Streamlining Production: ECRS Approach to Enhancing Efficiency in Case Tank Sub Weld of Hydraulic Excavator

Chutharat Wonginyoo, Prapatson Bumpen *, Pilada Wangphanich and Ninlawan Choomrit
[1] *Department of Industrial Engineering, Faculty of Engineering, Srinakharinwirot University, Ongkharak, Ongkharak, Nakhon Nayok, 26120 Thailand*
***Corresponding Author E-mail:** Prapatson.bumpen@g.swu.ac.th
Received: Jun 11, 2025; **Revised:** Aug 15, 2025; **Accepted:** Aug 25, 2025

Abstract

This research aimed to reduce the production time in the manufacturing process of fuel tanks, with a focus on enhancing the efficiency of the process to better meet customer demands. A study of the production process revealed that the primary issue was in the welding stage at the top of the tank using a robot, which took 2 hours and 45 minutes. Almost half (1 hour 22 minutes) of the time were spent on setting the position of the workpiece—a step that must be repeated each time a new workpiece was introduced. This significantly contributed to reducing throughput and increasing labor costs. To address this issue, the research team applied the ECRS concept to analyze and streamline the production process by eliminating unnecessary steps. Consequently, the team designed and developed a workpiece holding fixture to assist in the welding process. This fixture ensured the workpiece was positioned accurately without the need for repeated setup. Two conceptual designs of the fixture were initially developed and evaluated using FEA. After evaluation by engineers and welding staff, using AHP, the best option was determined. As a result of this improvement, cycle time in robotic welding was reduced to 1 hour and 23 minutes a 49.26% reduction.

Keywords: Fuel tank, Fixture, Finite element analysis, Analytic hierarchy process

1. Introduction

The factory studied in this research manufactures case tank sub welds for the hydraulic excavator manufacturing industry. The Case Tank Sub Weld is a fuel tank assembled from 25 component parts. The main production process involves welding, including manual MIG welding and robotic welding. The production line consisted of a total of five workers. The process could be categorized into six main operations: laser cutting, bending, tack welding, manual welding, robotic welding, and product packaging, as illustrated in **Figure 1**. The researchers utilized the Yamazumi chart (**Figure 2**) to analyze the production workflow. Tasks were categorized according to the responsibilities of the five workers, clearly illustrating the distribution of working time for each individual. This visualization enabled a systematic analysis of workload balance among the workers.

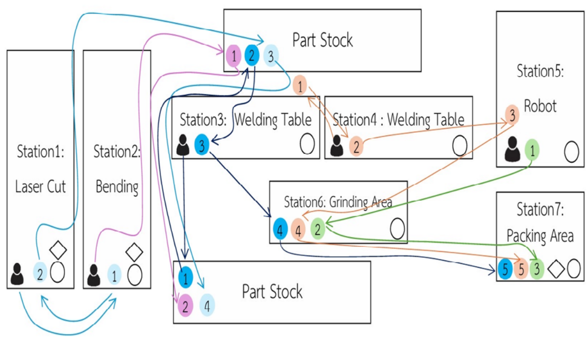

Figure 1 Production line

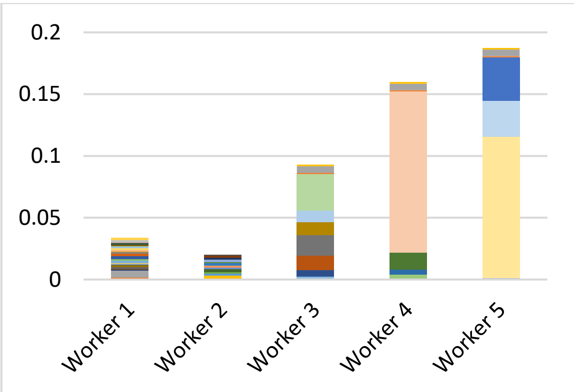

Figure 2 Yamazumi chart of each worker

The analysis revealed that Workers 1 and 2 had lighter workloads compared to the others. These two workers were responsible for laser cutting and bending, which are relatively simple tasks requiring less specialized skill, allowing them to be performed more quickly. In contrast, Workers 3 to 5 handled welding processes, which demand higher precision, attention to detail, and expertise—resulting in significantly longer working times. Additionally, unnecessary movement within the production line was observed, contributing to time waste and reducing overall work efficiency.

The research team conducted an analysis of the production line problems by utilizing the why why analysis methodology in order to identify the root causes of the workflow imbalance and the excessive processing time observed in certain operations. This was particularly evident in the welding stage, which demands specialized skills and involves high complexity. The analysis revealed that the inability to produce case tanks within the required timeframe was the result of multiple interrelated factors. The primary issues identified included the failure to meet the production deadline and delays encountered during the robotic welding process.

The research focused on two key issues for improvement. The first issue concerned the prolonged duration of the robotic welding operation. To address this, the team proposed the design and implementation of a fixture device to assist in the positioning of the workpieces during the robotic welding process, thereby reducing setup time and enhancing overall efficiency.

The second issue related to the failure to complete production within the scheduled timeframe. To resolve this, the research applied the principles of ECRS, which are Eliminate, Combine, Rearrange, and Simplify, as a strategic approach to process improvement. ECRS was deemed most appropriate because it effectively addresses repetitive tasks by eliminating waste and simplifying processes. Its proven track record in similar industrial environments makes it a reliable tool to enhance productivity, reduce labor costs, and streamline the overall process effectively.

From the study of case tank sub weld production line for hydraulic excavators, it was found that the existing production process could not meet customer demands, requiring 11 hours and 51 minutes to complete—exceeding the takt time of 9 hours and 36 minutes. This delay was caused by unclear work procedures, improper task sequencing, and unnecessary movement, which adversely affected production capacity accuracy and delivery planning. Therefore, this research aimed to enhance the efficiency and productivity of this process.

