Journal of Engineering Science and Technology
Vol. 18, No. 1 (2023) 210 - 226


# STATIONARY SPOT WELDING (SSW) QUALITY IMPROVEMENT USING SIX SIGMA METHODOLOGY AND A POKA YOKE JIG DESIGN

YUSLIZA BINTI YUSUF*, MUHAMMAD SYAHMI ABD HALIM

Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
*Corresponding Author: yusliza@utem.edu.my

**Abstract**

Stationary spot welding (SSW) is a semi-automatic procedure that is used to connect two or more pieces with fast and repetitive cycle times. Due to the rapid cycle time, human error is unavoidable, resulting in issues such as missed spots and wrong spot locations. In this project, difficulties are explored in order to eliminate those problems and then a poka yoke jig is developed to avoid problems from increasing. The Sig Sigma DMAIC approach was used in this study to describe and assess a problem, analyse the root cause of the problem, enhance the process, and regulate the process. Later, the design and construction of a poka yoke jig was undertaken. After implementing the poka yoke jig throughout the SSW process, it was found that, cycle time process involved was consistently stable at 0.3s to 0.4s compared to the process without implementing jigs and problems like as missing spots and incorrect spots were eliminated completely.

Keywords: DMAIC, Human error, Poka yoke jig, Six sigma, Stationary spot welding.

## 1. Introduction

Stationary Spot Welding (SSW) is a process that allows for the joining of various materials inside a single component. SSW manufacturing lines are typically operated by humans and using spot welding equipment. Based on the spot welding method for joining sheet metal, this process results in a quick production cycle, low costs, and the most efficient and competitive joint technologies, particularly in the automotive, aerospace, and other metal processing sectors. However, due to the production line's shorter cycle time and the human component of the SSW manufacturing process, human error is unavoidable. This will result in customer service concerns and a decrease in the quality of the final product.

According to statistics from one of the Malaysia’s automotive supply vendors for internal production defects between February and March 2021, there are two major quality issues at play: spot missing and incorrect spot position. The issues developed as a result of a manual manufacturing line and insufficient control over planned and actual output, resulting in 10 customer complaints. Consequently, manual inspection, which included physically checking the part and noting the spot area, was undertaken to minimise the number of complaints. Additionally, work instructions were created to explain to the operator the Standard Operating Procedures (SOP) for doing inspections and verifying the final choice. However, all of these remedial efforts were ineffective in eradicating the core cause of the spot missing and incorrect spot location issues.

Motorola's ground-breaking Six Sigma quality management system, which incorporated the DMAIC technique, was established in the mid-1980s by Bob Galvin and Bill Smith [1, 2]. Manufacturers have discovered that the DMAIC approach is an effective way to handle quality issues and boost production efficiency. Error-proofing approach Poka yoke, on the other hand, is a three-tiered inspection system that incorporates judgement (informational) and source (source) inspection. Using the Poka yoke system, a full assessment is made, and the system is able to provide recommendations and take fast action. When it comes to preventing part defects, it is one of the devices or techniques [3, 4]. Using the Poka yoke system, this jig might assist improve the manufacturing line's efficiency and uniformity, as well as eliminate quality issues, according to earlier research [3].

As a consequence, this research was conducted to address the real problems of spot missing and incorrect spot location in the SSW process manufacturing process employing the Six Sigma methodology of Define, Measure, Analyse, Improve, and Control (DMAIC). The recommended improvements include using a poke yoke jig in order to decrease human error and mistakes throughout the SSW process.

## 2. Six Sigma Methodology- An Overview

Sir Bill Smith created and executed Six Sigma at Motorola in 1986 with the goal of boosting production volumes through process variation elimination. Six Sigma is a collection of highly successful systematic procedures and tools referred to as DMAIC that are used to boost production volumes and analyse various elements of any process. Among the benefits of utilising the extended Six Sigma methodology is the ability to boost a company's earnings. The primary objective is to increase both quality and productivity.

The DMAIC cycle consists of five systematic techniques that define and value the problem, evaluate current performance and determine the desired service level, analyse root causes of problems to determine the root cause, improve the process, and control the enhanced process to ensure the improvement is sustainable [5] (Fig. 1). “Define” is the first stage in identifying the critical issue that has to be resolved or enhanced, and from there, more precise goals and targets for problem resolution become apparent. This stage entails mapping the approach, aim, scale, and primary purpose, as well as comprehending how the problem affects and concentrating on the issue at hand [6, 7].

