Welding Processes via Lean Six Sigma Framework

Divyansh Srivastava[1], Utkarsh Chadha[2]*, Pratyush Prakash[3], Arshdeep Kaur[2], Molly Code[2], Gaurav Chhablani[3], Sakshi Santosh Kumbhar[3], Girish Yemul[3], Vezhavendhan R[3], Won-Chol Yang[4]

[1]Technische Universitat Darmstadt, Darmstadt, Germany
[2]University of Toronto, Toronto, Ontario, Canada M5S 1A1
[3]School of Mechanical Engineering (SMEC), Vellore Institute of Technology (VIT), Vellore, Tamilnadu, India – 632014.
[4]Faculty of Materials Science and Technology, Kim Chaek University of Technology, 60 Kyogu, Pyongyang, Democratic People's Republic of Korea

*Corresponding: utkarshchadha1302@gmail.com

Abstract. The Lean Six Sigma (LSS) Framework is a tool to encounter waste management, reduction, regulation, and direct manufacturing processes. It is utilized in welding and has been proven to benefit the process by focusing on wastage reduction and directing the process precisely. Industrialization leads to the destruction of natural resources like water and land. The wastage control and process regulations for higher efficiency are minimal in various welding industries. This review explains how the LSS methodology can help reduce or eliminate defects observed in the industrial welding process. The fundamental and primary tool of LSS is known as the DMAIC principle (Define, Measure, Analyze, Improve, and Control). The process works by converting problem-solving into steps and setting milestones to monitor progress. DMAIC has been extensively utilized in a lot of studies for welding process optimization. This review provides an overview of the welding processes regulated using the LSS framework, the changes observed in various welding processes, and further guidance in sustainable welding practices.

Keywords: Lean Six Sigma; Welding; Manufacturing; Sustainable Practices;

1.0. Introduction

Welding is an intricate and prominent field of study most industrial applications rely on, being widely implemented within the industry. Welding processes in industries usually face issues or errors which can be solved on the ground level using current industry technologies. However, there is still a lack of mitigation strategies where Lean Six Sigma can actually help personnel follow a set of rules and guidelines to avoid errors and wastage during the process [1].

Lean Six Sigma (LSS), as shown in Figure 1, is a combination of 'Lean' emphasizing waste reduction, while 'Six Sigma' aims to reduce errors and defects. This synergy has revolutionized the manufacturing and welding industry, by not only quality and waste, but also improving the operational conditions, constraints, or limitations of the process through the support of research [2-4].

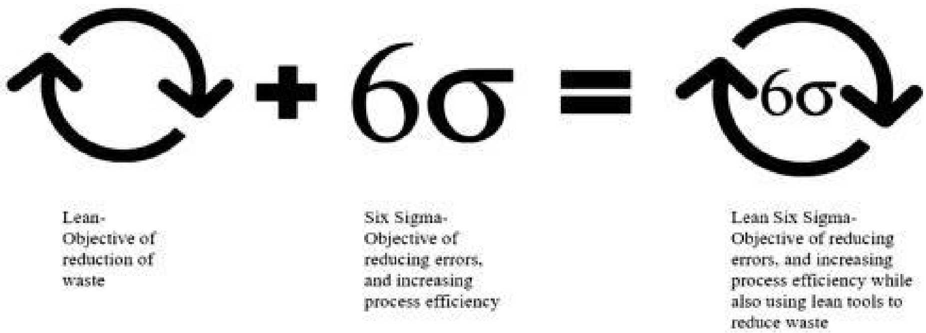

Figure 1. Lean Six Sigma [1]. Adapted with Permission, Elsevier B.V.

Total quality management is adopted in the welding process to increase the efficiency and performance of the final welded materials at the industrial level. It has principles, rules, & regulations for standard and essential operations inside the industrial manufacturing process. Six Sigma is a six-level mechanism and system utilized to improve output efficiency. It is used to manufacture vital products and design processes to increase the reliability and compatibility of products at an industrial scale [5, 6]. The main objective behind Six Sigma practice in companies and industries is to improve manufacturing quality and efficiency to meet customers' demands and satisfaction. This process also helps minimize defects and directly impacts the failure of products at different testing phases and situations. This technology uses emphatical and statistical techniques for quality management and to reduce the multiple variabilities in production and regular business development processes. Additionally, the technology is famous for statistical modeling development and the growth of advanced materials manufacturing processes. Six Sigma technology requires a quality check that tests the Defects Per Million Opportunities (DPMO) for the betterment of the product to further show the long-term defects, problems and hazards that may occur in the future [5-7].

The DPMO calculates the level of variability and defects in the manufacturing product in ideology, basic design, and the product development phase. This process helps achieve quality improvement in a sustainable manner that requires commitment from working employees, companies, and organizations [5, 7]. The phenomena are known as LSS methodologies on the extensive use of Six Sigma in some groups or a particular bunch. It is a process in which every integral member's collective team effort, participation, and proper contribution must improve and make something performance efficient [1, 6]. This process depends upon the team effort and full participation of every member because the target is not achievable by a single or some members in the group. It only looks more realistic and achievable if it gets effort from every vital member [8-10]. All of the welding processes are an industrial-level complex work function, so the head of the team and the company's higher-level members always choose LSS methodologies in which they form many teams of remarkable people and assign them small pieces of the leading project plan so that on completion of small projects and their proper integration makes the main project half-way done and it gets centralized by this step. Adopting the LSS methodology is that it distributes welding processes uniformly and gets the work done at a remarkably improving rate. This step also reduces variability in basic DMAIC and business plans, increasing the overall efficiency of manufacturing products [11-14].

This review provides insight into LSS implementation in welding processes and how such processes are impacted. Additionally, this study focuses on case studies in academia and the industry that have implemented Lean Six Sigma, and emphasize specific LSS tools that have been implemented in welding research.

2.0. Welding Defects

Weld defects are faults and discontinuities that weaken joints, further compromising their intended function that lead to weld failure. These discontinuities may be accepted or rejected, and are dependent on three factors: type, size and location. Defects are common occurrences in all welds, being present indefinitely. However, it is only when these discontinuities exceed their appropriate acceptance standards, is when they become a true defect [15].These defects can be either internal or external and have a variety of causes including improper arc voltage, speed of travel during the weld, and overall poor welding skills [15].

2.1. Common Types of Welding Defects

Common welding defects are shown below in Figure 2. Cracks, Slags, Poor Penetration, and Lack of Fusion are internal defects that significantly weaken the integrity of welds as they grow rapidly and worsen the material over time.