2. Literature Survey

The Eliminate-Combine-Rearrange-Simplify (ECRS) methodology is a structured approach to process re-engineering that aims to enhance operational efficiency. This technique employs process mapping tools to identify underlying inefficiencies and systemic issues within workflows. By applying four fundamental principles—eliminating non-value-adding activities, combining redundant tasks, rearranging the sequence of operations for optimal flow, and simplifying complex steps—the ECRS method facilitates the redesign of processes to improve productivity and reduce waste [1]. Examples of research that applied the principles of ECRS include:

The supply of parts to the assembly line faced delays and inaccuracies due to inefficient transport and mislabeling. To resolve these issues, the Lean ECRS approach was applied through new tag designs, improved operational methods, and redesigned storage layouts and supply routes. These measures reduced transfer times and route overlaps, while improving supply accuracy to the assembly line [2].

The assembly process could be improved by identifying constraints and bottlenecks, then applying ECRS analysis to streamline operations. By removing or simplifying low-impact and unnecessary steps, the process became more efficient, reducing both operator workload and the risk of errors [3].

To enhance production capacity using the ECRS method, processes were streamlined by reducing unnecessary steps and balancing workloads across stations. Labor efficiency was improved by minimizing operator numbers, guided by HMI analysis to eliminate non-value-adding activities. The process tree technique was used to rearrange equipment for better line balancing and reduced idle time. Additionally, placing materials closer to equipment helped minimize operator movement and improve workflow efficiency [4].

Finite Element Analysis (FEA) is a crucial tool for simulating mechanical behavior prior to manufacturing. It provides accurate insights into stress and deformation, especially when using three-dimensional models that capture complex geometries more realistically than 2D simulations. FEA begins with discretization, where the structure is divided into small elements connected at nodes. The process involves applying material properties, defining boundary conditions, and introducing external loads. The software then solves equations for each element to calculate nodal displacements, from which strains and stresses across the entire structure are derived. This predictive capability allows engineers to optimize designs, reduce material waste, and minimize the risk of failure before physical production [5]. Research examples that applied FEA simulation were as follows:

To improve assembly efficiency by replacing manual handling with a semi-automated jig, jig was designed and evaluated through FEA. FEA results confirmed the structural integrity of the design, supporting its effectiveness in reducing workload and enhancing the reliability of the assembly process [6].

FEA was used to evaluate a transformable pin array fixture system designed for flexible part positioning. The results showed that optimizing part alignment in the XY plane significantly reduced deformation during ultrasonic welding and screwing, improving assembly quality [7].

A fixture design for aircraft door drilling that integrates ergonomic considerations and structural evaluation using FEA was proposed. The FEA results showed that the maximum von Mises stress and overall stress distribution were within acceptable limits, confirming the fixture's structural integrity and practical applicability [8].

The Analytic Hierarchy Process (AHP) is a widely used multi-criteria decision-making method, particularly effective in complex situations involving multiple stakeholders, qualitative judgments, and long-term impacts. AHP structures decision problems into a hierarchy and utilizes pairwise comparisons to evaluate alternatives based on both subjective and objective data. Its effectiveness depends on the quality of available information and the decision-maker’s understanding of the problem. While inconsistencies may arise due to incomplete data or uncertainty, AHP remains a reliable and transparent tool for prioritizing and selecting among competing alternatives in complex environments [9]. Studies that employed AHP for decision-making evaluation, for instance, were:

To address the challenges of reducing the design cycle and improving jig quality, this study proposed the development of a flexible and intelligent case database system for welding jigs. A key component of the system was the application of the AHP, which was employed to systematically classify and prioritized the influence factors affecting the design of welding jig units. By using AHP, the study enabled a structured evaluation and categorization of jig units corresponding to various sheet metal components, supporting more efficient and informed design decisions in automotive body engineering [10].

The objective was to design a jig capable of detecting reversed or missing jaws to prevent defective products from reaching customers, while also maintaining flexibility for use with various plastic seal products. The House of Quality (HOQ) methodology was initially employed to identify and prioritize key design criteria. The criteria with the highest weights—flexibility, ease of maintenance, ease of use, longevity of jig usage, and accuracy checking—were subsequently selected for further evaluation. These five critical criteria were incorporated into an AHP framework to systematically assess and determine the optimal jig design based on their relative importance. The integration of HOQ and AHP provided a structured decision-making approach to enhance jig performance and product quality [11].

This study aimed to develop an adjustable angled welding fixture by initially conceptualizing four design alternatives based on input from 25 experienced welders. The AHP was employed to systematically evaluate and select the most suitable fixture design according to criteria including reliability, rigidity, and ease of use. Structural performance of the selected design was further assessed through FEA to ensure strength and stability during operation. The proposed fixture design was expected to reduce setup time, minimize defect occurrence, and decrease the need for post-welding quality interventions [12].

3. Research Methodology

3.1 Current state analysis

The robotic welding process involved multiple stages and was time-consuming. An analysis of the current state identified a total of 23 steps within the process, as presented in **Table 1**. Among these, delays primarily occurred during the setup of welding positions for the subcomponents, which consisted of nine individual parts. For each cycle, the robot must be reconfigured to accommodate new weld positions, and the welding torch must be removed and cleaned. The step involving the removal and cleaning of the welding torch cannot be eliminated, as it directly influenced weld quality. However, the analysis revealed that the setup stage for the robot's weld positioning presented an opportunity for improvement and time reduction.