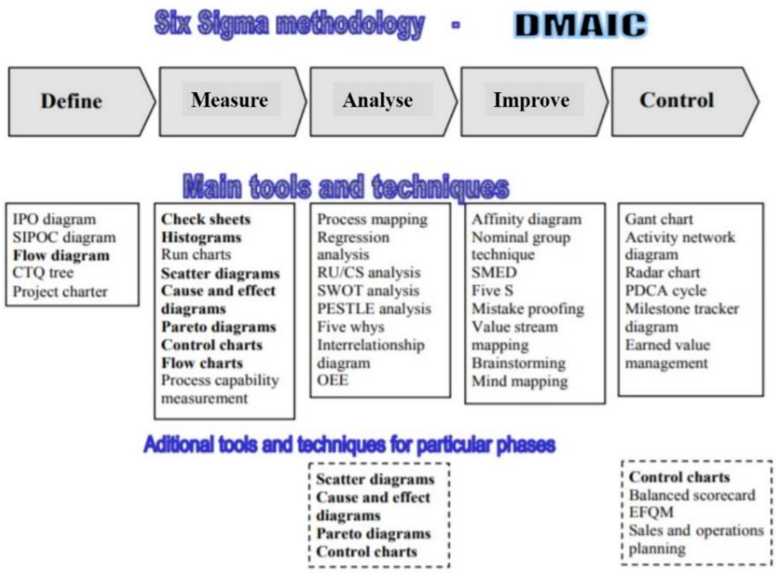


**Fig. 1. DMAIC the Six Sigma methodology.**

Throughout the “Measure” phase, data will be gathered and examined to help clarify numerous issues highlighted during the definition stage. As a consequence of the data gathered from this recorded customer feedback, it is feasible to prioritise issues that need to be solved first in order to avoid future customer service issues. As a result, to facilitate visualisation of the data, it was transformed into a pareto chart, as seen in Fig. 2. The evaluation begins with the highest bar value since it indicates the most critical problem that has to be fixed during the review. The red line depicts the cumulative percentage level of faults, and all subsequent action should be directed at correcting the biggest issue first [8, 9].

The "Analyse" stage is concerned with determining the root cause of issues, comprehending completely why faults occurred, and analysing and prioritising opportunities for progress improvement [8]. Various analytical tools and process analysis approaches are utilised during the analysis step to determine and confirm the root cause of the problem [6, 10]. As a result, they must generate causal hypotheses, assess some essential causes, and validate hypotheses. This may be accomplished through the use of a cause and effect diagram. The cause and effect diagram (Fig. 3), often known as the Ishikawa or fishbone diagram, is a method for discovering the root cause of a problem by drawing a link between the effect and all probable sources of the effect. Once finished, the diagrams assist in identifying the underlying problem and making recommendations for future development. There are five primary categories that are frequently used in cause-and-effect diagrams: machine, man, method, and measurement, collectively referred to as 4M, plus one extra parameter: environment The cause-and-effect diagram depicts the brainstorming session's probable causes [8]. Brainstorming for fresh ideas is a problem-solving approach that entails communication and debate. At this step, it is necessary to investigate the problem and provide several ideas for resolving the fault. This stage concludes with a list of potential substitutes. The reason might be a human error, a machine malfunction, a measurement error, or a procedure error. Numerous issues are grouped into numerous categories, including defective components, tool or machine damage, and human error.

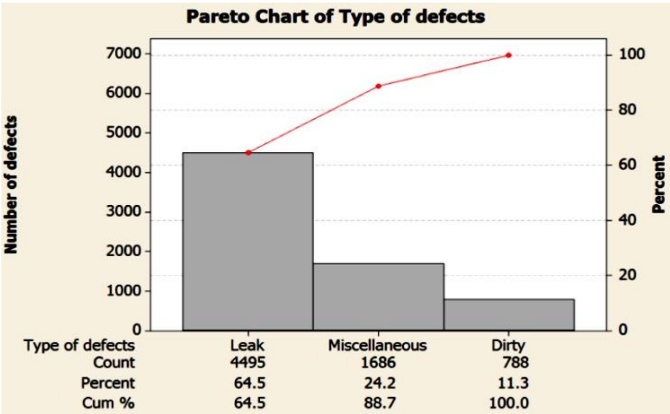


**Fig. 2. Example of Pareto chart result [8].**

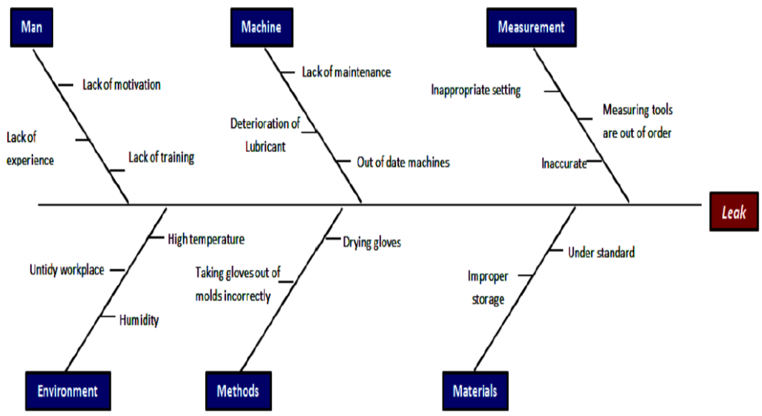


**Fig. 3. Example of cause and effect diagram analysis for SSW issue [8].**

The "Implementation" stage is concerned with the process of implementing the strategy. This pertains to the materials required, the processing of those materials, and the procedures that are ultimately applied in the workplace. At this step, the primary focus of the study is on the underlying problem, which is compiled utilising a quality control method. The reason might be human, mechanical, measurement, or method-related. After determining the root cause of the problem through numerous potential solutions, it is time to choose the appropriate technique for diagnosing the root cause problem that has been specified. Thus, in this study, the ideal answer is to adopt the Poka yoke technique, also known as "fool proof," because this way was chosen based on cost, the tool's efficacy in modifying current systems, the ability to generate new solutions, and its simplicity of operation [11]. The usage of a Poka yoke jig will aid employees in completing the operation more effectively and efficiently, resulting in an increase in production output on the manufacturing line. Additionally, the usage of this Poka yoke jig eliminates the need for specialised employees to supervise the operator's operation, saving money and time. The Poka yoke jig will be pre-designed to fit current conditions and the manufacturing team's comfort. This design will take production costs, material choices, and jig maintenance into account.

The "Control" phase is where the effectiveness of the variables that have been implemented is determined, as well as where this phase of monitoring is applied to the new process to determine whether it is operating smoothly or not, and how effective it is at resolving issues that arise [12]. Additionally, it is where processes are examined to determine whether the core issue can be resolved efficiently or whether any alterations to the process are necessary to improve it in light of current situations. In this situation, an analysis of the improvements gained by raising the quality of the product given to customers and the efficiency of the manufacturing lines will be undertaken. During this control phase, many approaches can be employed to assess whether a process improvement was effective under specified parameters.

