteristics and measurements such as process capability, DPMO and process sigma level of defective welds currently generated.

While the analyze phase extensively evaluated the root causes of the weld defects for possible solutions through several LSS tools and techniques, such as brainstorming, Pareto chart, fishbone analysis, 5H-1H analysis and ANOVA. Also, it was observed, through Pareto chart, that the three main types of weld defects – slag inclusion, incomplete fusion and spatter – became evident as common faults among the pipeline welders. These issues were apparently supported through the conducted survey questionnaire.

After careful analysis of the previous phase, then comes the improve phase which consolidated the evaluated solutions: need for appropriate and regular training, adequate remuneration as incentives and regular eyes test of pipeline welders. The use of brainstorming, FMEA and simulation played vital roles in arriving at these solutions.

To monitor and control these recommendations, adequate mechanism must be put in place to sustain process improvements. Thus, the control phase which continuously monitor and review the processes to sustain the desired gains under strict quality controls. To achieving these operational improvements, effective practices and operational procedures through adequate documentation and regular monitoring mechanism (statistical process control) must be put in place based on international standard procedures.

However, considering certain limitation encountered during this period and the limited case companies involved in this research work, it is recommended that further study in the future should be sought to engage greater number of oil and gas pipeline construction companies and the possible cost implications. This will serve adequately for greater understanding of the magnitude of cost reduction, process efficiency and reaching more organizations to obtain comprehensive analysis in deciphering sufficient implications of weld defects in the oil and gas pipeline construction operations.

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# APPENDICES

## Appendix 1. Survey Request Email and Questionnaire

Hello,

I am currently rounding up my master's degree in Industrial Systems Analytics at the University of Vaasa, and conducting a study titled **"Utilizing Lean Six Sigma Model to Improve Managing Projects in the Oil and Gas Pipeline Construction Phrase: A Case Study of Selected Companies in Lagos State, Nigeria."**

I kindly solicit your assistance in responding to the attached questionnaire. Your response coupled with your wealth of experience and knowledge will provide vital information towards achieving the objectives for the research.

The provided information will be treated with the utmost confidentiality and no person responding to this questionnaire will be referred to by name. Its intended purpose is academic only.

Your prompt response in answering this questionnaire will be highly appreciated. And thank you in advance for your valuable contribution.

Kind regards,

Oluseye Michael Johnson

Email: oluseye.johnson@student.uwasa.fi

Tel: +358440667327

**INSTRUCTIONS**

There are three main parts to this questionnaire. The first part (**SECTION ONE**) tends to seek the background information of all the respondents, such as job title/position held, gender and working experience. The second part (**SECTION TWO**) tends to only concentrate on the pipeline project managing personnel, by targeting the various scenarios towards the preparation, during and overall performance of the pipeline construction phase activities. While, the third part (**SECTION THREE**), concerns the pipeline welders and fitters, which seeks the overall evaluation of their critical input during and build-up of the pipeline welding activities.

**SECTION ONE: RESPONDENT'S BACKGROUND INFORMATION**

Name (optional) ……,……………………………………..……………………………………………….

Please indicate your gender: Male [ ] Female [ ]

Job position…..........……………………………………………………………………………….……

Name of work place ……………………………………….……………………………………..…….

E- mail ……………………………………………………………………………….…………………….

Mobile / create serial number………………………….........................................................

City……………………………………………………………………………………………………..….

Country…………………………………………….……………………………………………………

Please tick your years of working experience and all academic / welding qualification:

| | | |
|---|---|---|
| 1 – 4 years [ ] | Certificate [ ] | Mechanical Engineer [ ] |
| 5 – 15 years [ ] | Lower Diploma [ ] | Pipeline Engineer [ ] |
| 16 – 25 years [ ] | Higher Diploma [ ] | Offshore Engineer [ ] |
| 26 – 40 years [ ] | Bachelor's Degree [ ] | Chemical Engineer [ ] |
| Above 40 years [ ] | PGD Degree [ ] | Petroleum Engineer [ ] |
| | Master's Degree [ ] | Gas Engineer [ ] |
| | Others specify: | Mechanical Fitter [ ] |
| | | Welding & Fabrication [ ] |
| | | Dye Penetrant Inspection [ ] |
| | | Radiographic Film Interpretation [ ] |
| | | Ultrasonic Testing Inspection [ ] |
| | | Visual Inspection [ ] |
| | | Others specify: |

**SECTION TWO: PIPELINE PROJECT MANAGING PERSONNEL**

*Please indicate your opinion by ticking the appropriate column on the scale 1 – 6 the following relative importance of each effect to achieve success in the welding processes during pipeline construction phase activities.*

### 2.1 Man factors

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 2.1.1 | Ineffective communication practices | | | | | | |
| 2.1.2 | Lack of quality supervision practices | | | | | | |
| 2.1.3 | Lack of Lean Six Sigma process practices | | | | | | |
| 2.1.4 | Poor project re-design/changes | | | | | | |
| 2.1.5 | Project rework leading to extra cost | | | | | | |
| 2.1.6 | Project rework leading to delays | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.1.7 | Irregular re-training of welders | | | | | | |
| 2.1.8 | Total Quality Management practices | | | | | | |
| 2.1.9 | Tight work schedule | | | | | | |
| 2.1.10 | Improper workforce motivation | | | | | | |
| 2.1.11 | Lack of welder competence & skills | | | | | | |