Table 1 Current state of robot welding process

Process steps	Time	○	⇨	D
1. Load the workpiece into the robot	0:06:11	○	➡	D
2. Set up the weld seams for pieces 1, 2, and 3	0:34:17	○	⇨	◗
3. Robot welds piece 1	0:03:34	●	⇨	D
4. Remove and clean the torch head	0:04:06	○	⇨	◗
5. Robot welds piece 2	0:04:21	●	⇨	D
6. Remove and clean the torch head	0:03:56	○	⇨	◗
7. Robot welds piece 3	0:02:43	●	⇨	D
8. Remove and clean the torch head	0:03:39	○	⇨	◗
9. Set up the weld seams for pieces 4, 5, 6, 7, 8, and 9	0:47:05	○	⇨	◗
10. Robot welds piece 4	0:04:27	●	⇨	D
11Remove and clean the torch head	0:04:29	○	⇨	◗
12. Robot welds piece 5	0:02:53	●	⇨	D
13. Remove and clean the torch head	0:04:15	○	⇨	◗
14. Robot welds piece 6	0:03:32	●	⇨	D
15. Remove and clean the torch head	0:04:57	○	⇨	◗
16. Robot welds the inner side of piece 4	0:02:46	●	⇨	D
17. Remove and clean the torch head	0:04:35	○	⇨	◗
18. Robot welds piece 7	0:02:38	●	⇨	D
19. Remove and clean the torch head	0:04:29	○	⇨	◗
20. Robot welds piece 8	0:03:29	●	⇨	D
21. Remove and clean the torch head	0:04:32	○	⇨	◗
22. Robot welds piece 9	0:03:49	●	⇨	D
23. Remove and clean the torch head	0:04:27	○	⇨	◗
Total	2:45:10	10	1	12

3.2 Process Improvement Using ECRS Principle

Following the completion of root cause analysis of the production line issues, the research team implemented process improvements by applying the ECRS principle, which stands for Eliminate, Combine, Rearrange, and Simplify. In this study, the focus was placed on the application of Eliminate, Rearrange, and Simplify, with the goal of enhancing production line efficiency, reducing waste, and shortening processing time. As shown in **Figure 1**, the production line consisted of six processes: laser cutting, bending, tack welding, manual welding, robotic welding, and product packaging. When broken down into detailed steps, the entire process comprised a total of 57 steps. **Table 2** presented the application of the E, R, and S principles to improve selected steps within the process. These principles were utilized to eliminate unnecessary activities, rearrange work sequences for smoother operations, and simplify certain tasks to enhance overall efficiency.

1) Eliminate

The analysis revealed that workers spent unnecessary time walking back and forth to collect components from multiple baskets. This issue was addressed by consolidating all required components into a single "complete kit" placed in one basket. As a result, workers could retrieve all necessary parts in one trip, thereby reducing walking time, simplifying material handling, and minimizing the risk of picking errors.

2) Rearrange

In the welding process of components 14 and 15, it was observed that following the original sequence caused delays due to the need for positional adjustments to achieve the correct angle. The improvement involved pre-welding these two components together before attaching them to the main tank. This adjustment significantly reduced the time spent on alignment, minimized deviation, and improved the accuracy of the welding operation.

3) Simplify

Three areas in the process were identified for simplification:

- Small Jig Handling Issue: The original jig design was too small, making it difficult for workers to handle. The solution involved welding an additional handle onto the jig, allowing for easier gripping and reducing the risk of slippage during use.

- Robot Positioning Setup: The process of setting the welding robot's position was time-consuming. To address this, a fixture was designed and implemented to ensure accurate and consistent positioning of the robot each time it is used. This allowed welding operations to start more quickly, with greater accuracy and fewer setup errors.

- Deburring Process: Previously, deburring was performed manually by workers. This was improved by introducing machinery to perform the task, resulting in higher precision, consistency, and reduced processing time.

Table 2 Process steps modified using E, R, and S

Process steps	E	C	R	S	Before	After
Steps 1-39	-	-	-	-	1:17:20	1:17:20
Step 40 Walking to pick up parts	✓	-	-	-	0:03:42	0:00:23
Steps 41-44	-	-	-	-	0:53:35	0:53:35
Step 45 Switching the welding sequence of parts 14 and 15	-	-	✓	-	0:15:15	0:11:05
Step 46	-	-	-	-	0:05:52	0:05:52
Step 47 Improving the jig for track welding	-	-	-	✓	0:20:11	0:16:13
Step 48	-	-	-	-	0:01:31	0:01:31
Step 49 Using fixtures in robot welding	-	-	-	✓	2:45:10	1:23:48
Steps 50-52	-	-	-	-	4:02:26	4:02:26
Step 53 Chamfering with machinery	-	-	-	✓	0:43:08	0:35:48
Steps 54-57	-	-	-	-	1:23:14	1:23:14
Total Time					11:51:20	9:35:24

3.3 Process Improvement through the Design of a Fixture for Robotic Welding Operations

An analysis of the existing production process revealed that delays in the robotic welding stage were primarily caused by the need to reconfigure the robot's position every time a new workpiece was introduced. This repetitive and time-consuming task not only increased the overall production time but also heightened the risk of positioning errors. To address this issue, the project team developed a new fixture using a concept design approach. The development process involved several key steps: identifying the root cause of the problem, defining the fixture's objectives, reviewing relevant theories and background information, analyzing the workpiece structure, and proceeding to design and evaluate the suitability of the fixture. If the initial design failed to meet the criteria, it was revised and redesigned. The final steps included prototype development and trial implementation to ensure it met the required standards before finalizing the design.

The critical design requirements for the fixture were identified through process analysis and operator feedback. These requirements include the ability to securely hold the workpiece in place, facilitate ease of installation and removal, enable convenient transportation and cleaning, ensure lightweight construction, and achieve high positioning accuracy. Drawing and Functional design options were illustrated in **Figure 3–6**.