## 3. Poka Yoke Jig - An Overview

Jigs are designed to boost productivity; the ideal jigs and fixtures provide reproducibility and interchangeability in the manufacturing of identical parts. Jigs and fixtures are critical devices in the manufacturing business because they aid employees in making their production processes easier. Jig is a critical instrument in manufacturing. The tool that bears the primary forces will ultimately shape the work item [13]. Numerous attempts have been made to create and produce jigs and fixtures that can accommodate different component variations. Thus, jigs and fixtures are critical in the business, mainly for the manufacturing and installation of high volumes and complicated goods. If it cannot escape, it is not a good dimension [14, 15]. As a consequence of employing a jig, components that escaped to the assy process were discovered, and the checking procedure took significantly less time than the prior check. The time stamps for the measurements taken with the height gauge and the jig [16].

The poka yoke system is a quality control principle that regulates how a process or product operates in order to prevent mistakes caused by human error. The fundamental objective of Poka yoke is to reduce faults to zero [14]. The poke-yoke method is a technique for organising labour and minimising or eliminating human error. Human visual examination and the use of measuring instruments are inherently insecure due to the influence of human variables. Because errors are an inherent part of human behaviour, we cannot hold humans accountable for any errors. By utilising Poka yoke, it is feasible to eliminate errors caused by human factors and decrease labour time [15, 16]. Typically, a Poka yoke jig is designed in such a way that it avoids human mistake by detecting the primary issues. Numerous jigs are built in the automobile sector to aid operators in assuring proper assembly and exact placement, while automated equipment assist operators in doing their tasks accurately and efficiently.

## 4. Case Study

### 4.1. The company

A case study was conducted at a medium-sized company that produces various child components for a Malaysian automotive company. This business is ISO 9001:2015 certified and uses cutting-edge machine technology. Their primary area of expertise is the production of a diverse range of items, such as sheet metal plates joined with stamping and stationary spot welding equipment. This company manufactures a variety of goods using the spot welding process and is experiencing rejection and rework on a number of its products. As a result, when it comes to improving an existing process, DMAIC should be the method of choice if the problem is complex, or the risks are high. Its structure and discipline prevent teams from skipping critical steps, increasing the likelihood of a successful project. DMAIC is probably all that is required to improve conversions and yields, or to remove a bottleneck here and there.

### 4.2. Project objectives

The primary objective of this study is to increase the quality and productivity of spot welding components by implement quality tools methodology. Specifically, the objectives are as follows:

- To analyse quality issues of stationary spot welding (SSW) quality issues in industry by using Six Sigma (DMAIC)
- To design and develop a poka-yoke (JIG) to implement solutions that will remove the causes of problem occur in spot welding
- To evaluate the fabrication jig function in order to prevent future defects from re-occurring.

### 4.3. Project methodology

The Six Sigma process improvement in this project is consistent with the DMAIC methods concept. It begins with the identification of problems and concludes with the retention of programmed benefits. Once a Six Sigma project has been completed using the DMAIC approach, management will be able to recognize the concrete advantages of the project and its direct influence on keeping comparable projects.

#### 4.3.1. Define Phase

Table 1 summarise a two-month data collection on the issues encountered during the production of selected components and categorise them according to relevant processes. According to the data collection, the most often occurring major issues in February and March are child part offset, spot missing, and wrong spot position. For missing spots, the defect increases from 96 pcs in February to 125 pcs in March, a 30% increase. Meanwhile, the child part offset issue, which began with 56 defective units in February and increased to 80 defective units in March, indicates a 43% rise. The wrong spot position issue contributed to the primary issue, with 76 % increments between February and March, ranging from 50 to 88 damaged pieces.

Additionally, it can be shown that of the process areas affected, spot welding is the most problematic, necessitating swift and urgent action to resolve the issue. The stated procedure of finding issues began with monitoring the complete component production process using a flow chart to better clearly examine the processes involved. The flow chart (Fig. 4) depicts the process, which is crucial for comprehending the process and recognising potential difficulties.

**Table 1. Defects data for February and March 2021.**

| No. | Defect Issues | Not Good (NG) Part Quantity, (pcs) | | Process Area |
|---|---|---|---|---|
| | | February | March | |
| 1 | Centering NG | 4 | 3 | Assemble process |
| 2 | Hole missing | 4 | 5 | Stamping |
| 3 | Hole offset | 7 | 9 | Assemble process |
| **4** | **Child part offset** | **56** | **80** | **Spot welding** |
| **5** | **Spot missing** | **96** | **125** | **Spot welding** |
| 6 | Spatter | 4 | 0 | Spot welding |
| 7 | Nut offset | 10 | 13 | Spot welding |
| 8 | Nut inverted | 2 | 0 | Spot welding |
| **9** | **Wrong spot position** | **50** | **88** | **Spot welding** |
| 10 | Over cut | 28 | 10 | Stamping |
| | Total | 261 | 333 | |