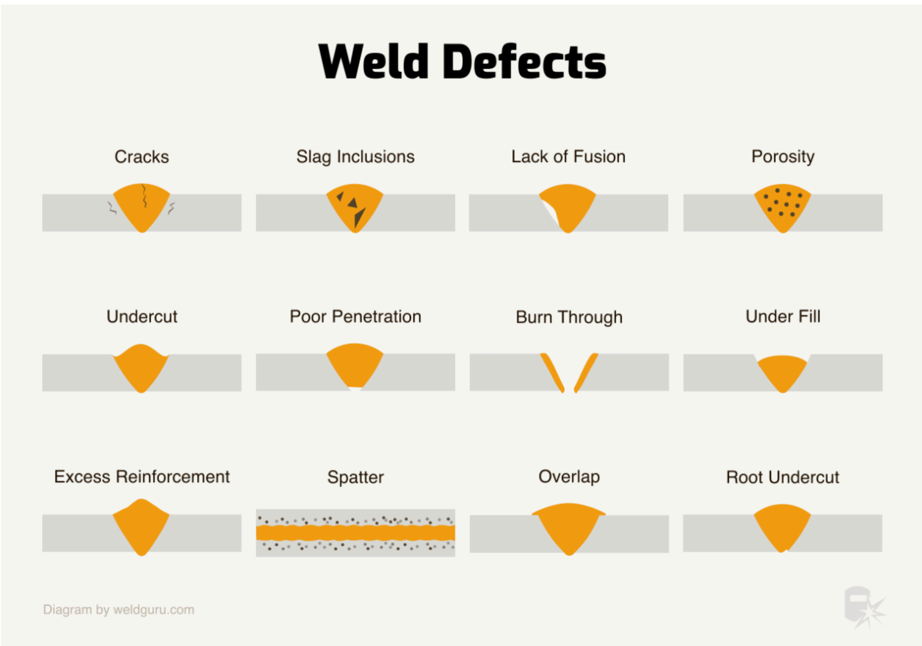

Figure 2. Common types of welding defects [16]

There are three main types of cracks; Longitudinal cracks - run parallel to the weld, Transverse cracks – traverse the width of a bead, and Crater cracks – often form at the end of welds when arcs are terminated [17]. Slags commonly occur in flux-related processes, and form in brazing, stick, flux-cored, and submerged arc welding [17]. Poor penetration occurs when weld beads do not fully penetrate the bottom of butt joints [17]. A lack of fusion results when the filler material does not bond properly with the base metal, further leading to structural weaknesses such as voids and gaps [17].

Contrarily, Porosity, Undercut, Burn-Through, Under-Fill, Excess Reinforcement, Spatter, and Overlap are external defects that make materials more prone to cracks and failures, causing significant risk to structural integrity [17]. Porosity occurs when gas bubbles become trapped inside the weld bead, weakening the joint and impacting the weld's durability. Undercuts arise where grooves run along the toe of the weld [17]. Burn-Throughs are the result of excessive heat creating holes in metal that ruin the joint. Under-fill's are formed when the weld bead is recessed below the surface of the base metal, while Excess Reinforcement is the occurrence of too much filler material in the weld [17]. Figure 3 below portrays the cause and effects of welding defects.

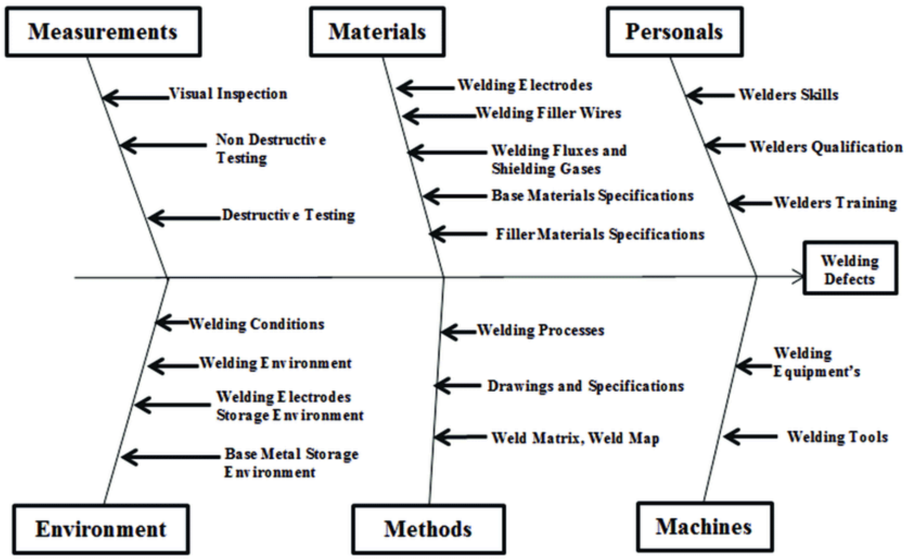

Figure 3. Cause and Effect Diagram of Welding Defects [17].

2.2. Standards and Classifications of Welding Defects

The International Organization for Standardization (ISO) has multiple standards pertaining to common metals and alloys used in welding processes. These welding standards include ISO 5871 containing assessment criteria for fusion-welded joints [18], and ISO 10042 containing assessment criteria for arc-welded joints [19]. These standards are used to measure the degree of imperfections and defects a weld can possess before it is deemed unsafe. Additionally, these ISO standards sort welds into categories of B, C, and D, based on the amount and severity of defects within a certain amount of area. Welds that are categorized as B-Level welds are of the highest quality, deemed by the minimal amount of defects [18].

2.3. Implementation of LSS in Welding Defects

Lean manufacturing strives to reduce waste in eight key areas of the manufacturing process [20]. These areas are defects, excess processing, overproduction, wait time, inventory, transportation, motion, non-utilized talent and skills. Six Sigma's purpose uses teams that are assigned a well-defined project and problem, the team is trained in statistical thinking, the team practices the DMAIC approach, and the management environment is conducive to supporting the former initiatives [21]. Combining Lean manufacturing with the data driven Six Sigma strategies, the goal is to reduce the opportunity for defects to occur, versus traditional methods of defect detection. LSS strategies could prevent these contingencies from hindering an entire project, and allow for the project to reach the client with reduced time and cost [22].

