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Verifying Welding Processes Selection for a Case Study Using an Analytic Hierarchical Process

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ABSTRACT

This paper aims to develop a framework for differentiating the selection of welding processes using specialized knowledge-based expert systems, which are particularly useful in dealing with issues that require complex decision-making. A program was created and programmed using the process information maps (PRIMAs) matrix in Visual Basic Access for selecting welding processes in a study. The program is in two stages. In the first stage, it excludes non-candidate operations according to several criteria, the most important of which is the type of metal and its thickness. The second stage is arranging operations using multi-criteria methods for decision-making through research to resolve complicated problems involving multiple factors. The hierarchical analysis process (AHP) was used. It is considered one of the most frequently used multi-criteria decision-making methods. The selection of analytic hierarchical process. AHP criteria depend on experience and knowledge rather than specific data for selecting alternatives and determining weights. The methodology is straightforward, easy to comprehend, and applicable to various domains needing intricate decision-making. The program results are compared with those of a previously published case to choose the best welding processes for a study case, which is a home radiator, and results matching the candidate processes were discovered.

Keywords: Expert system, Welding process selection, MCDM, Analytic hierarchy process.

1. INTRODUCTION

Expert systems are a type of artificial intelligence that makes substantial use of specialized knowledge to handle real-world problems that would ordinarily require the assistance of a technical human expert **(Gupta, 2017)**. Expert Systems (ES) are relatively expensive to build yet simple and inexpensive to operate. Furthermore, ES enable the automation of many jobs

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that human specialists would be unable to do efficiently **(Adekunle et al., 2016)**. Expert systems' capacity for reasoning aids in decision-making. A computer program known as an expert system duplicates a human expert's thought process to resolve complicated decision issues in a particular field and is on par with human intelligence and expertise **(Brown et al., 2002)**. As computing power increases, businesses increasingly turn to automated expert systems rather than human specialists **(Krishnamoorthy and Rajeev, 2018)**. Transporting large assemblies and complex production issues are resolved by welding. Therefore, welding is crucial for various applications in industries like oil and gas, aerospace, automotive, and automobile **(Ishak, 2016; Al-Mukhtar, 2019; Al-Mukhtar, 2020)**. There has been an increase in welding methods and equipment since the Industrial Revolution. The foundation of manufacturing production is intelligence. In the manufacturing sector, welding is the fundamental processing technique **(Wang et al., 2023)**. Research about welding expert systems in industrialized nations is relatively comprehensive. The investigation into developing a welding expert system commenced around the mid-1980s. The first documented case of a relevant nature is the Weld Selector, a system for selecting welding materials that the United States Welding Institute and the Colorado Mining Institute collaboratively created. Over three decades of extensive research, numerous expert systems about welding have been developed, exhibiting a comprehensive range of functionalities encompassing nearly all facets of the welding process **(Krishnamoorthy and Rajeev, 2018)**. The system uses algorithms and inference mechanisms to solve problems, utilizing the Process Information Maps (PRIMAs) matrix. It adapts the matrix to the knowledge base, analyzing content knowledge rules and performing expert thinking. The system learns and adds solved problems to the knowledge store **(Lucas, 1995)**.

Welding is a critical technology in modern manufacturing and has been a study center in manufacturing technology worldwide. Metal welding refers to joining two metal parts by subjecting them to elevated temperatures that induce melting or softening. This can be accomplished with or without using filler metal and done with or without applying pressure **(Doos and Hussein, 2010; Brunton et al., 2017)**. The weldability of different metals differs as per the definition provided by AWS. Weldability indicates to the ability of a material to be successfully welded into a planned-for, carefully designed structure and to work effectively in its intended use within specified fabrication conditions **(Kalpakjian and Schmid, 2014)**. As stated by the American Welding Society (AWS), this joining mechanism was developed by more than seventy-two welding processes **(AWS, 2020)**. The selection of a welding process is influenced by various factors such as production cost, joint design, desired performance, end-use, manpower experience, parent metal characteristics, common type, accuracy, accessibility, welding equipment availability, welder skill, material type, and thickness **(Khan, 2007)**. Metals used in welding can be similar or different. Unfortunately, welding procedures are harmful to the environment and people **(Schwartz and Aircraft, 1993; Balasubramanian et al., 2000; Balasubramanian et al., 2009; Blunt and Balchin, 2002; Brown et al., 2002)**, so strict safety and health precautions must be taken. The manufacturing industry faces challenges in selecting the proper welding process (SWP) for metal welding due to the increasing number of welding agents. The SWP decision is a critical stage in welding process planning, and solving this problem is challenging. Among the first methods were knowledge-based and expert systems that automated material selection, virtual welding diagnostics, and process control during welding, and SWP **(Chakraborty and Zavadskas, 2014)**. After that, many methods constructed based on structured decision-making procedures were developed, either with or without utilizing knowledgebases and expert systems. Several of the most common Multi criteria decision making (MCDM)