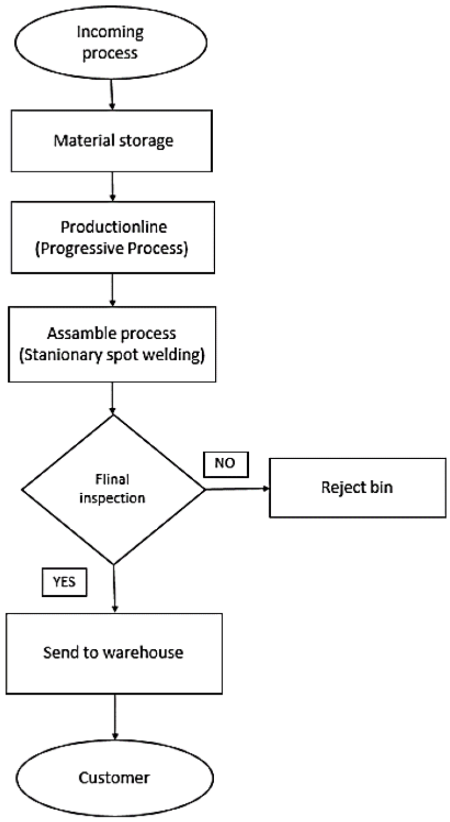


**Fig. 4. Flow chart of production process flow.**

### 4.3.2. Measure phase

During the measurement phase, the Pareto chart was used to identify the number of faults in the component manufacturing process, as seen in Fig. 5. According to Pareto charts, there are two primary issues that account for around 80% of rejected items owing to quality problems. The two most significant issues with quality are missing spots and wrong spot position. In studies, the terms "missing spot" and "wrong spot classification" relate to insufficient spot procedures or spots performed outside of the specified region during quality inspection, resulting in goods that do not fulfil customer criteria.

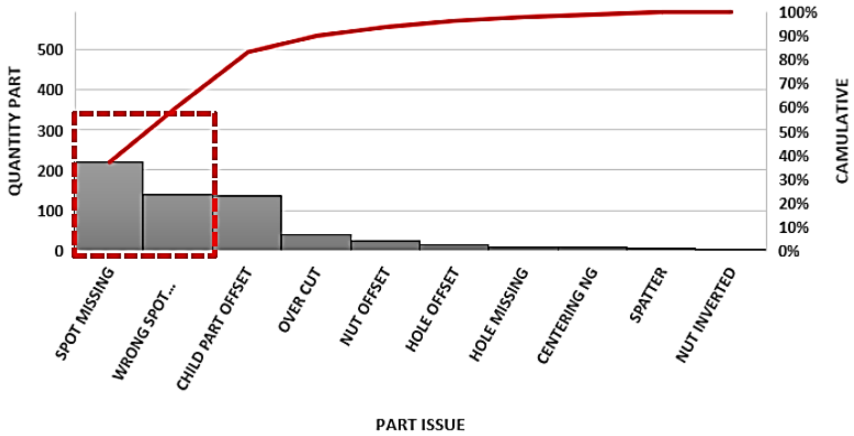


**Fig. 5. Pareto chart for defects part February and March 2021.**

### 4.3.3. Analyse phase

This section of the study will concentrate on issues with a high incidence of occurrence. As the Pareto chart indicates, miss pot and incorrect spot locations have a high rejection rate; so, the fish bone diagram approach is used to determine the underlying cause of these two issues. The fish bone diagram is a research that was conducted to analyse and identify the primary issues that arise when a place is absent or incorrectly located using a cause and effect diagram and by establishing four goals that occur using 4M. (Machine, Material, Method and Measurement). As a result, different issues might be seen when this 4M is used, including issues related to missed spot welding and incorrect spot location (Fig. 6). One might infer that this problem exists as a result of a dearth of equipment (methods and measures) and operator (human) solutions. When addressing this issue, emphasis should be placed on procedures and personnel that assist the operator in determining the level of a part in order to meet the customer-specified quality level.

### 4.3.4. Improve phase

After determining the root cause of the problem encountered, it is time to choose the appropriate technique for diagnosing the root cause problem specified. As a result, the best option in this research is to apply the Poka yoke technique, often known as "fool proof," because this way was chosen based on cost, the tool's efficacy in changing current systems, the ability to generate new solutions, and its ease of operation.

In this study, it was determined that a Poka yoke jig would be used, which would aid workers in completing the procedure more effectively and efficiently, hence enhancing productivity on the manufacturing line (Prabowo and Aisyah, 2020). Additionally, the usage of this Poka yoke jig eliminates the need for specialised employees to supervise the operator's operation, saving money and time. The Poka yoke jig will be pre-designed to fit current conditions and the manufacturing team's comfort. This design will take production costs, material choices, and jig maintenance into account.

Additionally, throughout the design selection process, ideas must be generated not just in terms of design, but also in terms of user safety, manufacturing, and maintenance costs. As a result, throughout this design selection process, the four distinct design types with their associated benefits and drawbacks must be enhanced to accommodate the process circumstances and jig itself. As a consequence of this design decision, an appropriate jig design has been produced by considering the spot welding process and the issues to be overcome. Several jig design concepts were developed in this study in order to arrive at the most optimal and appropriate design that may aid in resolving the problem of existing flaws in the production line.