ISO standards and having employees trained to implement these standards align with the Six Sigma approach to welding. Coupling the highly trained employees for both high quality welds and immediate detection of errors, the lean approach to reducing manufacturing waste leads to quality production.

3.0. LSS Tools & Their Relevance for Welding Process

The 5S (Sort, Set in order, Shine, Standardize, Sustain) Methodology

The 5S methodology is derived from the Japanese words for the acronym. The 5S method is used to aid in continuous development and improvement of the welding process [23, 24]. The 5S method focuses on the workplace with the philosophy that if the workplace is well established, and the workers are trained to follow the appropriate checklists and order of events, the likelihood of weld defects is significantly reduced [24]. Figure 4 shows the application of the 5S process in Electric Arc Welding.

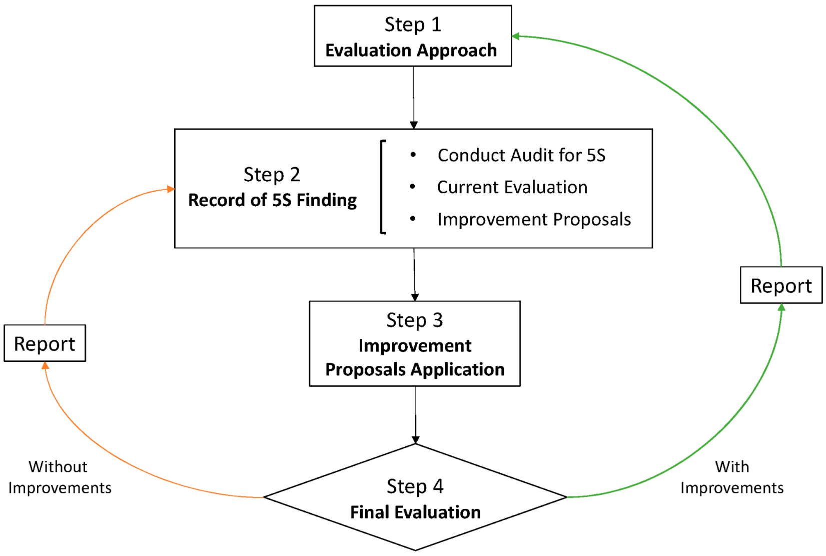

Figure 4. 5S Approach for Electric Arc Welding Process [24].

Table 1. 5S Applications.

5S Process	Application [24]	Example 1 [23]	Example 2 [23]
Sort	Divide goods, material, and equipment based on requirements of welding team and facility	Disposing of items that are damaged and non-reusable	Organizing and returning misplaced items
Set in Order	Desired tools and goods are organized for efficient access	Safety items must be stored in an easily accessible space in case of emergency	Organize items based on frequency of use
Shine	Maintain cleanliness and hygiene in the work environment	Clean machines based on a predetermined schedule and checklist	Workplace and floors must be cleaned daily
Standardize	Ensure all steps (sort, set in order and shine) are regularly followed	Audit workers to ensure all steps are being followed	Educate workers on the standards of the 5S methodology
Sustain	Create a manageable 5S process that is	Leaders should center company values around 5S philosophy	Workers should have clear understanding of 5S

	sustainable for leaders and workers to follow		and eagerness to uphold 5S principles

Implementing the 5S Philosophy ultimately optimizes the space and time of welding processes. Goods can be rearranged and grouped based on size and characteristics, ensuring that equipment is kept in correct order, and safety kits are placed in accessible areas. The reduction of searching, waiting and excess activities can improve the utilization of time and space during welding processes as well.

Kaizen

Kaizen is a Japanese term that indicates continuous improvement [25]. This philosophy continuously adapts to the evolving demands within the welding process and thus increases productivity while striving for zero defects in welding [25]. Two of the most critical challenges that are faced in the industry are the limited availability of skilled labor and the increasing need for productivity and cost effectiveness. Figure 5 below visualizes the detailed methodology. The kaizen approach tackles this issue by distributing workloads based on skill set evaluations through statistical techniques []. This allows for efficiency in welding processes and increased production that further contribute to cost and cycle-time reduction. In addition, the process addresses issues faced at welding lines, which include wastage of extra material, deposition, and reduction of joint strength due to material defects [25]. Addressing these problems in the design phase will allow space to implement appropriate modifications to optimize resources and production in comparison to traditional methods.

Figure 5. Kaizen in the Welding Process [26].

Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a Lean Engineering Tool which helps solidify understanding of the problem, the solution, and the path to get there. Figure XX highlights the relationship between material and information flow. This provides detailed insight into sources of waste, and offers an opportunity for organizational leaders to address the issue. Additionally, Figure 6 depicts the process starting from material collection, welding, assembly, finishing, to checking and supplying the project to the client [27, 28].

To carry out VSM in the welding shop floor, value added (main activity) and non value added activities (inventory, wastes) are marked. More data is then collected, such as cycle time, number of operators, available working time per shift, actual machine working time, and time taken to switch between producing products. Based on these inputs, several lean measurements such as lead time are taken, which involve the times taken by each part to move from starting to finishing processes. Value adding time is also calculated which involves the actual time involved during the welding process which includes value added activities. Moreover, the Takt Time is calculated from the customer requirements and available working time. The unnecessary waiting times may be reduced by cross team collaboration amongst different departments to ensure that each worker is able to contribute adequately. This creates a flexible structure in organizations where improved communication cuts down the time involved in non value added activities, and thus, increasing team efficiency [29-31]. Finally, the layout of the welding shop floor may be redesigned to eliminate storage time, and to be utilized for functions such as fabrication, assembly, and cleaning to reduce excess inventory. It is determined that continuous flow of production can help to increase the overall process cycle efficiency.