techniques are, in and of themselves, fundamental knowledge-based systems. Despite this, most of the approaches being supplied cannot formally accommodate actual medium or large industrial challenges. This is because they are crude plans that have the potential to fail in most industrial scenarios while remaining practical in workshop situations **(Omar and Soltan, 2020).** Shield Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Gas Metal Arc Welding(GTAW), Flux Cored Arc Welding (FCAW), oxyacetylene arc welding (OAW), Resistance spot Welding (RSW)or seam welding(RSEW), and torch or oxyacetylene brazing (TB) are the welding processes that are utilized the most frequently within the welding industry **(Bower et al., 2010)**.
Nowadays, many publications have appeared on selecting the best welding processes using multi-criteria decision systems. Some of those used in designing and solving the Selection Welding Process problem will be classified. The summaries are organized in chronological order as follows: **(Darwish et al., 1997)** tried 30 different welding methods to come up with a way to choose the best one for each case based on what they knew. In their method, they consider factors like the type of product, the type of material, the thickness of the material, how it will be used, the quality level, the type of joint, and the position of the welding. Their system must first check for welding processes. **(Brown et al., 2002)** offered a process for determining the optimal joining technology. The method aimed to show possible joining processes that could work in certain situations. The selection criteria for the method are the joint's function (type of load and strength), its technical information (such as its shape and material), its spatial information (such as its thickness and size), and its economic factors (such as the amount that needs to be made and the number of skills that need to be used). These needs are stored in a database and built into software. These systems only show possible ways to weld without doing a full pick. **(Esawi and Ashby, 2004)** proposed an approach for selecting a joining method, operationalized through software. The identification of procedures that meet design criteria for material, joint configuration, and loading is facilitated by a search engine, which stores the specific information of each joining process in a database. It is more relevant to prioritize the ranking of processes based on their individual production rate or equipment cost after their isolation. **(Jafarian and Vahdat, 2012)** suggested a knowledge-based system for selecting the best welding technique under specific conditions. Considering the operator factor, alloy class, material thickness, deposition rate, capital cost, joint configuration, design application, welding location, equipment mobility, and filler metal utilization, they utilized nine crucial welding processes. This system revealed that the best welding techniques for high-pressure vessels are Gas Tungsten Arc Welding (GTAW), Plasma Arc Welding (PAW), and Electron Beam Welding (EBW). **(Jayant and Dhillon, 2015)** used a knowledge-based analytical hierarchy process (AHP) method to create a structured method for fabricate high-pressure vessels. Scientists compared five types of welding based on their design uses joint arrangement, welding location, part thickness, weld quality, capital cost, deposition rate, material class, welding technique, operator factor filler, metal usage, and equipment mobility **(Capraz et al., 2015).** AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodologies were employed to select an optimal welding process for a storage tank made of plain carbon stainless steel. The researchers employed the AHP methodology to assign weights to the criteria based on expert opinions. Subsequently, the TOPSIS approach was utilized to rank the various welding techniques that were accessible. The individuals submitted applications for the SMAW, MIG, GMAW, GTAW, and Sub Merged Arc Welding(SAW)procedures. However, the current approaches to addressing the WPS problem vary based on the chosen differentiation principle **(Al-Mendwi and Doos, 2019).**

optimized the welding process for fabricate crude oil tower joints built of dissimilar materials and thicknesses using the upgraded PROMETHEE II's (AHP) technology. One can select from four welding procedures: FCAW, SMAW, GMAW, or SAW. Twelve factors that are considered when choosing a welding process: Design Application (DA), Welding Configuration (WC), Welding Weights (WW), Material Type (MTY), Material Thickness (MTH), Cost of Welding (CoW), Positional Welding Capability (PWC), Operator Factor (OF), Welding Quality (WQ), Filler Metal Utilizations (FMU), Deposition Rate (DR), and Welding Procedures (WP). According to the results, FCAW is the superior welding method**.**
(Al-Mendwi and Doos, 2020) developed a program to identify and choose five arc welding procedures that differ in design and technology: GTAW, SMAW, SAW, or FCAW. The program consists of two main modules: one studies the weldability of common metals and alloys, and the other studies the compatibility between these processes and common formations. The software has been verified in twelve case studies, allowing automated selection of the ideal welding process for specific joint tasks. **(Omar and Soltan, 2020)** utilized a two-phase decision support framework, FUZZY-AHP, and FUZZY-TOPSIS. The first phase is to exclude processes that are not compatible with the required application based on a specific category of criteria. Having done that, he can now do the basic stake operation. It weighs the standards. They applied the program to a real-life case study of plumbing applications in site welding. According to the analysis conducted, it has been determined that the most suitable welding technique for this scenario is the TB procedure, followed by TIG and SMAW. A decision framework was presented for welding process selection that was both flexible and adaptable. It filtered the provided processes twice using two sets of strict criteria, considering cost, quality, and availability into account.it is equipped with a sophisticated decision-making engine that is incorporated. Consequently, it may guarantee the proper choice when differentiating a larger range of industrial operations, regardless of how complex the products and welding procedures are. **(Al-Mendwi and Doos, 2023)** employed AHP and the Extended PROMETHEE II (EXPROM2), a variant of the Preference Ranking Organization Method for Enrichment Evaluations PROMETHEE II. The empirical evidence substantiated the utilization of an on-site welding methodology for a storage container possessing a volumetric capacity of 16,000 m^3. Five distinct welding processes can be considered: FCAW, SAW, SMAW, and GTAW. The preferred welding process is (SMAW). **(Al-Mendwi and Doos, 2023)** examined the considerations involved in selecting appropriate welding methods for fabricating small carbon steel tanks with a volumetric capacity of 55 cubic meters. Five welding procedures were selected for this study, namely GMAW, SMAW, SAW, FCAW, and GTAW. The methodology incorporates the utilization of MCDM and QFD. The chosen methodology indicates that the (GMAW) approach is the most favorable welding technology for the specific application. Several methods for selecting a welding process have been described based on mathematical techniques or self-selection models that rank the relevant concepts that must be considered in a multi-criteria and multi-parameter process such as welding that has previously described a summary of the methods and results of authors who have developed the knowledge process about this subject. After the increase in the diversity of products and materials used in manufacturing processes worldwide, the need for welding processes used in assembling the parts of these products has increased. Therefore, welding processes have varied greatly, and choosing the optimal welding process for a specific application has become very difficult and depends on the experience of some specialized engineers. To make choosing the best welding process easy, fast, reliable, and completely reliable.