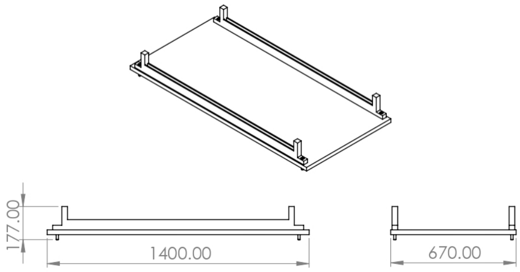

Figure 3 Drawing of model 1

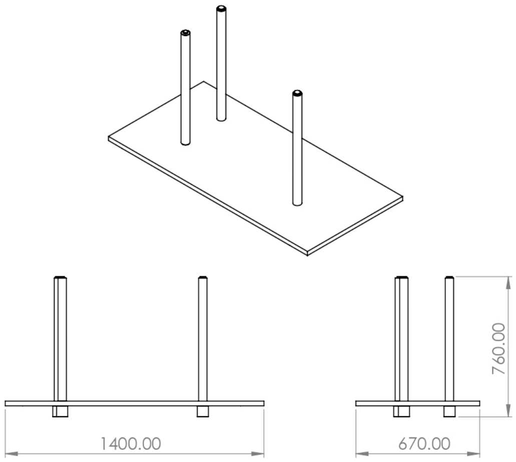

Figure 4 Drawing of model 2

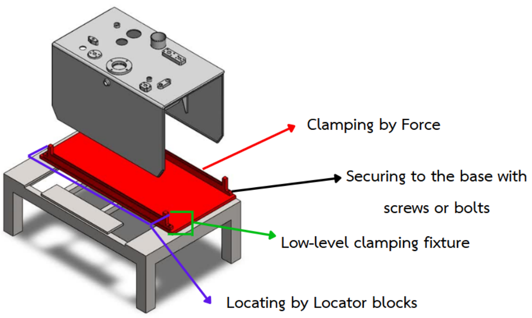

Figure 5 Functional options of model 1

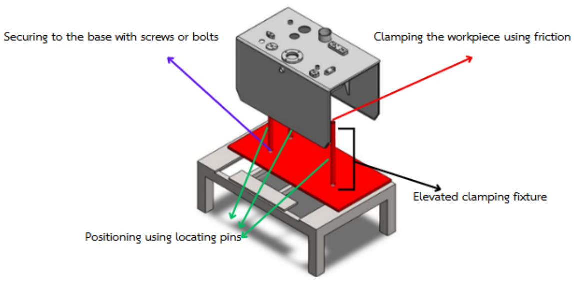

Figure 6 Functional options of model 2

Conceptual design details: Model 1 employed a simplified structure with a reduced number of components, promoting ease of manufacturing and minimizing overall weight. However, its operational flexibility was limited, as it required the workpiece to be modified in advance to ensure a precise fit with the fixture base. In contrast, Model 2 integrated additional structural reinforcements and precision alignment mechanisms, which improved positional accuracy and structural rigidity. These enhancements, however, introduced greater complexity, increased weight, and higher manufacturing costs. Given these trade-offs—namely, between simplicity and robustness, as well as between precision and manufacturability—a comprehensive evaluation was necessary. FEA was employed to assess mechanical performance, while AHP was used to systematically compare design alternatives across multiple decision criteria.

4. Structural Strength Analysis Using Finite Element Analysis

The research team applied FEA to evaluate the structural integrity of a workpiece clamping device used in the welding process of hydraulic excavator fuel tanks. The analysis was performed using SolidWorks Simulation, an engineering analysis software capable of accurately assessing stress, deformation, and the safety of components under various applied loads. Initially, two 3D models of the clamping device (Model 1 and Model 2) were designed based on a conceptual design approach using carbon steel material SS400, which has a yield strength of 351.571 MPa according to JIS G3101 standards. The analysis process began with defining the material properties, setting the mesh details using 3D solid elements with a curvature-based mesh and a high mesh density, setting a fixed geometry boundary condition at the base of the device, and applying a vertical compressive force of 1790 N at the workpiece support point (equivalent to approximately 179 kilograms, which is the weight of the workpiece). Meshing was then performed, followed by an analysis of stress distribution—indicating internal forces within the material under external loads—to evaluate high-risk areas for cracking or failure. Deformation analysis was used to observe changes in shape or position of the component under load. Shear stress distribution was also examined, highlighting areas with significant shear force tendencies. Finally, the factor of safety was assessed by comparing the material's maximum load-bearing capacity to the actual stress obtained from the simulation, in order to evaluate the safety level of each model under real-world operating conditions. Four key outputs from FEA—namely, stress distribution, deformation analysis, shear stress distribution, and safety factor analysis—were utilized to evaluate the mechanical properties of each model. One design was considered structurally superior based on its performance in these analyses, as it exhibited lower peak stresses in critical regions, reduced deformation under applied loads, and a higher safety factor.

However, while these results provided valuable insight into the structural performance of the fixtures, the analysis did not account for the potential stress and deformation that may be induced in the workpieces during clamping. Although the workpiece weight was included as an applied load in the FEA to ensure fixture integrity, the mechanical response of the workpiece itself was not examined. Incorporating this aspect in future analyses would offer a more comprehensive understanding of how the fixture may influence product quality.

4.1 Structural Strength Analysis of Model 1

Model 1 showed a concentration of maximum stress at the side support area, with a maximum equivalent stress of 0.63 MPa and a maximum deformation of 0.00094 mm, both of which were within acceptable limits. Additionally, the maximum shear stress at the screw mounting points was found to be 0.081 MPa. The minimum Factor of Safety (FOS) was as high as 557.85, indicating that this model possessed good strength and structural stability (displayed in **Figure 7–10**).