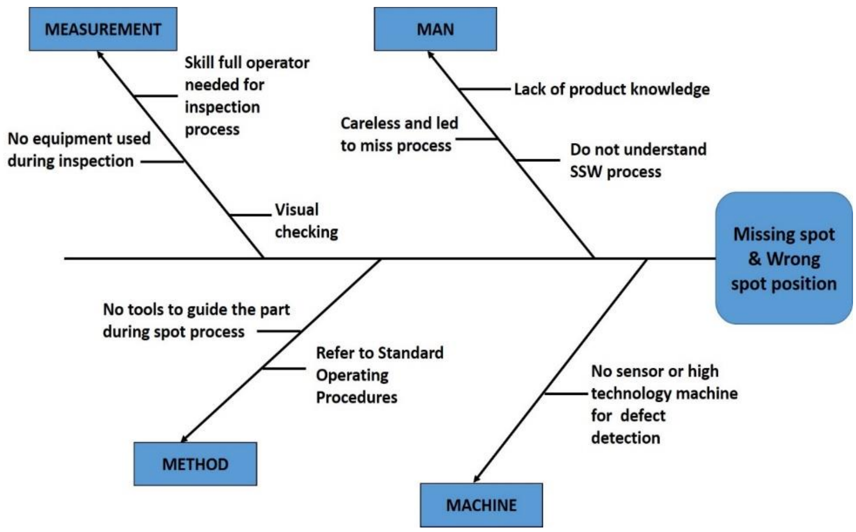


**Fig. 6. Cause and effect diagram for defects; miss spot and wrong spot position.**

## 4.3.5. Control phase

The control phase of this study is the procedure that establishes the relevance of jig installation for the spot welding process. Three operators perform stationary spot welding (SSW) using the same created Poka yoke jig, and the test procedure is performed up to four times for each process with and without a jig. The data collected will be used to determine the efficacy of the improvement that happens with and without the use of the Poka yoke jig.

Table 2(a) illustrates the defect (NG) product rate of rejection for the kid part location and hole centering, which both caused 66.67 percent rejection during the spot welding operation performed by three operators, and only 8.3 percent spot accuracy was obtained from 12 parts recorded. On the other hand, the right and left child part dimensions are fixed for all three operators, and they are capable of producing a perfect finish for child part position, hole centering, and spot welding precision, as shown in Table 2(b).

Additionally, the cycle time is critical in determining the effectiveness of the designed Poka yoke jig during the spot welding process. Figure 7 depicts the cycle time study for the total of 12 trials undertaken. The cycle time for the process without the Poka yoke jigs is an average of 0.26 seconds, whereas the cycle time for the process with the jig is 0.32 seconds. It demonstrates that by employing the jig, the operation is slowed by 0.1 second. However, cycle time without a jig recorded a faster cycle time than with a jig, but there is a rate of inconsistency in the data obtained, where the cycle time recorded is long on the third attempt of the second operator (0.40 seconds) and the third attempt of the third operator (0.69 seconds). This is due to the time taken during the process of positioning the mother and child parts incorrectly before the spot process occurs, which is one of the causes of problems.

As a consequence of the results, it can be stated that employing a Poka yoke jig is capable of producing high-quality items, as evidenced by the data obtained. Additionally, by utilising this jig Poka yoke, the operator's rejection rate from human error may be reduced to zero, which helps the operator significantly and instils confidence when doing stationary spot process welding.

**Table 2. Data for Poka yoke jig effectiveness evaluation.**

**(a) Without jig.**

| | **Operator 1** | | | | **Operator 2** | | | | **Operator 3** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No. of trials \ Inspection criteria** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | % Finish Good |
| **Hole centering** | NG | NG | OK | NG | OK | OK | OK | OK | OK | NG | OK | OK | 66.67% |
| **Position child part** | NG | NG | OK | NG | OK | OK | OK | OK | OK | NG | OK | OK | 66.67% |
| **spot accuracy** | NG | NG | NG | NG | NG | NG | NG | OK | NG | NG | NG | NG | 8.30% |

**(b) With jig.**

| | **Operator 1** | | | | **Operator 2** | | | | **Operator 3** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No. of trials \ Inspection criteria** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | % Finish Good |
| **Hole centering** | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | 100% |
| **Position child part** | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | 100% |
| **spot accuracy** | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | 100% |

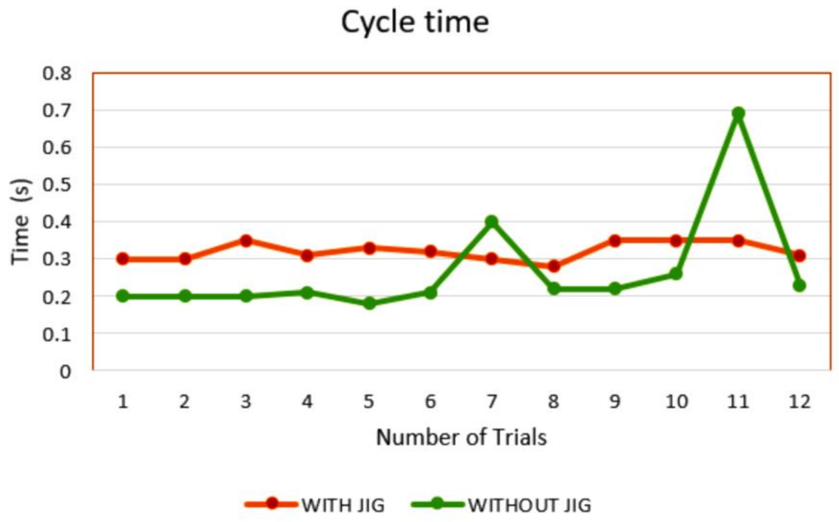


**Fig. 7. Cycle time study for SSW process with and without the Poka yoke jig.**

### 4.4. Poka Yoke jig design

In order to obtain a balanced mix of design qualities at a fair cost, the first step in creating a jig and fixture is to evaluate its functional needs. The tool design approach should explicitly identify the problem that has to be solved and achieved at this point. The design process of this project also includes product analysis, such as clamping position, material selection, and additional analysis and information from the design. Before acquiring the final jig design based on the collected data, the design process goes through many steps. Following that, suggestions will be obtained by exhibiting the difficulties that need to be handled, as well as other aspects such as process safety. After the design has been agreed upon, the process of the idea will be made into a drawing so that you can clearly understand the desired shape of the jig as well as the compatibility of the product and its process. Several design concepts have been offered in this project in order to obtain the ultimate best ideal design of poka yoke jig to utilize throughout the SSW process.