There has become an urgent need to automate the selection of the optimal welding process that accomplishes the work with high quality, without defects, at the lowest price, and with high production speed. The proposed framework for welding process selection is shown in **Fig. 1** below.

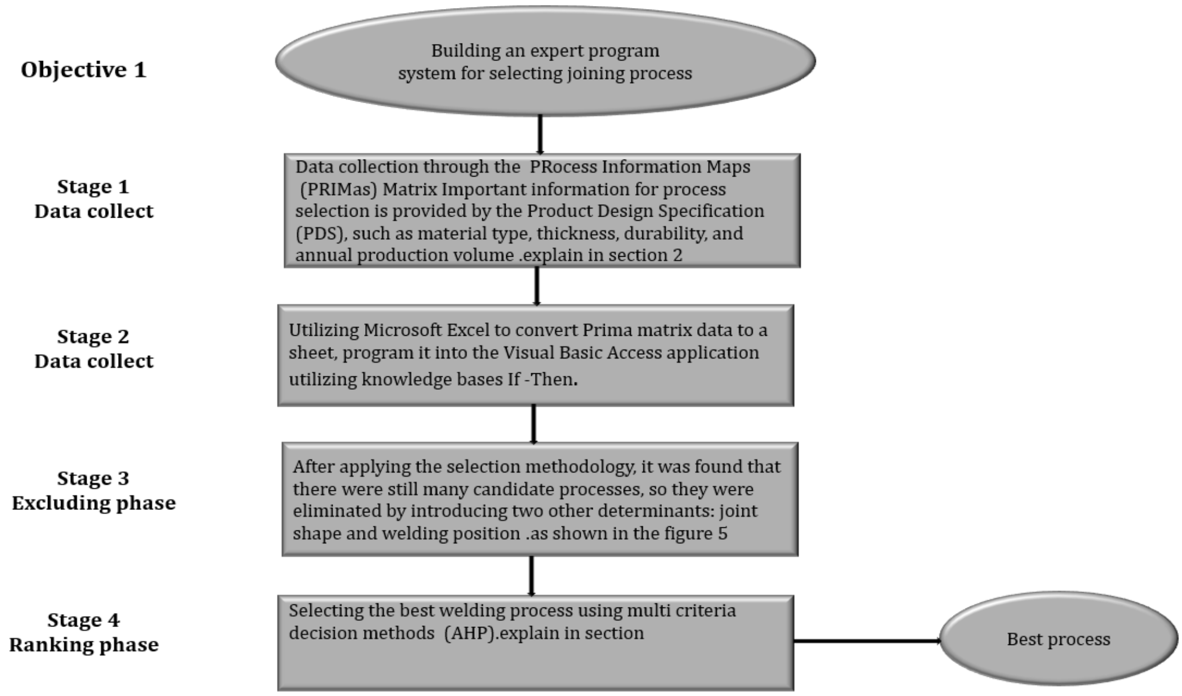

Figure. 1 Proposed framework for welding process selection

2. METHODOLOGY OF SELECTION WELDING PROCESS

2.1 Collecting and Classifying the Affected Factors

The goal of the approach for selecting welding processes is to provide a way to find practical ways of welding and to highlight potential processes that can be welded in the given circumstances. For the selection methodology to be effective in operations, Data collection through the PRIMAs Matrix Important information for process selection is provided by the Product Design Specification (PDS), such as material type, thickness, durability, and annual production volume. Another determinant, the shape of the joint, was selected to reduce the candidate operations, and the selection criteria used during the initial stages of the program will be explained below.

1. **Material types:** The compatibility of the parent material with the welding process is determined by the material being used for welding. The approach to selection has considered a significant fraction of the materials utilized in creating technical products. A large proportion of the materials used in engineering manufacturing have been included in the selection methodology. These materials range from ferrous alloys to precious metals.
2. **Material thickness:** The methodology considered the thickness of materials suitable for the welding process.
3. **The degree of permanence:** an essential consideration while deciding on the best connecting procedures, considering both the joint's in-service behaviors and the

eventual disassembly requirements. There are three distinct kinds of selection criteria available.

(a) A permanent joint prevents linked components from disassembled without rupturing them. Examples of similar processes include welding, riveting, connecting, etc. It may produce a robust, trustworthy, leak-proof, and adequate joint, making it safe for heavy-load applications.
(b) A semipermanent joint is a joint that can be disassembled for purposes of repair, maintenance, or transit, yet may be reversed without harming the material. Intense heat permanently connects metal components in soft soldering, brazing, and welding.
(c) A non-permanent joint refers is a fastening technique that can be easily separated. This technique is primarily used in replacement, maintenance, repair, or adjustment work, including nuts and bolts, screws, and rivets.