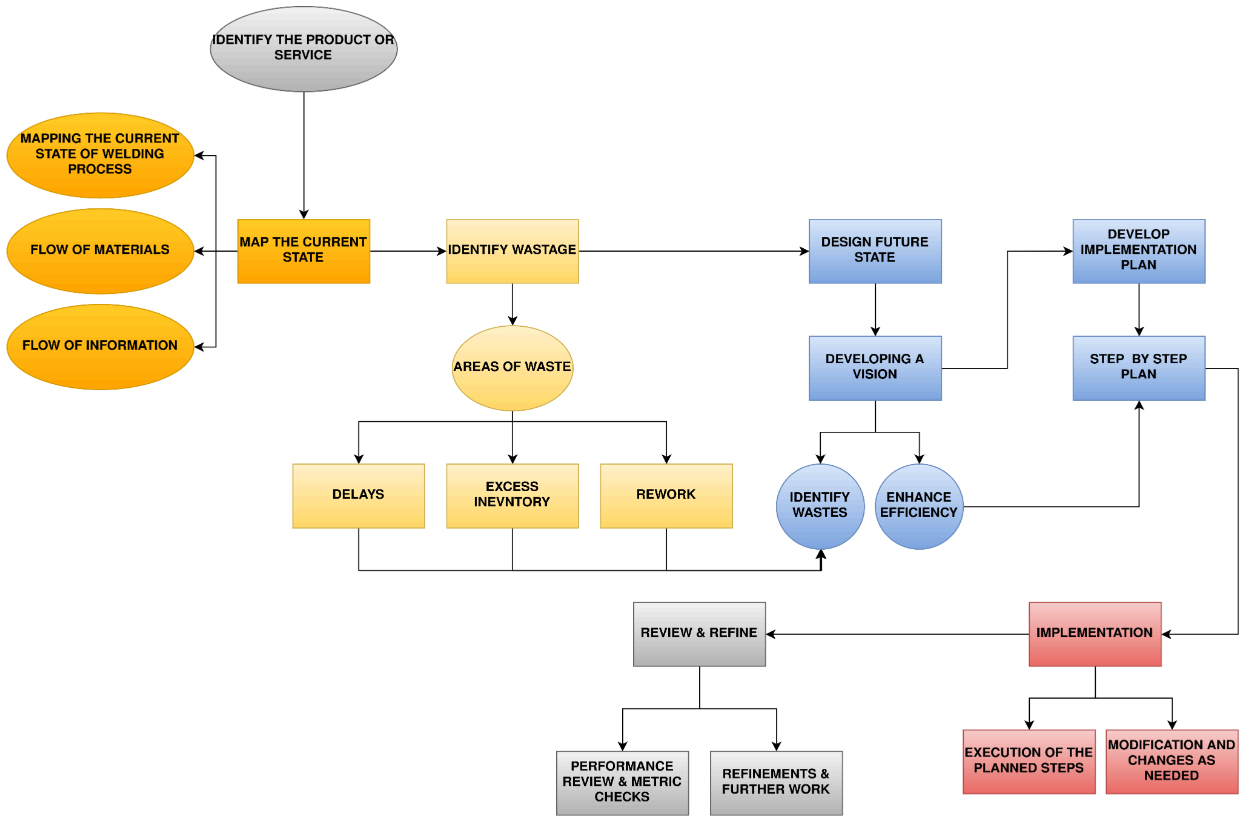

Figure 6. Value Stream Mapping for Welding.

It is preferred to start with a small quantity of schedule so that workers are not overburdened and it is easy to monitor and keep track of the work in progress and can respond to change in demands during the manufacturing process quickly. In this way management can utilize these lean tools in order to make themselves more competitive among their customers and get better output from within and thus it can become a part of their business strategy too [32, 33].

Root Cause Analysis (RCA)

This technique helps to find out the primary cause or the root cause of the problem occurring during the welding process. It can be the defects caused in the joints, insufficient power supply & material flow, deposition of material, metallurgical properties of the material, atmospheric conditions, etc. Firstly, the symptoms are checked to identify what kind of problem is occurring and a sufficient amount of data is collected to see the impact caused due to these problems. The below mentioned flowchart represents the workflow of this technique . There are several tools which can be used to identify and analyze the root cause of the problem such as '5 Whys', Fishbone diagram (Cause & Effect Diagram) which is also called Ishikawa diagram. These tools help to identify the technical parameters such as welding current, electrode design, amount of shielding gas , gap between the welding rod and metal piece, surface finish of the material, microstructural properties of the material, cooling time, etc. responsible for the welding defects and failure [34, 35].

The Cause & Effect Diagram is an analytical tool and one of the seven quality control techniques which takes into account variations caused during the welding process and its parameters. This diagram can be plotted for various welding defects such as cracks, undercut, porosity, lack of penetration, excessive penetration , etc in the welding process to understand which are the major defects occurring during welding, why these defects are occurring and the parameters associated with it such as coating of electrode with flux , size of electrodes, welding speed, shape of the plasma arc etc.so that appropriate solutions can be produced for the same. The defects can be further analyzed by determining its causes such as problems occurring in machines, not using standard methods, faulty tools, inexperienced labors, man-made errors, measurement tools are not accurate, human fatigue, unclean area,incorrect welding parameters etc [36, 37].

This type of Statistical analysis can help the organization further to achieve high quality and reliable products meeting quality standards and customer demands. It can eliminate or reduce the deviations caused in the process by collecting and analyzing data and making sure that the cost involved is minimized. Due to this approach the welding process can also be redesigned and optimized based on the problem. '5 Why' approach can also be used as a brainstorming approach to find the appropriate root cause of the problem and further suggest ideas to prevent it. These solutions can then be monitored on a consistent basis to check whether the problem is resolved or not. This Lean Six Sigma framework takes into account the limitations occurring during other techniques such as Non destructive testing, Numerical analysis, etc. and is much more cost effective and easy to use [38, 39].

This type of analysis is quite reliable and can be taken into account during early development stages too which will prevent any problem occuring in future. The basic steps involved are to identify the issue ,its factors and why these factors are caused along with its effects. The level of importance can also be given to each factor to determine its criticality and a mathematical relationship can be developed between the input and output parameters to get the optimum weld quality Once the critical parameters are found out they can be further optimized for further development of the welding process.and simulation plus experimental techniques can be modified too for better correlation between them [40].