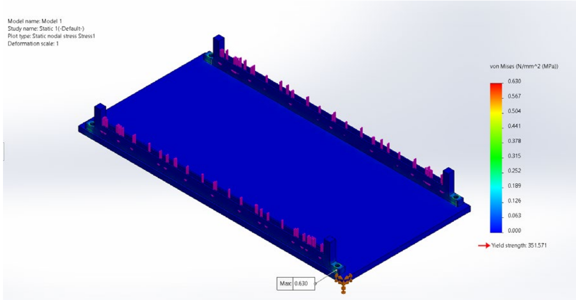

Figure 7 Stress distribution of model 1

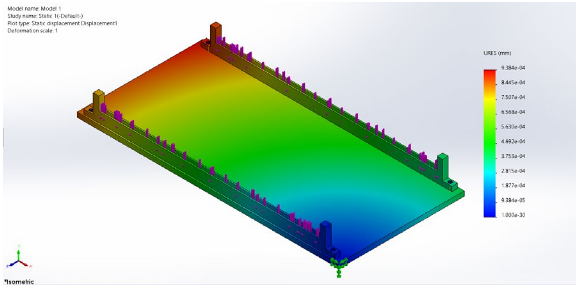

Figure 8 Deformation analysis of model 1

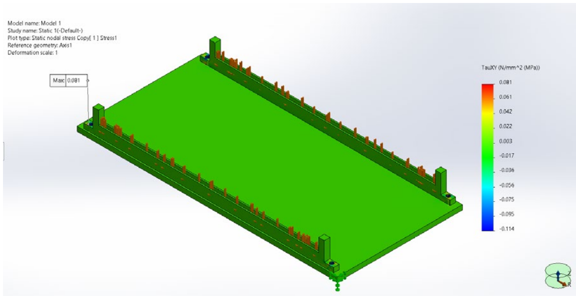

Figure 9 Shear stress distribution of model 1

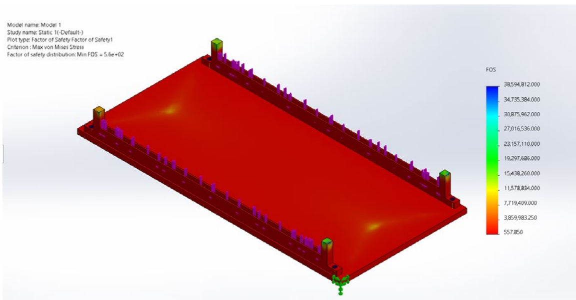

Figure 10 Safety factor analysis of model 1

4.2 Structural Strength Analysis of Model 2

Model 2 showed a concentration of maximum stress at the side support area, with a maximum equivalent stress of 2.408 MPa and a maximum deformation of 0.0023 mm, both of which were within acceptable limits. Additionally, the maximum shear stress at the screw mounting points was found to be 0.292 MPa. The minimum Factor of Safety (FOS) was as high as 146.02, indicating that this model possessed good strength and structural stability (illustrated in **Figure 11–14**).

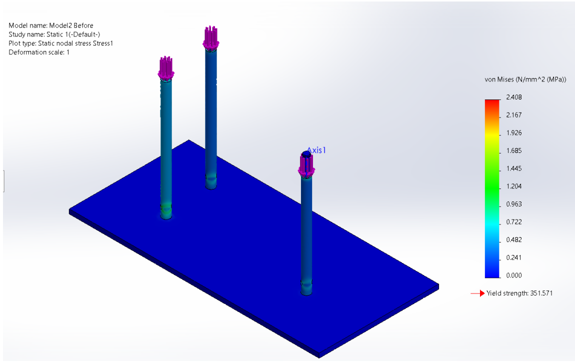

Figure 11 Stress distribution of model 2

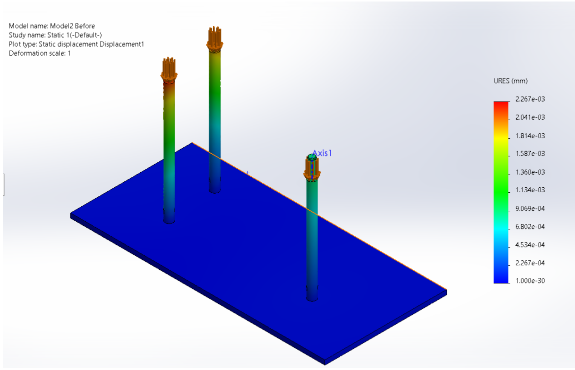

Figure 12 Deformation analysis of model 2

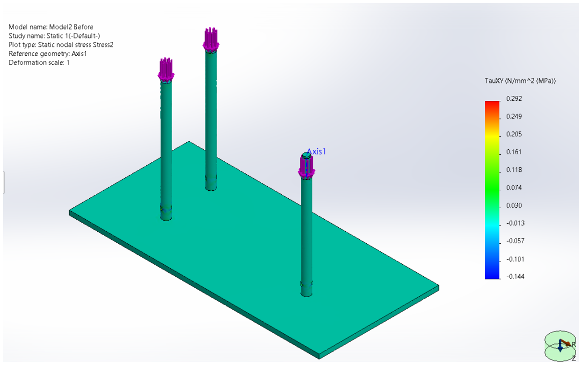

Figure 13 Shear stress distribution of model 2

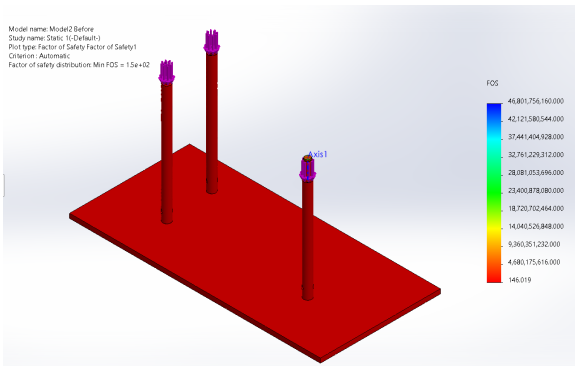

Figure 14 Safety factor analysis of model 2

The analysis indicated that Model 1 demonstrated superior engineering strength, while Model 2 offered better practical suitability for the actual welding process. Both models had undergone FEA to evaluate their mechanical properties. However, to ensure a more comprehensive assessment for real-world application, additional factors should also be considered in the decision-making process.