4. **Quantity of product** or production volume refers to how many products can be produced in a specific time.
5. **The shape of the joint:** a junction point or edge where two or more metal or plastic parts are attached. The American Welding Society names five different joint types: butt, corner, edge, lap, and tee.

For the method to be helpful, it must be easy to understand, use on paper, and flexible enough to work with software. Processing information maps (PRIMA) and putting them in was done with the help of consultation papers. Sheets in Excel **(Swift and Booker, 2013)** were the first to use the array to choose how to make products. The program's parameters are arranged hierarchically in **Fig .2.**

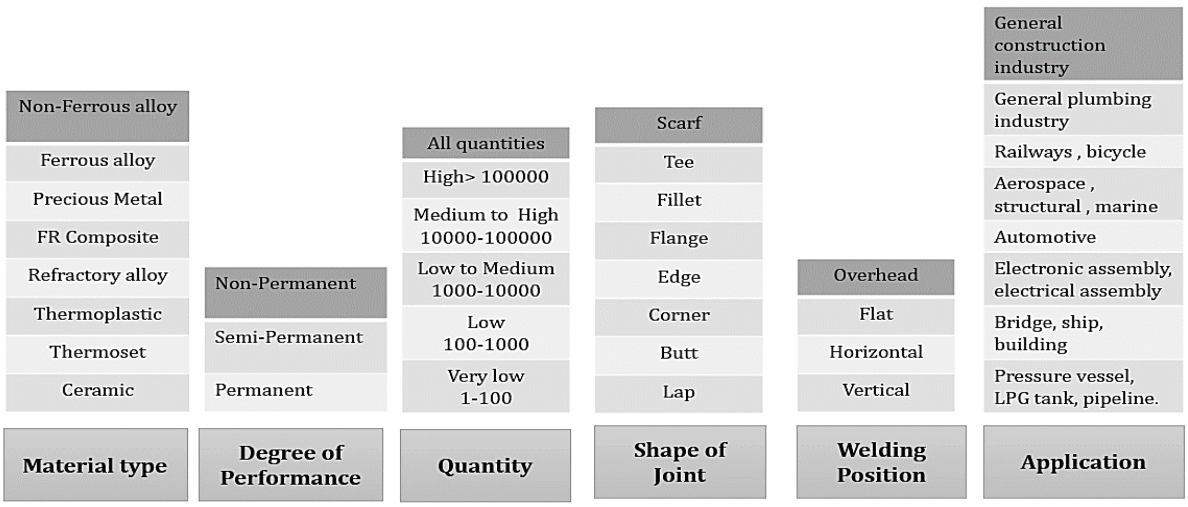

Figure 2. A hierarchical scheme for program factors

2.2 Design of the Expert System

Expert systems consist of a knowledge base, an inference engine, and a user interface, which interact with both users and experts during their creation and usage. The user interface of an expert system consists of an inference engine, an explanation system, and a knowledge-based editor **Fig. 3 (Kadir et al., 2023)**. The inference engine uses rules and facts to derive conclusions, using both forward chaining, backward chaining, or a combination. A knowledge-based editor allows the user to edit information within the system, which is typically inaccessible to the end user. An expert system's design, development, and uses involve multiple people. The end-user is the person who needs the system, while the knowledge engineer designs the rules based on observation or expert questions. The domain expert is crucial in developing an expert system, as they must explain their methods to the knowledge engineer. The inference engine uses a problem-solving strategy to imitate a specialist's reasoning process by matching the IF part of rules with known facts in working memory **(Adekunle et al., 2016)**.

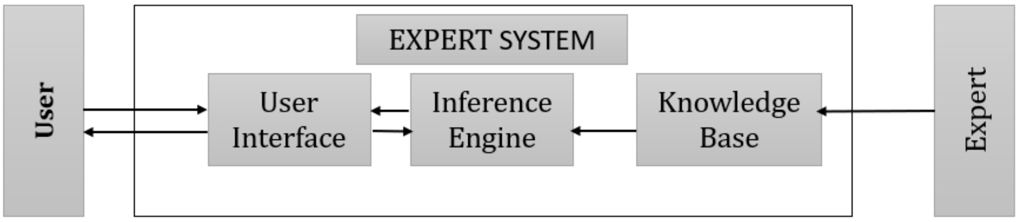

Figure 3. The general structure of expert systems.

User interface is the user, while the knowledge base is a structured structure of expert knowledge comprising rules, facts, networks, and frameworks, and the inference engine is responsible for reaching conclusions. The expert program is implemented using IF-THEN rules, and the system is built using one of the available programs, Visual Basic Access. **Fig. 4** illustrates the algorithmic structure of the expert system adopted in this work.