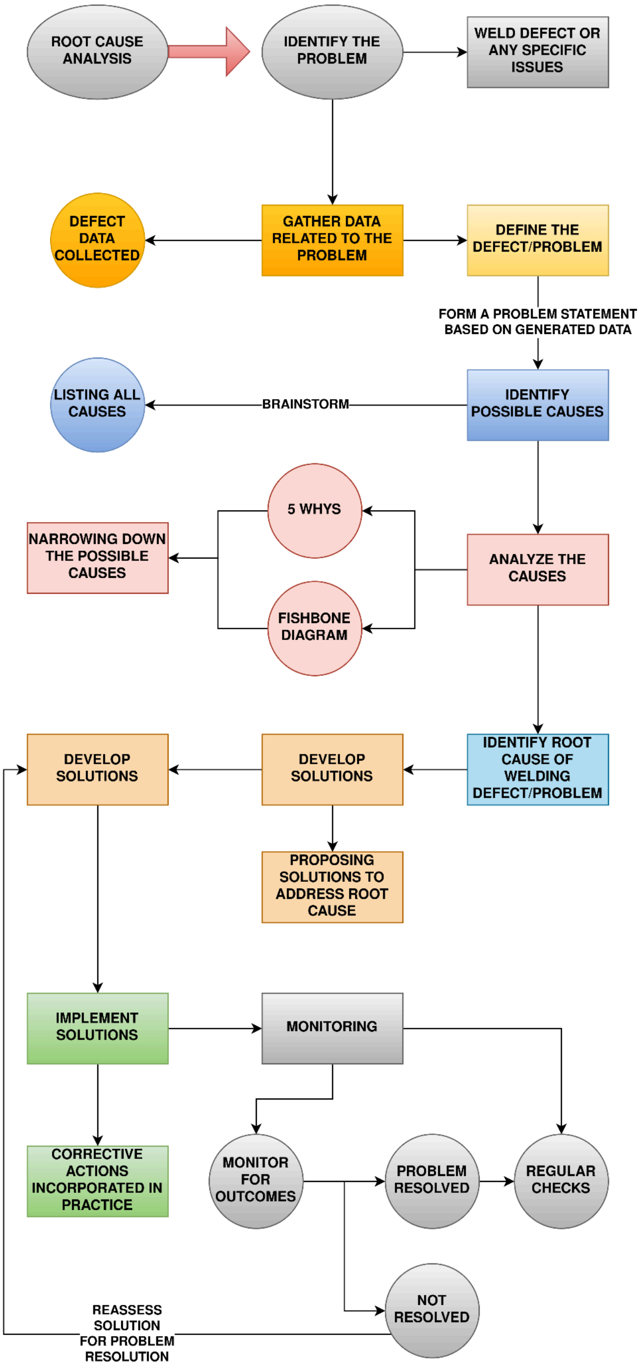

Figure 7. Root Cause Analysis for Welding.

Control Charts

This technique is used to control, measure and monitor the variations observed during the welding process, consistently helping to achieve proper quality welds (Figure 8). It enhances the stability of output for the process carried out. It is a statistical-based approach that plots graphs to visualize the variations observed in welding parameters. Productivity levels may be maintained as the mean, range and standard deviations are calculated and monitored over time for given welding parameters [41, 42]. The variations occurring during the welding process may be caused by natural occurrences such as environmental conditions, operators and material properties. Since the control limit values are defined for the same, the values plotted in the graph provide a sense of what process parameters are effective for welding arcs to ensure stability is achieved. Furthermore, the welding process can be optimized through software such as Minitab, which is applicable for analysis and is cost-effective, thus saving large quantities of resources [43]. It becomes convenient to use these tools during quality inspection or checking of the welded joints of the product. If the sample points in the charts are falling outside of the control limits, this indicates that welding defects may be occurring. Generally, it is preferred to collect more data so that the results produced after analyzing them are more reliable. This technique may further prevent rework or repair action of welded parts as the problem occurring can be detected in the initial stage itself. Along with the X-bar, R charts for voltage and Moving Range, charts may also be plotted to check occurring process variations and their reasons due to which problem-solving steps can be made [44].

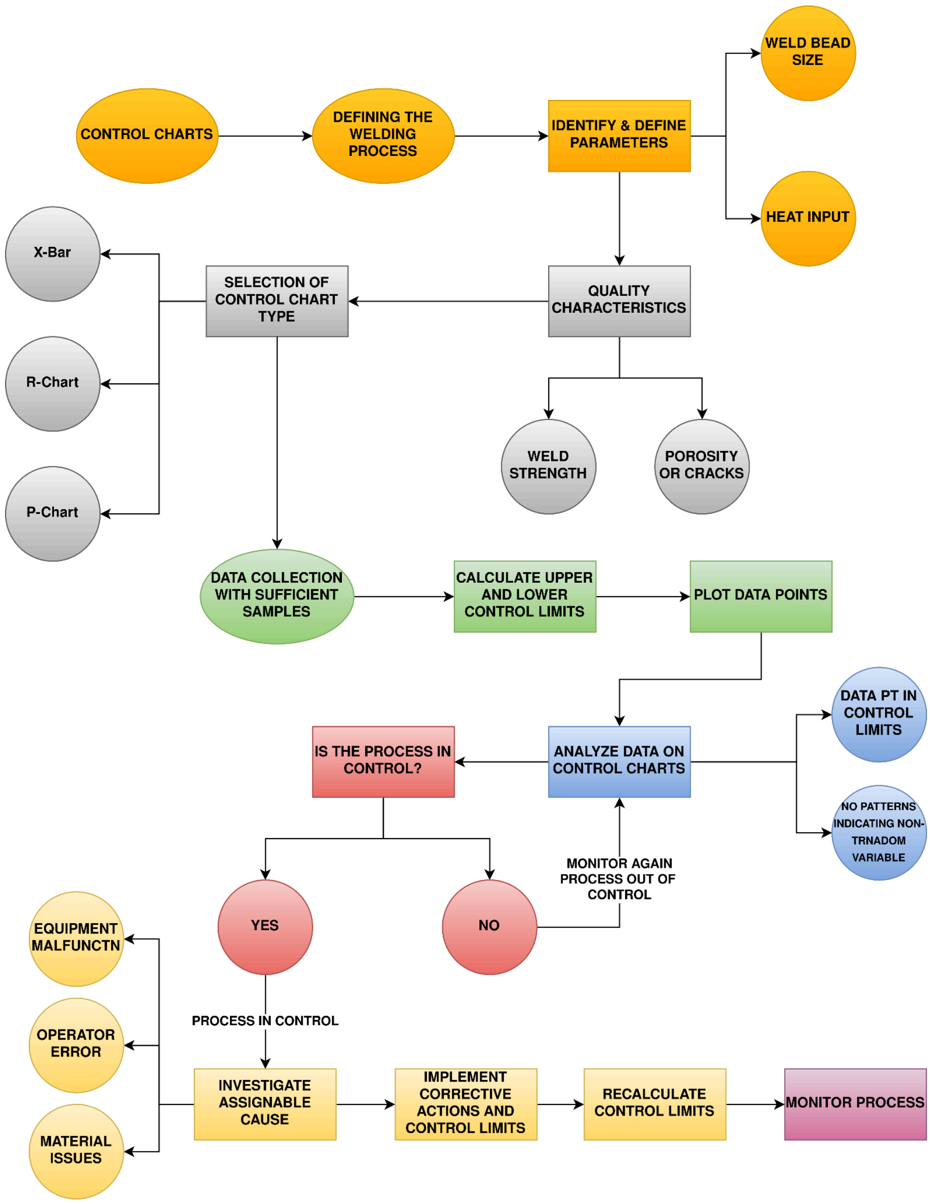

Figure 8. Control Charts in Generic Welding Engineering Scenario

Failure Mode and Effects Analysis (FMEA)

As shown in Figure 9, FMEA (Failure Modes & Effects Analysis) is an effective tool to note the potential problems and their occurrences in products. It indicates the severity of the problem alongside its motivating factors (i.e. current, voltage, weld speed) [45, 46].