To further evaluate both models in a more structured and comprehensive manner, the AHP was employed. AHP provided a systematic framework to prioritize criteria through pairwise comparisons. This approach ensured that the final selection reflected not only technical performance but also practical considerations. Five criteria for selecting a welding fixture for a fuel tank were positioning accuracy and repeatability (PA), robot accessibility (RA), ease of loading and unloading (EL), full weld coverage without reorientation (FW), fixture flexibility (FF).

A fixture that ensured precise and repeatable placement reduced defects and enhanced overall production reliability. Robot accessibility, which referred to how easily the robot could reach the workpiece, played a role in reducing setup time and improving operational efficiency. Easy loading and unloading reduced cycle time, enhanced safety, and minimized operator fatigue. Welding without repositioning reduced setup time and interruptions. Fixture flexibility reduced the need for multiple setups, cutting costs and increasing adaptability to diverse production needs.

Pairwise comparison was used to evaluate the relative importance of criteria or alternatives. Saaty's 1–9 scale was applied [13], where a score of 1 denoted equal importance, while 3, 5, 7, and 9 indicated increasing levels of preference—from moderate to extreme. Intermediate values (2, 4, 6, 8) were used to express compromise between two adjacent judgments. When one element was assigned a value relative to another, the reciprocal value was automatically assigned in the opposite direction. The pairwise comparison process involved evaluating criteria or alternatives two at a time to determine their relative importance. Each pair was rated using a standardized scale, and the results were used to calculate weights or priorities that reflected the overall ranking. The evaluation involved four assessors, consisting of one production line engineer and three production line workers, all of whom had between 5 and 10 years of professional experience. The judgments were recorded in a comparison matrix, forming the basis for calculating priority weights. The results were shown in **Table 3–5**.

Table 3 Pairwise comparison matrix

Criteria	PA	RA	EL	FW	FF
PA	1	2	3	5	7
RA	1/2	1	2	3	5
EL	1/3	1/2	1	2	3
FW	1/5	1/3	1/2	1	2
FF	1/7	1/5	1/3	1/2	1
Sum	2.176	4.033	6.833	11.5	18

Table 4 Normalize the matrix

Criteria	PA	RA	EL	FW	FF
PA	0.460	0.496	0.439	0.435	0.389
RA	0.230	0.248	0.293	0.261	0.278
EL	0.153	0.124	0.146	0.174	0.167
FW	0.092	0.083	0.073	0.087	0.111
FF	0.066	0.050	0.049	0.043	0.056

The normalization was performed column-wise using Eq. (1):

$$a_{ij}^{*} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{1}$$

Where: a_{ij} was the original value in row i, column j of the pairwise comparison matrix. n was the number of criteria.

Once the matrix was normalized, the priority weight (or eigenvector) was calculated by averaging the normalized values across each row, as demonstrated in Eq. (2).

$$w_i = \frac{1}{n}\sum_{j=1}^{n} a_{ij}^{*} \tag{2}$$

Where: w_i was the priority weight of criterion i.

Therefore, the priority weight for PA was the average of the PA row, which was equal to 0.444. The weights for the other criteria were 0.262, 0.153, 0.089, and 0.053, respectively.

Weight sum vector of criteria was used to assess the consistency of the pairwise comparison matrix. This vector represented the combined weighted influence of all other criteria on each individual criterion, based on the assigned pairwise comparison values and the resulting priorities, as demonstrated in Eq. (3).

$$Ws_i = \sum_{j=1}^{n} a_{ij} \cdot w_j \tag{3}$$

Where: Ws_i was weight sum for criterion i, w_j was the priority weight of criterion j.

The weighted sum vector for PA was (1 × 0.444) + (2 × 0.262) + (3 × 0.153) + (5 × 0.089) + (7 × 0.053) = 2.243. The weighted sum vectors for the other criteria were 1.320, 0.768, 0.447, and 0.264, respectively.

After calculating the weight sum vector, each element W_{si} was divided by the corresponding priority vector element w_i, and the average of these values gave λmax (the maximum eigenvalue of the pairwise comparison matrix) in Eq. (4):

$$\lambda\text{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{Ws_i}{w_i} \tag{4}$$

As a result, the maximum eigenvalue of the pairwise comparison matrix, or λmax, was 5.028.

To check the consistency of the judgments in the pairwise comparison matrix, the Consistency Index (CI) was calculated using Eq. (5):

$$\mathrm{CI} = \frac{\lambda\mathrm{max} - n}{n - 1} \tag{5}$$

The Consistency Ratio (CR) was calculated by first determining the Consistency Index (CI) from the pairwise comparison matrix's maximum eigenvalue, then dividing the CI by the Random Index (RI). A CR value below 0.10 indicated acceptable consistency in the judgments. The consistency index (CI) was calculated as (5.028 - 5) / 4 = 0.007. The RI for a matrix of size 5 was 1.12. Then, the consistency ratio (CR) was calculated as 0.007 / 1.12 = 0.006, which was less than 0.1. Therefore, the judgements were acceptably consistent.

After evaluating the criteria in AHP, the next step was to evaluate the alternatives with respect to each criterion. After creating pairwise comparison matrices for the alternatives under each criterion, calculated their local priorities (weights), and synthesized the results to determine the overall priority of each alternative.

Model 1 was calculated as

(0.444 × 0.25) + (0.262 × 0.67) + (0.153 × 0.17) + (0.089 × 0.67) + (0.053 × 0.25) = 0.385.