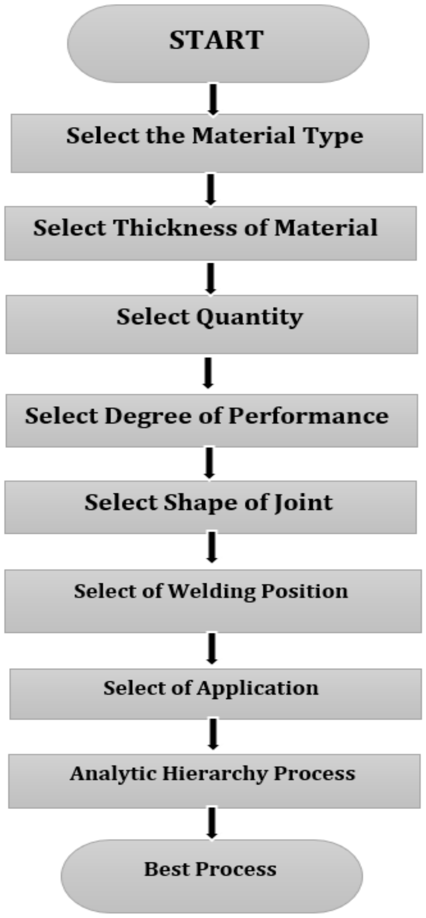

Figure 4. The algorithmic structure of the expert system in this work

2.3 Analytic Hierarchy Process (AHP)

It is one example of frequently used multi-criteria decision-making methods. It is one example of frequently used multi-criteria decision-making methods. Thomas L. Saaty introduced AHP in the 1970s, and until today, it is the most used method by researchers for solving complex problems involving multiple and incompatible factors. This method is easy and straightforward to understand, it can be applied in different fields requiring complex decision-making. Testing the criteria in the analytical hierarchy process (AHP) relies on understanding and knowledge rather than specific data to select alternatives and determine weights. Still, it only considers expert ratings expressed as conventional numbers (crisps) ranging from 1 to 9, leaving out consideration of the uncertainty of expert ratings **(Rashed and Al-Dhaheri, 2018)**. It is designed to solve complex problems **(den Ouden and Hermans, 2009; Jayant and Dhillon, 2015)**. A method to choose a process that considers both qualitative and quantitative factors. Many ideals are at odds with each other. Accordingly, AHP is a popular way to measure things used to make a ratio scale used in multi-level hierarchical structures, whether the comparisons are discrete or continuous.
Three things set AHP apart from other ways of making decisions: 1) its ability to deal with both real and abstract factors; 2) its skill at organizing issues in a way that helps us understand how decisions are made; and 3) its capacity to keep an eye on how consistently a decision maker employs their judgment. An AHP's ability to help people make decisions by showing how different factors combine in complicated situations. The method has decision-makers organize the transparent parts of the problem into a hierarchy, then rate the importance of each factor, and finally come up with a solution. Within this process, people making the decisions must organize the apparent factors in the problem into a hierarchy, rate the importance of each factor, and then state their choice for each decision option related to that factor. The method makes a prioritized rank order that shows how much each option is preferred overall. Compared to other decision-making methods based on multiple variables, the AHP is superior. It is meant to encompass both tangible and intangible elements, which is especially relevant when subjective judgments of different individuals play a role in the decision process. Following are the steps to complete an AHP **(Vaidya and Kumar, 2006; Jayant and Dhillon, 2015; AL-Aga and Burhan, 2023):**

1. Split the decision-making problem into three stages, as shown in **Fig.5.**
   Stage 1: A general goal to be achieved
   Stage 2: Factors reflect for achieving the general goal. Ones that were collected from experts and sources.
   Stage 3: Alternatives to be evaluated.

2. Each criterion should be given a weight that shows how important it is to each choice criterion. As shown in **Table 1**, The scale for pair-wise comparison If we suppose that there are N criteria to consider in a decision, the comparison of i^{th} pair criteria with respect to j^{th} pair criteria produce a square matrix, A_1.

Table 1. Scale for pair-wise comparison **(Saaty, 2008)**

Degree of importance	Definition
1	Equal
3	Moderately preferable
5	Strongly preferable
7	Very strongly preferable
9	Extremely strongly preferable
2,4,6,7	intermediate values between adjacent scale values
Reciprocal of above Numbers (1/2, 1/3, 1/4 etc.)	If a criterion is assigned to one of the above numbers when compared with another, the second will be assigned the reciprocal of the number when compared with the first.

3. Following the construction of the pair-wise comparison matrix for a given criterion, synthesizing each alternative's normalized priority takes place. The procedure involves three steps. Firstly,
   a) The values in each column are added together. Secondly,
   b) Each element in the column is divided by the total of the column, resulting in a normalized pair-wise comparison matrix. Lastly,
   c) The average of the elements in each row of the normalized comparison matrix is computed, estimating the relative priorities of all the alternatives. This task can be executed by utilizing the following equations:
   When the geometric mean (GM) is calculated,
   GM= $[\prod_{j=1}^{n} a_{ij}]$ (1)
   where a_{ij} =1, when i= j, and $a_{ij}=\frac{1}{a_{ij}}$ (a_{ij} is the significance of the i^{th} criterion in comparison to the j^{th} criterion).
   d) The relative normalized weight (w_j) for each criterion can be determined by calculating the geometric mean of (i) its rows and normalizing (ii) the geometric mean of the rows in the pair comparison matrix.

$$w_j = \frac{GM_j}{\sum_{j=1}^{n} GM_j} \quad (2)$$

   e) $A_3$and A_4 matrices are gotten via A_3=A_1×A_2 andA_4=$\frac{A3}{A2}$, where A_1=$[w_1, w_2, w_3, w_4 \dots . w_N]^T$
   f) The maximum eigenvalue (λ_{max}) is the median of the matrix A_4 .
   h) The consistency index (CI) is calculated by:

$$CI=\frac{(\lambda_{max}-N)}{(N-1)} \quad (3)$$

   Deviation from consistency is directly proportional to the value of (CI).
   i) The Consistency Ratio (CR) is calculated from:

$$CR =\frac{CI}{RI} \quad (4)$$

   The random index, denoted as RI, is used in this context. The concept of RI performances the many requires of comparison matrices. **Table 2** presents the recorded values of the Resilience Index (RI) in relation to the respective number of qualities. The typical value used to reflect the impartial evaluation by the decision maker typically falls within the range of 0.1 or lower.