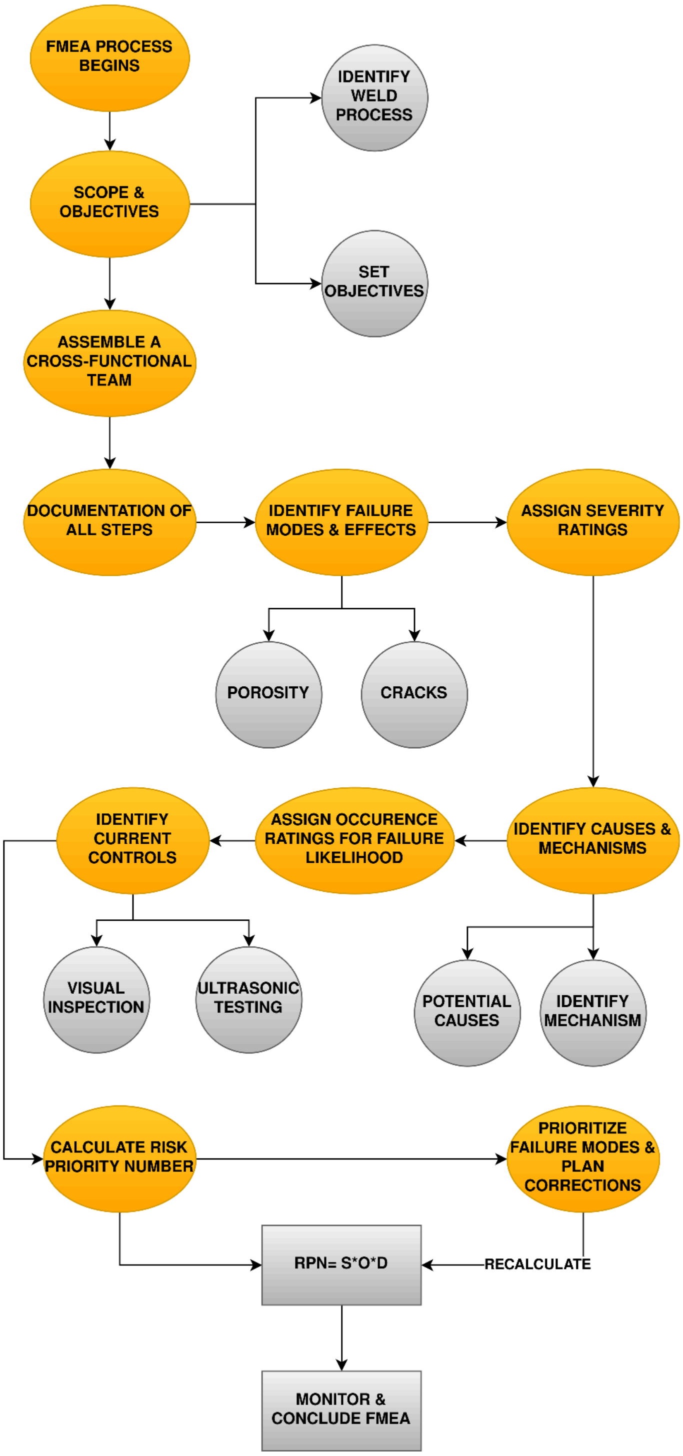

Figure 9. FMEA for Welding Engineering.

Solutions are developed from this tool to make more reliable welded products. By implementing these improvements in the development stages, further processes may be carried out at welding workshops and optimized process parameters to reduce defects. The RPN Number is calculated based on the severity of risk, occurrence and detection of the associated failures alongside the rating values given. The failure with the largest RPN value indicates the riskiest problem in the welding setup and is modified accordingly to meet safety standards [47-49].

RPN = S (Severity) x O (Occurrence) X D (Detection)

Generally, there are many products with complex welding and manufacturing systems. FMEA can ensure that this process runs while meeting customer-specific demands. The strength of welded joints is crucial as it examines possible welding defects such as porosity and undercuts. Analyzing the cause and effect of these factors may optimize equipment, resources, time, wastage and expenses. Aside from defects, possible welding failures include short-circuiting, improper grounding, safety light detectors such as LEDs not working, welding rod eroded, issues with cooling, and welding arc stability. These defects may be identified using the FMEA technique upon welding processes and as a checklist to meet the safety standard and customer-specific requirements of welded products. The significance of this tool is that it helps to create a feasible and sustainable solution required by industry standards [50-52]. There are two types of FMEA - Process FMEA and Design FMEA (DFMEA) which deal with locating failure modes at process stages and design stages. These LSS tools can develop a correlation between design, simulation and welding to develop better simulation models that identify problems before physical tests.

4.0. DMAIC for Welding Processes

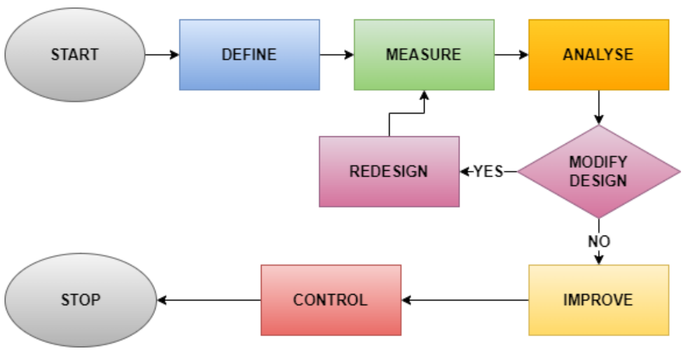

Figure. Flow of a generic DMAIC Process [1].