Model 2 was calculated as

(0.444 × 0.75) + (0.262 × 0.33) + (0.153 × 0.83) + (0.089 × 0.33) + (0.053 × 0.75) = 0.616.

The chosen design was selected based on the AHP outcome, which demonstrated that it achieved the highest overall priority score due to its superior performance across the evaluated criteria. Notably, positioning accuracy and repeatability (PA) were the most influential criteria in the final decision. As a result, Model 2 was selected for implementation in the production line.

Table 5 Overall priority table

Criteria	PA	RA	EL	FW	FF
	0.444	0.262	0.153	0.089	0.053
Model 1	0.25	0.67	0.17	0.67	0.25
Model 2	0.75	0.33	0.83	0.33	0.75

During the development of fixture model 2 and its trial use in the production process, two limitations were identified. The first issue was the difficulty of fastening the three clamping rods to the screws underneath. To address this, the screws were welded directly to the base plate, and holes were machined into all three rods to facilitate easier operation. The second issue involved the third clamping rod, which could not properly grip the workpiece. This was due to limitations in welding the internal subcomponents CTSW-14 and CTSW-15, causing the clamping rod to interfere with the welded subcomponents. To resolve this, the third rod was modified by machining it down to the appropriate size.

After two modifications, as presented in **Figure 15**, a structural strength analysis of the device was conducted using FEA. A maximum equivalent stress of 3.022 MPa and a maximum deformation of 0.0036 mm, both of which were within acceptable limits. Additionally, the maximum shear stress at the screw mounting points was found to be 0.219 MPa. The minimum Factor of Safety (FOS) was as high as 116.35, indicating that this modified model possessed good strength and structural stability.

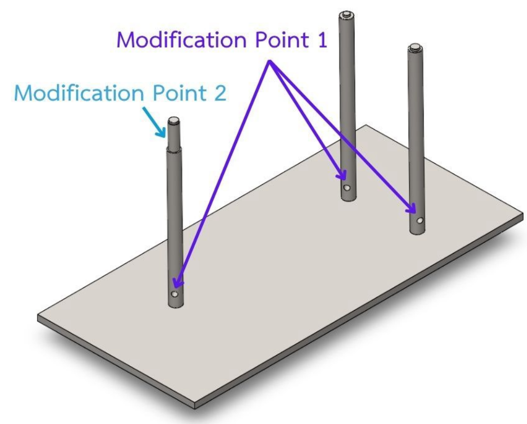

Figure 15 Fixture model 2 after improvement

5. Results and Discussion

A prototype of the fixture was developed and manufactured for actual use in production. It was not only tested but also implemented in the production line, where some adjustments were made to improve operator usability and convenience. This practical implementation enabled effective validation of process time improvements and confirmed the fixture's suitability for ongoing use.

After improving the production process of hydraulic excavator fuel tanks by applying the ECRS principles along with designing a fixture, the research team conducted a comparative analysis before and after the improvement, as shown in **Table 6**. By implementing a fixture in the robotic welding process, the setup time required for workpiece positioning was reduced by 1 hour and 22 minutes, as determined from the average of 10 production cycles, representing a reduction of 49.26%. This resulted in the production time per piece decreasing from 11 hours 51 minutes to only 9 hours 35 minutes. Consequently, production became faster and better met customer demands.

Table 6 Results of improvements

Methods	Before	After	Reduction
Eliminate Walking to pick up subcomponents	0:03:42	0:00:23	89.64%
Rearrange Switching the welding sequence of parts 14 and 15	0:15:15	0:11:05	27.32%
Simplify - Chamfering with machinery	0:43:08	0:35:48	17.00%
- Improving the jig for track welding	0:20:11	0:16:13	19.65%
- Using fixtures in robot welding	2:45:10	1:23:48	49.26%

In addition to reducing setup time, the implementation of the new fixture led to several qualitative improvements in the robotic welding process. It enhanced the accuracy of workpiece positioning, thereby improving welding precision and significantly reducing rework caused by misalignment. Additionally, it improved product consistency by ensuring uniform workpiece alignment across production cycles.

From the cost-benefit analysis, the total production cost for the fixture was 9,289 Baht. This cost comprised:

1) Steel base (SS400): 3,000 Baht
2) Three steel columns (SS400): 6,000 Baht
3) Bolts: 200 Baht
4) Labor cost (1 hour): 89 Baht

The fixture significantly reduced production time by an average of 2 hours 16 minutes per piece (calculated as time saved per piece: the original production time was reduced from 11 hours 51 minutes to 9 hours 35 minutes). This translates to labor cost savings of 201.63 Baht per piece.

The break-even point calculation showed that the fixture investment would be recovered after producing approximately 47 pieces (Break-even point = Cost of fixture/Labor cost saving per piece = 9,289 / 201.63 ≈ 46.07 pieces). This demonstrates that investing in the fixture is highly cost-effective and its cost could be recovered within a short period.

6. Conclusion

This research article aimed to improve the production efficiency of hydraulic excavator fuel tanks, focusing on reducing the time in the robotic welding process. It was found that the main cause of wasted time was the setup of workpiece positioning every time the workpiece was changed. Therefore, the research team applied the ECRS principles to analyze the process and designed a fixture to ensure accurate workpiece positioning and reduce setup steps. As a result, the research succeeded in reducing non-value-added time from unnecessary movement and complex steps by 18 minutes and 47 seconds. It also reduced the robot welding position setup time by 1 hour and 21 minutes. Consequently, the production process was improved to meet customer demands, with the final production time reduced to 9 hours and 35 minutes.