#### 4.4.1. First concept jig design

The first approach, illustrated in Fig. 8(a), utilises the pedal's foot to move the electrode during stationary spot welding. This first design has a rectangular jig with dimensions of 73 mm × 140 mm × 10 mm (length × width × thickness). Following that, the handle for this jig is a circular handle with the notion of a screw that is easy to replace if there is a problem. Additionally, on the right and left sides, the guiding pin is employed. The guide pin is used to maintain the proper state of the control portion. This is also a poka yoke system that may be used to control mistakes caused by incorrect part placement. The magnetic component is positioned between the guiding pins on the stiff component. The purpose of this magnet is to maintain the part in a fixed condition, preventing it from moving easily. The guideline that the tolerance on the component must not exceed, which is visible with the naked eye, is one of the others employed in this initial jig idea, and the worker may control whether or not the part's form is in excellent condition. The spot region is designed like a "C," and the tip electrode will be inserted into the "C," requiring the spot.

However, this first design has a problem with the jig handle because the spot welding process requires high pressure to be applied through the electrodes with the thickness of the jig, and this screw concept will result in handle looseness due to the fact that high pressure makes it easier for the handle to crack and break. Additionally, the notion of the "C type" shaped spot has an issue with the accuracy of the spot since it permits the region to not be set in one direction when performing the spot operation. This will result in an inconsistent spot area. Additionally, this first design concept has a problem with the jig handle, as the spot welding process requires high pressure to be transmitted through the electrodes with the thickness of the jig, and this screw concept will result in handle looseness due to the fact that high pressure makes it easier for the handle to crack and break. Additionally, the notion of the "C type" shaped spot has an issue with the accuracy of the spot since it permits the region to not be set in one direction when performing the spot operation. This will result in an inconsistent spot area.

### 4.4.2. Second concept jig design

The second design depicted on Fig. 8(b) is the same as the first design concept where this design employs a pedal foot to move the electrode on the fixed weld. This design has a rectangle form of 115 mm x280 mm x 8mm (length x width x thickness) (length x width x thickness). Next, the design employed for the handles for this jig is right and left handles that are permanent in nature on the jig where both hands are necessary to be used in this jig. In addition, guiding pins are employed on the right and left. The usage of guide pins is utilised to regulate the component always in the desired state. This is also the improper poke yoke system that may control the offender from installing the wrong component. The usage of magnets is utilised to provide the part a fixed state so that it does not move readily. Among others that are employed in the idea of this jig is a frame-shaped design that is in the form of a part that is used for the spot welding procedure. In this approach, it streamlines the procedure by only positioning it according to the shape of the product. Another feature to this jig design is clamping is utilised to retain the child component on the surface of the mother part so that it is always in a fixed condition to simplify the spot welding process. The design for the spot region has a "round type" form where the tip electrode has a semi-circular shape. This will facilitate the job in the welding process with a good enough accuracy for each item produced where the end electrode will be put in the region of the round shape in accordance with the electrode size that has been specified.

Problem with this design in terms of safety on the jig handle, the spot area and the jig holding area are near to the spot region here may create major mishaps when neglect occurs during the process when the electrodes are under high pressure throughout the process.

### 4.4.3. Third concept jig design

Figure 8(c) illustrates the third design concept, which involves the use of hand pedals to move the electrodes on the fixed weld during the process. This design has a rectangular jig with dimensions of 180 mm x 140 mm x 10 mm (length x width x thickness). Following that, the handle for this jig is horizontal, requiring only one hand for control throughout the spot welding procedure. Additionally, guiding pins on the right and left are employed. Guide pins are used to maintain the intended state of the component. This is also the incorrect poke yoke system, which may be used to prevent an error from occurring due to the incorrect component placement. Magnets are utilised to secure the part, preventing it from moving easily. Another feature to this jig design is clamping, which is utilised to secure the child component to the mother part's surface, therefore facilitating the spot welding process. The spot area is designed in a "round type" manner, whereas the tip electrode is shaped. This semi-circular will facilitate work in the welding process with high accuracy on each part produced, as the end electrode will be placed in the area of the round shape according to the electrode size set, and additionally, this design will utilise the slot or plug-and-play concept to reduce maintenance costs when the spot area wears out.

The issue with this jig idea is the horizontal handle component, which does not suit the spot welding process, since it must be put in the proper location for spot welding, and the repeated procedure causes discomfort to the operator's wrist.

### 4.4.4. Fourth concept jig design

Similar to the previous concept of stationary spot welding, the idea design utilises hand pedals to move the electrodes during the welding process. This design is inspired by the shape of a ping pong bat, which is both convenient to use and comfortable to carry. Additionally, guiding pins are employed on the right and left. Guide pins are used to keep the component in its intended state. This is also the wrong poke yoke system, which may be employed to avert an offence caused by improper component placement. Magnets are used to secure the component, which prevents it from moving freely. Additionally, this jig design has clamping, which secures the child component to the mother part's surface, aiding the spot welding process (Fig. 8(d)). The spot area is shaped like a "round type," however the tip electrode is shaped like a semi-circular. This will accelerate the welding process and assure the accuracy of each item produced. The form of the frame is dictated by the bump on the component in the jig concept, which ensures that the part is always correctly positioned.

This jig is ideal for doing spot welding. A minor flaw in terms of jig maintenance is that because a portion of this spot is caused by high pressure spots and high electrical flow is used to create them, when the process is repeated frequently, the round type welding part will crack or the shape will become imperfect, necessitating the rebuilding of the new jig.