DMAIC is the most commonly used Six Sigma Tool in welding (As shown in Figure X). The DMAIC in welding can be explained in the following manner:

(1) In an industrial setup, where the issues in the welding process are initially identified, the personnel, after identifying the issues, must set a goal, i.e., reduction of welding defects by a certain percentage. The scope is defined to cater to the problem, avoid scope creep (unexpected deviation from the goal), and further involve the stakeholders from the initial step and transmit the progress information [53].

(2) The definition then allows further documentation of the welding process to measure various aspects (materials used, equipment, and techniques) and facilitate data collection (ex., Weld strength, time per weld, etc.) [54].

(3) Root cause analysis is conducted, where the welding issues are detected, for example, operator skills, material issues, equipment settings or any calculation errors, etc., are accounted for. This further allows the use of a performance metric, which helps keep the progress measurable and guides the personnel while executing the project, i.e. welding operation [55].

(4) Improvements are needed in the technologies deployed in the industry, where the welding process should be assessed for possible improvements, for which research work is conducted, and a new change or a new model is proposed accordingly. Further, the proposed idea is tested in multiple iterations before officially being implemented to test its commercial and technical viability. Once tested successfully, and if it is viable, the team must develop a plan to incorporate the new welding innovations throughout [56].

(5) Once the improved model is approved and implemented, its performance and modifications should be documented to set a standard for the personnel to follow. Monitoring of this new, improved process is required to study the performance and utilize a benchmark study to compare the resulting outcomes for an opportunity to improve the process further [57].

There are cases where DMAIC was implemented successfully, with adequate results, as shown in Table X; the table is divided into components of DMAIC to explain the cases and their final outcomes.

Table 6. Prominent LSS (DMAIC) Case Studies in Welding Processes.

Case	D	M	A	I	C
[58]	Improving the mechanical properties of pipes joined together by friction stir welding.	Pipe wall thickness (t), tool travel speed (s), and tool rotation speed (n) would be this experiment's variables.	Each parameter affects the sample joint's tensile strength and hardness. Analysis of Variance, or ANOVA, was implemented to this effect.	The optimal range value of the machine tool of certain rotation speed (n) and tool moving velocity(s) was calculated	The optimal mechanical tool rotates at speed, and the same tool moving speed values were 1800 rpm and 4mm/min, respectively.
[59]	Investigating the manufacturing process	Process mapping, Data collection, Sigma-level	A Root Cause Analysis (i.e., fishbone diagram) was carried out to	1. Monitoring and reporting waste generation monthly	A control plan was designed and circulated to the firm to

	Constructing the SIPOC diagram Collecting preliminary data Drafting the problem statement	calculations, and Downtime measurements	identify all possible sources of waste, followed by the implementation of the Analytical Hierarchy Process (AHP) to find significant waste-generator	2. New control panel 3. Reaching out to a new supplier 4. New glass mixing machine 5. Remodeling maintenance program 6. Installing the extra reclaiming machine 7. Creating a daily cleaning schedule with a checklist, worker responsible, area, machines, and signature box	sustain the improvements made. Expectation setting is critical in eliminating ambiguities. Using the systematic methodology of DMAIC, the company could bring its waste ratio below 2%.
[60]	Determination of Critical to Quality determine the SIPOC diagram for better knowledge of the issue preparation of the welding map WPS/PQR and weld joints	Exploration affirmed that with the execution of the FMEA technique, the industry gets an outline of the means to be taken for what is to come with the goal that the dependability of a steam generator heater framework can be enhanced.	Circumstances and logical results charts show the connection between issues confronted with reasonable causes just as components impact it. The elements that impact and become reasons for harm to welds can be named man/personals, material, estimation, strategies, machines, and climate.	The objectives of this stage are to choose the complex arrangement, do experimentations to approve arrangements and relations between the impacts and causes through Root Cause Examination (RCA) instruments, conceptualize, and conversation	The final period of DMAIC is administered, which guarantees the motion cycles on the functioning to design and produce expected result & stick with original quality levels. The apparatuses used in this stage are a control plan, check sheet, and observation.
[61]	The company understands the customer's issues using SIPOC, Voice of Customer, and Quality	The nitty-gritty cycle planning, operational definition, information assortment outline, assessment	The third period of the DMAIC interaction incorporates the meaning of the fundamental driver of the imperfections	The objectives of this stage are to choose the issue arrangement, perceive the dangers and carry out the chosen arrangement. This progression	The adjusted interaction is exposed to a vigil at standard time spans to guarantee that the key factors do not show

Capacity organization.	of the current framework, appraisal of the current degree of measure execution, and so forth.	and the main reason investigation utilizing apparatuses like the fishbone chart focusing on the significance or criticality of each cause utilizing apparatuses, for example, the FMEA, WHY-WHY Investigation.	utilizes imaginative approaches to discover better approaches to improve, less expensive or quicker. Spontaneous creations in the process are done to keep the factors inside as far as possible.	unsuitable varieties.

5.0. Benefits

The implementation of the Lean Six Sigma framework in welding has several benefits that industries value to increase their competition and expand their businesses.

Quality Control and Defect Reduction
LSS focuses on improving the quality of the product by defect identification through intense analysis. The applications of this philosophy will minimize waste products that are the cause of defects, resulting in higher quality production. The use of LSS in welding has reduced the occurrence of defects to 3.4 per million products made [62]. It helps fix problems in earlier stages, reducing initial costs and production time.

Relying on Data
The statistical data and analysis that LSS collects improves the quality of products and their cycle time. Additionally, the data collected may be used to determine accurate prediction rates of future errors, allowing for organizations to foresee drawbacks ahead of time. The data pertaining to wastage and failure are kept for future reference in production [63]. A study conducted by the Institute for Supply Management (ISM) in 2022, compared current and past contracts that consisted of data pertaining to manufacturing methods. The implementation of suggested improvements reduced the average contracting cycle time (number of days between the beginning and end of the contracting process) by 30 % [63].

Increase in Revenue
The increase in manufacturing will result in the increase of company revenue. The high standard products will contribute to a stronger market, improving the business's revenue generation. The reduction in defects will also result in the decline of waste management costs, as they will be converted into sales. For instance, Linde Group, a gasses and engineering organization, conducted process revamping at several North American facilities in an attempt to improve process efficiency [64]. These LSS

projects were composed of processes being standardized to improve the ability of workers to transport between sites. The improvements implemented as a result of this method increased productivity by approximately 20 % and reduced production costs by roughly 13 % [64].