The combined ECRS, FEA, and AHP methodology offered strong potential for application to similar manufacturing processes across various settings due to its adaptable, structured problem-solving approach. Key factors for successful transfer included a clear understanding of the process, accurate system modeling with FEA, and precise data collection to ensure reliable analysis and decision-making.

This study uniquely integrated ECRS, FEA, and AHP to improve the welding process and fixture design, unlike previous studies that used these tools separately. While it shared common goals with past research—such as reducing operator workload, improving efficiency, and validating fixture strength—it went further by combining process improvement, structural analysis, and decision-making in one framework. Unlike prior works that focused only on workflow or fixture design, this study offered a more holistic and welding-specific approach.

To optimize fixture utilization and longevity, several key recommendations are proposed. First, the development of a comprehensive user manual and maintenance guide is essential to ensure correct operation, reduce errors, and significantly extend the fixture's service life. Additionally, future design improvements should focus on enhancing the fixture's flexibility, allowing it to accommodate a wider range of workpiece types and adapt to different production requirements.

Future research should focus on developing smart fixtures equipped with sensors to provide real-time feedback on workpiece positioning and clamping force, enhancing accuracy and preventing errors. Additionally, integrating the fixture into an Industry 4.0 framework would enable data collection for monitoring performance and predictive maintenance, improving overall production efficiency.

7. Acknowledgments

The authors wish to express their sincere gratitude to the case study company and its employees for their invaluable support in providing data and offering insightful guidance throughout this research. Special thanks are extended to Mr. Phuwanai Palakachen for his expert guidance and technical assistance with the simulation analysis.

8. References

[1] T. Hu, L. Yi, Y. Tang, Y. Chen and R. Hu, "Enhancing Nighttime Surgical Instrument Cleaning Efficiency: An ECRS-Based Approach," *Medical Science Monitor*, vol. 29, pp. 1–7, 2023, doi: 10.12659/msm.940346.

[2] T. Choojan and P. Chutima, "Lean Application for Parts Transportation Improvement in Automotive Factory's Warehouse," *Advanced Science,*

Engineering and Medicine, vol. 8, no. 10, pp. 780–784, 2016, doi: 10.1166/asem.2016.1938.

[3] L. Zhang, B. Wu, B. Zou and Z. Wang, "Research of Auto Parts Assembly Line Simulation and Optimization Based On TOC," *IOP Conf. Series: Earth and Environmental Science*, vol. 252, 2019, Art. no. 032125, doi: 10.1088/1755-1315/252/3/032125.

[4] S. M. Tang, W. Pei, and M. H. Chuang, "PV chart management innovation based on production balance ratio: a case study of Company S's GaAs process improvement for compound semiconductors," *The International Journal of Advanced Manufacturing Technology*, vol. 136, no. 5–6, pp. 2769–2799, 2025, doi: 10.1007/s00170-024-14963-0.

[5] P. Jindal, S. S. S. Bharadwaja, S. Rattra, Chaitanya, V. Gupta, P. Breedon, Y. Reinwald and M. Juneja, "Designing cranial fixture shapes and topologies for optimizing PEEK implant thickness in cranioplasty," *Journal of Materials: Design and Applications*, vol. 237, no. 8, pp. 1752–1770, 2023, doi: 10.1177/14644207231155761.

[6] H. Radhwan, M. S. M. Effendi, M. F. Rosli, Z. Shayfull and K. N. Nadia, "Design and Analysis of Jigs and Fixtures for Manufacturing Process," *IOP Conf. Series: Materials Science and Engineering*, vol. 551, no. 1, 2019, Art. no. 012028, doi: 10.1088/1757-899x/551/1/012028.

[7] J. W. Park, J. Park, H. Kim, N. Kim and D. Y. Kim, "Assembly Part Positioning on Transformable Pin Array Fixture by Active Pin Maximization and Joining Point Alignment," *IEEE Transactions on Automation Science and Engineering*, vol. 19, no. 2, pp. 1047–1057, 2022, doi: 10.1109/TASE.2021.3050403.

[8] A. Mamat, H. J. Yap, C. H. Tan and M. B. M. Asri, "Fixture Design for Outer Skin Aircraft Door Manual Drilling Operation with Finite Element Analysis and Ergonomic Consideration," *Advances in Materials Science and Engineering*, vol. 2022, 2022, Art. no. 4236629, doi: 10.1155/2022/4236629.

[9] W. H. W. Mahmood, A. N. M. Amin and L. Hanapiah, "Application of AHP on SMED for Jig and Fixture Design Selection," *International Journal of Human and Technology Interaction (IJHATI)*, vol. 4, no. 1, pp. 27–37, 2020.

[10] H. Yu, L. Zhang, and G. Li, "Research of analytic hierarchy process applying for case-based reasoning in automotive welding jig design," in *Proceedings 2013 International Conference on Mechatronic Sciences, Electric Engineering and Computer (MEC)*, Shenyang, China, Dec. 20–22, 2013, pp. 3222–3226, doi: 10.1109/MEC.2013.6885574.

[11] A. Z. M. Noor, F. A. Jafar, M. H. A. Bakar and S. Sulaiman, "Design of Reverse and Missing Jaw Detector Jig using Analytic Hierarchy Process (AHP)," *International Journal of Recent Technology and Engineering (IJRTE)*, vol. 8, no. 2, pp. 2229–2237, 2019, doi: 10.35940/ijrte.b2436.078219.

[12] C. Naksri, S. Chuchom and S. Chaiprapat, "Design of Fixture for Welding," *IOP Conf. Series: Materials Science and Engineering*, vol. 1163, no. 1, 2021, Art. no. 012007, doi: 10.1088/1757-899x/1163/1/012007.

[13] T. L. Saaty, "How to make a decision: The analytic hierarchy process," *European Journal of Operational Research*, vol. 48, no. 1, pp. 9–26, 1990, doi: 10.1016/0377-2217(90)90057-i.