### 4.4.5. Final concept jig design

As illustrated in Fig. 9, the final concept design in Solidworks software examines the overall evaluation of each design idea created to collect the jig's advantages and disadvantages by emphasising several factors such as problem solving during the stationary spot welding process, design suitability during the process, and safety during spot welding. The design chosen should place a premium on the cost of construction and maintenance in order to simplify process maintenance. Additionally, material selection has a significant impact on the process conditions, resulting in lower jig maintenance costs.

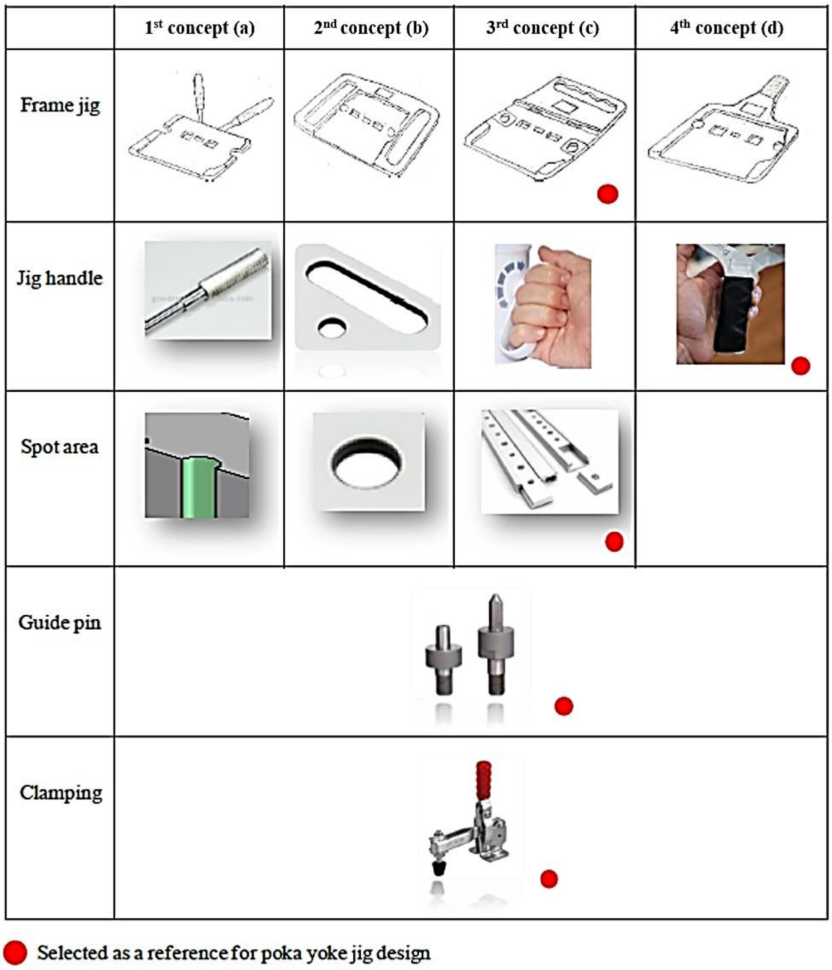


**Fig. 8. Various concept jigs design.**

The concept for the jig that will be manufactured is the result of research and refinement of several variables that are addressed. When doing stationary spot welding, the final concept was developed with the user's safety and efficiency in mind. The expression "ping pong bat" is used. This choice is based on the suitability of the spot welding process, which requires the use of both hands, as the process of simultaneously pressing the pedal and holding the jig demonstrates about safety, as the right and left hands are not free to move, reducing the risk of injury during the spot welding process.

Then, use a guide pin, a clamping fund magnet, or a combination of the two to secure the work piece on the jig. The guide pin holds the item in the previously determined position on the jig. On the jig, magnets are used to keep the component from moving. Because the part is not free to move on the jig, it provides excellent accuracy when spot welding, resulting in uniformity on each part. Clamping is used to secure an item so that it is difficult to move; in the case of clamping, it is used to secure the child part that is above the mother part in a permanent, non-moving state, allowing the desired shape to be produced with high accuracy during the spot.

Finally, this method decides to develop a tolerance guideline to serve as a reference for the operator. Because the operator can perform two processes simultaneously, namely welding and checking the product, the primary function is to detect the size of the product that has issues in terms of excess or deficient shape that has been specified by the customer and to perform the checking process prior to sending it to the customer. When using this jig, the business gains a number of benefits.

Furthermore, the primary consideration for the final concept design is maintenance costs because the equipment used must perform optimally in order to produce the product desired by the client. This jig's final design incorporates slots to simplify the process of changing the spot area and to reduce the cost of creating a new jig in an area prone to cracking or breaking.

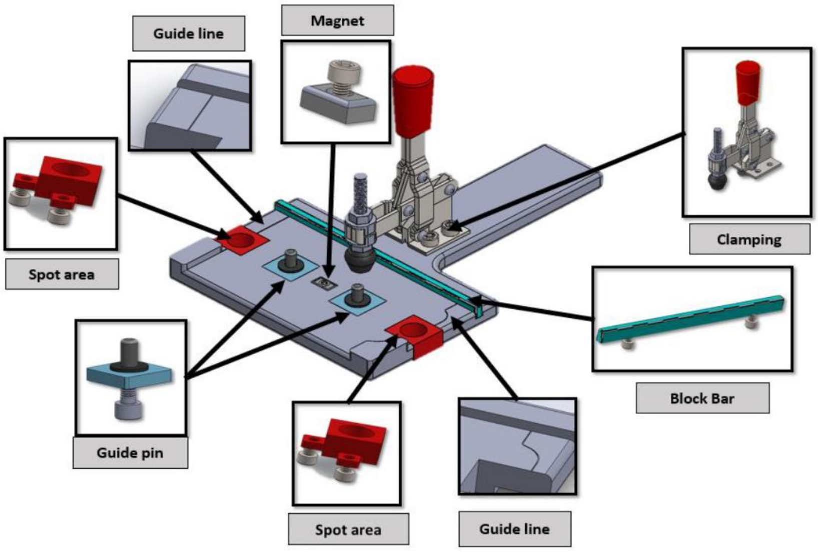


**Fig. 9. Final concept design of Poka yoke jig for SSW process in this project.**

## 5. Conclusion

This article describes a case study involving the use of the DMAIC problem solving approach to eliminate quality issues in the spot welding process at one of Malaysia's automotive small component manufacturers.