Improve Customer Satisfaction
The application of LSS in manufacturing will improve customer satisfaction through better product performance. In comparison to hearing customer feedback, LSS proves to be a proactive approach towards satisfying customer needs [65].

6.0. Limitations of the LSS as a Philosophy for Welding Engineering

Despite the growing popularity of LSS in Welding, the philosophy poses several limitations that hinder the efficiency of production and workplace if not approached correctly.

Time-intensivity
Implementing LSS into workplaces involves a large investment of time and resources to train employees, conduct data analysis and implement improvement projects. Companies must be prepared to allocate the appropriate amounts of time to ensure successful implementation. A study found that it takes roughly 2-3 years for companies to fully adopt LSS practices, indicating that the journey to full adoption is a gradual process, which does not reflect direct results [65-67].

Organizational Resistance
During the implementation of LSS, the need for highly skilled and experienced laborers arises, with the call for employees to quickly adapt to Six Sigma training. However, many organizations find difficulty in implementing such practices on larger scales. A survey revealed that 15% of companies encounter LSS resistance at executive levels during lean implementation [65][66].

Focus on Quality Only
LSS implementation in the welding industry only focuses on quality of production, with little attention towards production and efficiency rates. The overemphasis on defect reduction prevents companies from allocating attention towards other important factors such as customer experience, employee satisfaction and organizational growth. A review from Business Process Management journal stated that the project-centered strategy of Six Sigma through Green Belt and Black Belt improvements may create successful products, but do not iteratively improve their process. Critics stated they see ***"a risk that the belt-based infrastructure has an unavoidable tendency to glorify some people and, hence, not sufficiently support the TQM value of everybody's commitment"*** [65-67].

Increase in Production Costs
Due to the additional LSS techniques, labor costs, materials usage and time of manufacturing, production costs are expected to increase. Increases in the production rate may further lead to increases of product costs as well. As a result, it is predicted

that customers may search for lower-priced products that are not suitable for LSS manufacturing [68-70].

7.0. Summary & Conclusions

This paper was written to document many examples where LSS was successfully implemented in a welding context. What stands out most is the sheer versatility of LSS as a problem-solving methodology. From DMAIC to RCA, FMEA to SIPOC, we see how LSS is packed with tools that can remedy all shapes and sizes of problems. It was seen that LSS is used to reduce waste caused by welding defects like slag inclusion, lack of fusion, and porosity issues. This was remedied by applying RCA, where the root cause was ultimately the lack of cleaning of raw materials. This was achieved by running the problem through the DMAIC process, where it was found that tensile strength can be maximized by optimizing two welding parameters: tool travel speed and tool rotation speed. Whether improving dismal process efficiency by minimizing uncontrolled variation or reducing customer complaints through properly training welding operators, LSS has proven itself to be a powerful ideology all organizations should consider adopting to optimize their processes. Due to the significant implication of LSS, this ideology can be extended to any process in terms of optimization or rectification.

This review investigated how the LSS methodology can help reduce or eliminate defects observed in the industrial welding process. The fundamental and primary tool of LSS is known as DMAIC, which stands for Define, Measure, Analyze, Improve, and Control. The process works by converting problem-solving into steps and setting milestones to monitor progress by applying LSS methodology in these commonly used welding methods.

Even though LSS and its tools, like DMAIC, Root Cause Analysis, etc., can optimize various processes and cycles, it is still bound by many factors, mainly in the case of value-added and non-value-added processes. Any method or procedure can be segregated into value-added and non-value-added. This depends on whether a customer will pay for a certain step while manufacturing or any other process. The primary non-value-added methods are also legally bound, which means they must follow specific government standards. Failing to follow those can lead to legal action against the company.

After rigorously reviewing the types of welding processes and how to rectify or optimize them using the renowned LSS methodology and implementing its tools like DMAIC, JIT (just in time), Kaizen & Kaizen blitz, Poka-yoke, 5S, etc., it is recommended to use these tools if the operator is fully aware of the value-added and non-value-added processes.

8.0. Future Directions

The scope of this study will play a vital role in improving existing processes in the future by reducing and eliminating waste generation. Further research will provide more solutions to welding problems, where optimization is anticipated to provide level 6 quality according to the six-sigma requirement from the existing 3 to 4-sigma. This will lead to better productivity, lesser rejection, less material wastage, and higher profits for the organization [71-74].

Future prospects of LSS technologies and welding involve the use of Artificial Intelligence (AI) in various aspects. For instance, DMAIC stages can be augmented by AI which can accelerate processing speed and reduce labor intensive tasks of improvement projects [75]. Process improvement teams tend to use process maps and "five whys" root cause analysis. However, AI is able to perform these tasks faster and with higher accuracy, reducing labor. Robotic technologies can be used for repetitive processes within welding activities to be completed with higher precision and accuracy. Many companies have already begun to implement AI into their welding processes. One example is Johnson & Johnson, a pharmaceutical, biotechnology, and medical technology company that has executed an "intelligent automation" initiative that implements AI tools to automate processes and enhance productivity. Their cost analysis resulted in $500 million in savings [75].

However, as AI grows in importance for processing improvement, these new strategies will challenge current standards and philosophies. For example, current approaches rely on scripted routines that permit workers to utilize them. By using AI, the importance of these standardized tools can deteriorate, and may be resisted by Black Belts/consultants who are strong believers of the original LSS philosophy [75-77]. Moreover, the skills required to leverage AI in welding are not currently taught in LSS training, indicating that leaders need to promote updated training. One niche application of AI is to use virtual reality to facilitate new training and upscaling welders. Research can be further done on current project management strategies as well, to complement these new training methodologies.

The industry requires more optimization for manufacturing processes, especially in the automotive industry, where components like engines consisting of an air intake, pistons, cams, etc., require exceptional precision. Other elements like disc brakes, nuts, bolts, wheels, etc., have to undergo extreme variations in temperature and pressure, meaning any minor defect can result in a significant catastrophe. Hence, it is vital for the automotive industry and has enormous opportunities for development and research for various implementations of LSS methodologies [106-128].

Observing the capability of LSS in the industry reveals many domains where implementing this methodology can enhance productivity and provide revolutionary ideas that can change the face of mass production in the industries. Hence, it is vital for heavy and consistent research on various tools and methods of LSS. Optimization of welding as a process can also be enhanced using artificial intelligence, machine learning, or deep learning algorithms, and the implementation of LSS tools in such cases can be considered vital and groundbreaking.

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