4. The priority is synthesized in a manner that is analogous to the fourth stage. Next, proceed to calculate the total priority for each possibility. Next, choose the one with the highest ranking of priority. Seven criteria are identified based on the literature survey and source. **Fig. 5** shows the level and essential criteria considered when selecting the best welding process.

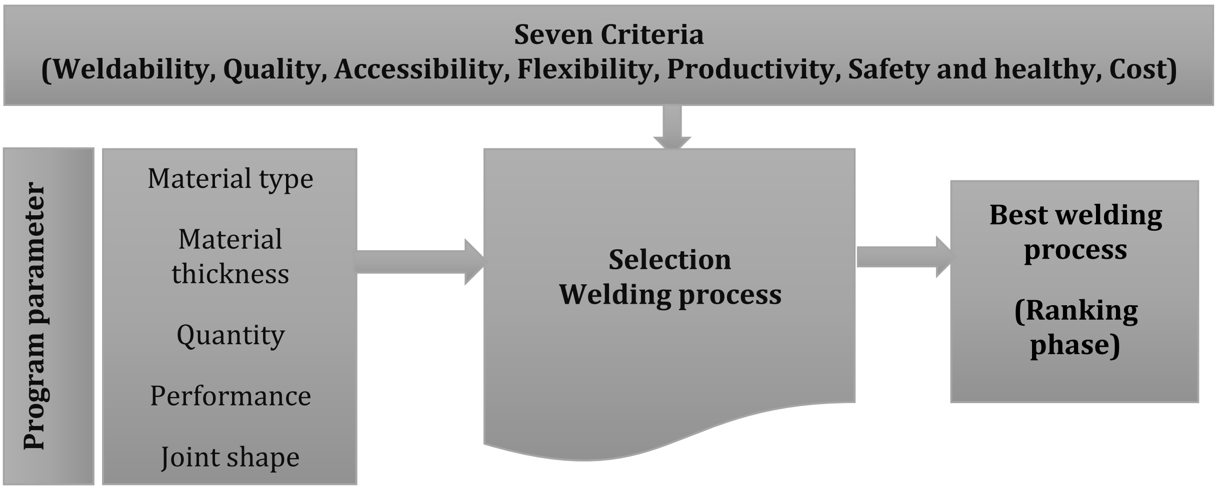

Figure 5. Stages for Welding process selection

Table 2. Random index (RI) values **(Al-Mendwi and Doos, 2023)**

n	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4
n	9	10	11	12	12	14	15	
RI	1.45	1.49	1.51	1.54	1.56	1.57	1.59	

3. EXPERT SYSTEM VERIFICATION AND VALIDATION

To verify the accuracy of the system, its outcomes, and its judgments. It is necessary to inquire as to the program's functionality. Does it behave like a real expert would? The solutions to these questions are discovered through system validation and verification. Verification is to demonstrate that the software is operating as expected and designed; however, validation challenges whether the system's actions reflect the choices made by the actual human expert. A case study, the domestic radiator of a researcher provides a brief explanation of the case study conducted to validate the program's findings, and the results of the human expert were compared to those of our program while choosing the optimal welding procedure. It's important to remember that the researcher's results were obtained in substantial agreement with those of the expert-system-based selector. The system's outputs and the researcher's anticipated outputs were compared to the case's requirements, as shown in **Table 3.**

3.1 Case Study

The radiator is a primary cooling system that uses a water pump to cool the movement system. It has many tubes connected by a small gap and thin external metal sheets for increased space. The hot water from the device's engine is transported through these pipes, exposed to fresh air, and attracted by a cooling fan. The water is then cooled and exits the radiator to the engine. If pressure increases due to heat, it is sent to the overflow tank or bladder. The thermal conductivity, water tightness, resistance to corrosion in fresh water, permanence, lap joint, and strength are all important limits imposed on home radiators due to their pressured nature. The dimensions of the component range from 1500 to 2000 mm, while the service temperature falls within the range of 300 to 400 K. The material utilized in the fabrication process consists of mild steel sheets with a thickness ranging from 0.8 to 2 mm. The subject matter pertains to conceptualizing a domestic radiator constructed using three corrugated mild steel sheets. As shown in **Fig. 6 (Esawi and Ashby, 2004),** the graphical user interface for the proposed framework and the program result according to the case inputs, as shown in **Fig. 7**. It was assumed that the quantity produced was very small because there was no information from the researcher about it.

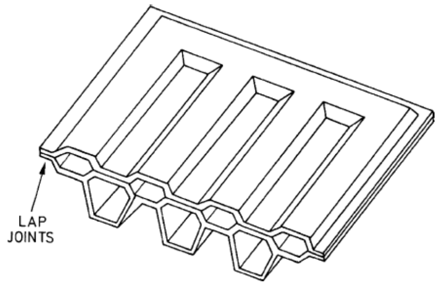

Figure 6. The domestic radiator **(Esawi and Ashby, 2004).**

3.2 Implementation of the Case Study in the Program

To find the welding process for the case study using the specifications given in the **Table 3.** The results of the process proposed in the program are shown in **Fig 7**.