During the Analyse stage, the root cause of the quality problem was identified as human error, and the number of defects can be reduced by using the poka yoke jig. The final design of this poka yoke jig includes slots to simplify the process of changing the spot area and to reduce the cost of manufacturing a new jig in a region prone to cracking or breaking. Missing spots and incorrect spot positions are consistently reduced by nearly 100% when the developed poka yoke jig is used.

Three operators use a poka yoke jig to demonstrate this, and it is proven that using the designed poka yoke jig has shortened their welding process cycle time while also removing quality issues that frequently arise.

Furthermore, in the future, it is recommended to use a pneumatic system to reduce cycle time in the process of assembling parts and jigs, where this system is suitable to be placed on the clamping part process by using a jig.

This pneumatic process uses air to easily and quickly move an object through valve input and output. Pneumatic is an environmentally friendly and safe system that can be used by many industries that value user safety, such as the pharmaceutical industry, food and beverages, and textiles.

## Acknowledgement

This work was supported by the Ministry of Higher Education Malaysia, Universiti Teknikal Malaysia Melaka internal grant (PJP/2020/FTKMP/PP/S01737).

## References

1. Sindha, N.; Suthar, K. (2017). Improve the productivity of spot weld components by implementing six sigma in manufacturing industry. *Proceeding of International Conference on Ideas, Impact and Innovation in Mechanical Engineering (ICIIIME 2017).* Pune, India, 72-78.
2. Padmarajan, N.; and Selvaraj, S.K. (2021). Sig sigma implementation (DMAIC) of friction welding of tube to tube plate by external tool optimization. *Materials Today: Proceedings*, 46(17), 7344-7350.
3. Soni, P.; and Yadav, T. (2018). Review paper on "Productivity improvement by using poka-yoke". *International Research Journal of Engineering and Technology*, 5(12), 761-763
4. Husin, Z. (2019) Optimizing productivity by eliminating and managing rejection frequency using 5s and kaizens practices: case study. *Independent Journal of Management & Production*, 10 (6), 1952-1970.
5. Subagyo, I.E.; Saraswati, D.S.; Trilaksono, T.; and Kusmulyono, S.M. (2020). Benefits and challenges of DMAIC methodology implementation in service companies: an exploratory study. *Jurnal Aplikasi Manajemen*, 18(4), 814-824.
6. Raman, R.S.; and Basavaraj, Y. (2019). Defect reduction in a capacitor manufacturing process through six sigma concept: A case study. *Management Science Letters*, 9(2), 253-260.
7. Ranade, P.B.; Reddy, G.; Koppal, P.; Paithankar, A.; and Shevale, S. (2021). Implementation of DMAIC methodology in green sand-casting process. *Materials Today: Proceedings*, 42(Part 2), 500-507.
8. Jirasukprasert, P.; Garza-Reyes, J.A.; Kumar, V.; and Lim, M.K. (2014). A six sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process. *International Journal of Lean Six Sigma*, 5(1), 2-21.
9. Memon, I.A.; Ali, A.; Memon, M.A.; Rajput, U.A.; Abro, S.A.K.; and Memon, A.A. (2019). Controlling the defects of paint shop using seven quality control tools in an automotive factory. *Engineering, Technology & Applied Science Research*, 9(6), 5062-5065.
10. Pugna, A.; Negrea, R.; and Miclea, S. (2016). Using six sigma methodology to improve the assembly process in an automotive company. *Procedia - Social and Behavioral Sciences*, 221, 308-316.

11. Prabowo, R.F.; and Aisyah, S. (2020). Poka-yoke method implementation in industries: A systematic literature review. *Indonesian Journal of Industrial Engineering & Management*, 1(1), 12-24.
12. Erbiyik, H.; and Saru, M. (2015). Six sigma implementations in supply chain: An application for an automotive subsidiary industry in bursa in Turkey. *Procedia - Social and Behavioral Sciences*, 195, 2556-2565.
13. Radhwan, H.; Effendi, M.S.M.; Rosli, M.F.; Shayfull, Z.; and Nadia, K.N. (2019). Design and analysis of jigs and fixtures for manufacturing process. *IOP Conference Series: Materials Science and Engineering*, 551, 012028,1-9.
14. Ardi, S.; Nurdin, M.A.R.; and Ponco, A. (2018). Design of poka yoke system on the process of mounting actuator bracket based on programmable logic controller in automotive manufacturing industry. *MATEC Web of Conferences*, 197, 14014.
15. Saidin, W.A.N.W.; Idris, A.Z.M.; Ravi, S.; Zaidi, A.M.A.; and Kasim, N.I. (2015). Detection of nut welding using poka-yoke roller coaster jig detection of nut welding using poka-yoke roller coaster jig. *Applied Mechanics and Materials*, 76,170-174.
16. Hernadewita; Tosa, F.A.; Santoso, Y.; Kusumah, L.H.: and Hermiyetti (2019). Application poka-yoke to capture defect (A case study in industry component otomotive). *SSRG International Journal of Industrial Engineering*, 6(1), 14-17.