**2.2 Machine/equipment factors**

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 2.2.1 | Unavailability of spares & equipment | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 2.2.2 | Incorrect use of equipment | | | | | | |
| 2.2.3 | Poor working condition of equipment | | | | | | |
| 2.2.4 | Improper storage of equipment | | | | | | |
| 2.2.5 | Insufficient equipment provision | | | | | | |
| 2.2.6 | Irregular maintenance of equipment | | | | | | |
| 2.2.7 | Not testing equipment before use | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.2.8 | Unsatisfactory equipment quality | | | | | | |

**2.3 Materials factors**

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 2.3.1 | Non inspection of supplied materials | | | | | | |
| 2.3.2 | Materials not match drawing specification | | | | | | |
| 2.3.3 | Improper use of materials | | | | | | |
| 2.3.4 | Improper storage of materials | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.3.5 | Unsatisfactory material quality | | | | | | |
| 2.3.6 | Not testing of materials before use | | | | | | |

**2.4 Environmental factors**

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 2.4.1 | Bad weather condition during construction | | | | | | |
| 2.4.2 | Day work | | | | | | |
| 2.4.3 | Inadequate health & safety provision | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 2.4.4 | Night work | | | | | | |
| 2.4.5 | Non provision of wind/rain shelter | | | | | | |

**SECTION THREE: PIPELINE WELDERS AND FITTERS**

*Please indicate your opinion by ticking the appropriate column on the scale 1 – 6 the following relative importance of each effect to achieve success in the pipeline welding activities.*

**3.1 Man factors**

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 3.1.1 | Non adherence to weld standards & procedure | | | | | | |
| 3.1.2 | Inadequate details in project drawings | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.1.3 | Irregular re-training | | | | | | |
| 3.1.4 | Irregular eye test check-up | | | | | | |
| 3.1.5 | Poor eyesight/injuries | | | | | | |
| 3.1.6 | Poor visual weld inspection | | | | | | |
| 3.1.7 | Possess inadequate welder/fitter certification | | | | | | |
| 3.1.8 | Pressure to finish welding activities | | | | | | |
| 3.1.9 | Poor project re-design/changes | | | | | | |
| 3.1.10 | Non provision of incentives/motivation | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.1.11 | Weld rework leading to project delay | | | | | | |
| 3.1.12 | Poor welder/fitter proficiency & performance | | | | | | |
| 3.1.13 | Poor wellbeing of welder/fitter | | | | | | |
| 3.1.14 | Poor welder/fitter work experience | | | | | | |

**3.2 Machine/equipment factors**

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 3.2.1 | Unavailability of spares & equipment | | | | | | |
| 3.2.2 | Incorrect use of equipment | | | | | | |

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|---|---|---|---|---|---|---|---|
| 3.2.3 | Poor working condition of equipment | | | | | | |
| 3.2.4 | Improper storage of equipment | | | | | | |
| 3.2.5 | Insufficient equipment provision | | | | | | |
| 3.2.6 | Irregular maintenance of equipment | | | | | | |
| 3.2.7 | Not testing equipment before use | | | | | | |
| 3.2.8 | Unsatisfactory equipment quality | | | | | | |

**3.3 Materials factors**

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 3.3.1 | Non inspection of materials | | | | | | |
| 3.3.2 | Inappropriate storage of electrodes | | | | | | |
| 3.3.3 | Improper use of materials | | | | | | |
| 3.3.4 | Provision of wrong material | | | | | | |
| 3.3.5 | Unsatisfactory material quality | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.3.6 | Insufficient material provision | | | | | | |
| 3.3.7 | Not testing of materials before use | | | | | | |

**3.4 Environmental factors**

| | | No Opinion | Does not affect | Slightly affect | Affect | Strongly affect | Extremely affect |
|---|---|---|---|---|---|---|---|
| 3.4.1 | Bad weather during activities | | | | | | |
| 3.4.2 | Day work | | | | | | |
| 3.4.3 | Inadequate health & safety provision | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 3.4.4 | Night work | | | | | | |
| 3.4.5 | Non provision of wind/rain shelter | | | | | | |

*Please state in writing your opinion and practices encountered in the pipeline welding activities. Also, specify others not included.*

3.5 List the welding processes that you mostly use, starting with the most frequent to the least.

***Denote by number: 1 = Gas Welding; 2 = MIG Welding; 3 = Plasma Arc Welding; 4 = SMAW Welding; 5 = TIG Welding.***

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3.6 List the welding parameters that are used during your welding operations.

***Denote by number: 1 = Arc Length; 2 = Welding Angle; 3 = Welding Current; 4 = Welding Speed; 5 = Welding Voltage.***

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3.7 List the weld defects that occur mostly in your welding operations in the past two years, starting with the most frequent to the least.

***Denote by number: 1 = (Incomplete Fusion); 2 = (Incomplete Penetration); 3 = (Porosity); 4 (Slag Inclusion); 5 = (Spatter); 6 = (Undercut).***

3.8 The weld defects that you mentioned mostly occurring in your welding operations in the past two years, can you estimate in percentage range their occurrences.

***Denote by alphabet: A = (0 – 20 %); B = (21 – 40 %); C = (41 – 60 %); D = (61 – 80 %); E = (81 – 100 %).***

3.9 How do you preserve the integrity of various types of electrodes used for welding?

4.0 How often do you conduct pre-heat and post-heat on weld joints during welding operations?