Table 3. A comparison between the results of the researcher and the results of the program

Parameter	Characteristic parameter	The researcher results	The program results
Material type	Carbon steel	RSEM	RSEM
Thickness	0.8 -2 mm	GW	GTAW
Degree of performance	permanent	TB	TB
Joint shape	lap	GTAW	GMAW
		GMAW	GW

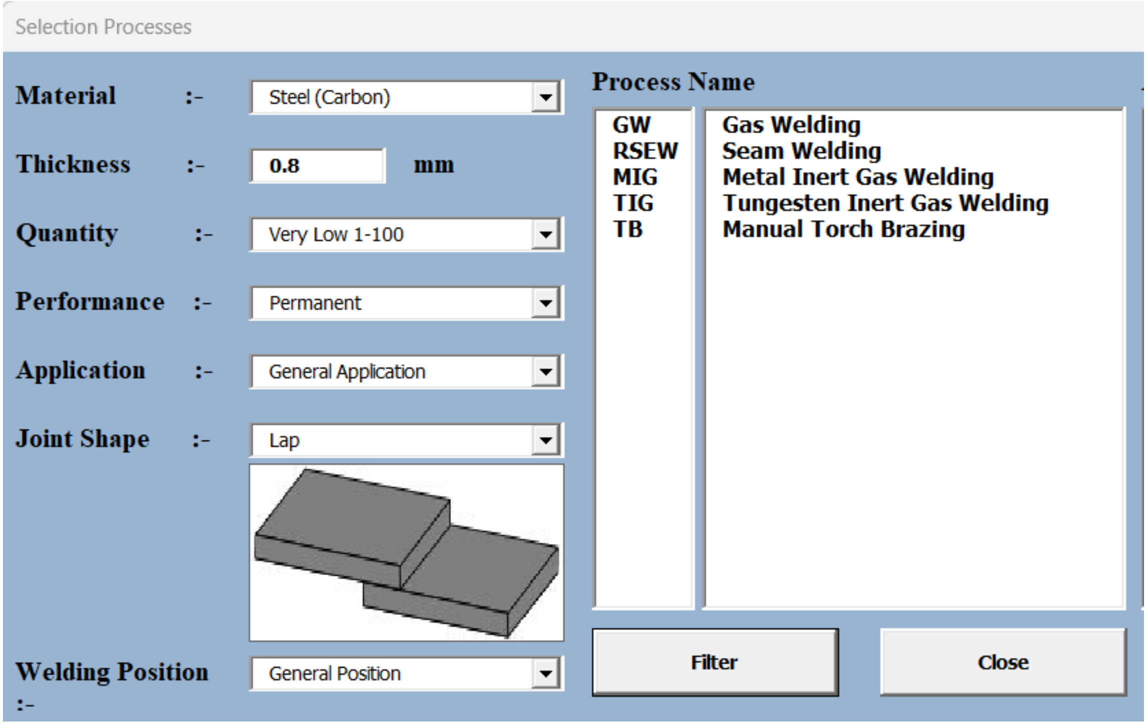

Figure 7. The graphical user interface for the proposed framework

4. RESULTS AND DISCUSSION

After applying the hierarchical analysis process to choose the best method from the proposed processes, it becomes clear to us from the results of the program that there are five permanent welding processes. **Table 4** shows the criteria chosen for the AHP model. AHP matrix, filled by experts and sources, was normalized and averaged to calculate weights for a domestic radiator. The maximum value was 7.575, with a CI of 0.096. The consistency ratio was 0.034, indicating reliability and consistency, with a CR of 0.0728, below 0.1.

Table 4. AHP for Expert's Criteria

Criteria	Weldability	Quality	Accessibility	Flexibility	Productivity	Safety & healthy	Cost	Priority weight
Weldability	1	1	3	3	0.2	0.2	0.2	0.081
Quality	1	1	3	3	0.3	0.3	0.3	0.095
Accessibility	0.3	0.3	1	0.3	0.2	0.2	0.2	0.036
Flexibility	0.3	0.3	3	1	0.2	0.2	0.5	0.063
Productivity	5	3	5	5	1	1	1	0.249
Safety	5	3	5	5	1	1	1	0.249
Cost	5	3	5	2	1	1	1	0.227

Table 5 shows the AHP normalized priority matrix according to several sources **(Jafarian and Vahdat; 2012 Jayant and Dhillon, 2015)**. The AHP built a (7×7) matrix in Microsoft Excel, Facilitating the pair-wise comparison. The AHP matrix considers several characteristics for prioritization, namely (weldability, quality, accessibility, flexibility, productivity, safety, and cost (including equipment and labor costs)). The criteria weights were taken from **(Esawi and Ashby, 2004; Kalpakjian and Schmid, 2014),** as shown in **Table 6**. The eighth column represents the results of solving the steps of the hierarchical analysis method.

Table 5. AHP normalized priority matrix.

Criteria	Weldability	Quality	Accessibility	Flexibility	Productivity	Safety & Healthy	Cost	Priority weight
Weldability	0.0566	0.0857	0.12	0.1551	0.0508	0.0508	0.0472	0.081
Quality	0.0566	0.0857	0.12	0.1551	0.0847	0.0847	0.0787	0.095
Accessibility	0.0188	0.0285	0.04	0.0172	0.0508	0.0508	0.0472	0.036
Flexibility	0.0188	0.0285	0.12	0.0172	0.0508	0.0508	0.1181	0.063
Productivity	0.283	0.2571	0.2	0.2586	0.2542	0.2542	0.2362	0.249
Safety	0.283	0.2571	0.2	0.2586	0.2542	0.2542	0.2362	0.249
Cost	0.283	0.2571	0.2	0.1034	0.2542	0.2542	0.2362	0.227

Table 6. Ranking of Welding Process Selection

The program results	Weldability	Quality	Accessibility	Flexibility	Productivity	Safety	Cost	Priority weight	Rank
RSEM	2	1	1	1	1	1	1	0.9345	1
GMAW	3	2	1	1	2	1	2	0.5465	5
GTAW	1	1	1	1	1	1	3	0.7443	3
GW	2	2	1	1	2	2	2	0.6505	4
TB	1	1	1	1	3	1	1	0.7478	2

The researcher's results appear through practical practice, such as this radiator being resistance seam welded, TIG welded, or brazed at a large production rate. The results of this program using the AHP revealed that RSEW was the optimal welding process, followed by TB, GTAW, GMAW, and GW. RESW is a process utilized in the radiator industry for welding carbon steel **(Al-Mukhtar and Doos, 2013)** and has a high production capacity **(Swift and Booker, 2013)**. TB is a versatile and economical method for short production volumes, easy-to-weld carbon steel, and small fabrication jobs **(Schwartz, 2003; Way et al., 2020).** However, GTAW is used when welding thick sections. One of the advantages of GTAW is that applications for which it is suitable include high-quality welds. No spatter exists because the GTAW post-cleaning is non-existent. After all, no flux is used. Unlike the GMAW process, where filler is used and post-process cleaning is required, GW is considered an economical and versatile process. The use is suitable for production and repair work with low quantities, but it is relatively unsafe and expensive to produce high-quality welds because it requires a skilled worker **(Groover, 2020).**

5. CONCLUSIONS

In this research work, we have developed a program using Visual Basic Access for selecting welding processes, which is very easy to use. The program can choose the type of welding required through several parameters, the most important of which are the thickness, material, type of joint, quantity of the product, and performance, whether permanent or semi-permanent. The reliability of the software has been tested using a published case. It was found that the results of the program matched the results of the researcher**,** which indicates that the program works well using the correct data. Through this process, it is ensured that the system works as the designer intended.
On the other hand, it is the process of reaching an acceptable level of confidence that the inferences drawn are correct and applicable. The program is easy to use and only requires a short time to display the results. The software offers flexibility in choosing a suitable welding process. The user can use the second-order process if the workshop's optimal welding process is unavailable. The research aims to explore the application of artificial intelligence in determining the most suitable joining methods for assembly and welding processes. It also presents suggestions for future research on setting variables to control and lists them for better understanding and improvement.

NOMENCLATURE

Symbol	Description	Symbol	Description
AHP	Analytic Hierarchy Process	PAW	Plasma arc welding
EBW	Electron beam welding	PRIMAs	Process Information Maps
FCAW	Flux-cored arc welding	SAW	Submerged arc welding
GW	Gas welding (oxyacetylene gas welding)	SMAW	Shield metal arc welding
GMAW	Gas metal arc welding	QFD	Quality Function Deployment
MCDM	Multiple criteria decision making	TB	Torch Brazing
GTAW	Gas tungsten arc welding	TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
MIG	Metal inert gas welding		

Credit Authorship Contribution Statement

Alyaa Jalal: Writing-review & editing, Software validation, Methodology.
Qasim Muhammad: Verification case study and Proof reading.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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التحقق من اختيار عمليات اللحام لحالة دراسية باستخدام طريقة التحليل الهرمي

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الخلاصة

تطور هذه الورقة إطار للتمييز بين اختيار عمليات اللحام من خلال استخدام الأنظمة الخبيرة المتخصصة القائمة على المعرفة حيث تعتبر مفيدة بشكل خاص في التعامل مع القضايا التي تتطلب قرارات معقدة، تم انشاء برنامج وبرمجته باستخدام مصفوفة خرائط معلومات العمليات (PRIMAs) في برنامج Visual Basic Access لاختيار أفضل عمليات اللحام في دراسة هذا البحث لموضوع اختيار عملية اللحام المناسبة. يكون البرنامج على مرحلتين يقوم في المرحلة الأولى باستبعاد العمليات غير المرشحة حسب عدة معايير أهمها نوع المعدن وسمكه اما في المرحلة ثانية وهي مرحلة ترتيب العمليات باستخدام طرق متعددة المعايير للقرار التي تستخدم من قبل الباحثين لحل المشكلات المعقدة التي تنطوي على عوامل مختلفة متعددة تم استخدام طريقة التحليل الهرمي. وتعتبر أحد الطرق على أساليب اتخاذ القرار المتعددة المعايير استخداما. يعتمد اختيار معايير (AHP) على الخبرة والمعرفة وليس على بيانات محددة لاختيار البدائل وتحديد الاوزان. المنهجية واضحة وسهلة الفهم وقابلة للتطبيق على مجموعة متنوعة من المجالات التي تتطلب اتخاذ قرارات معقدة. وتمت مقارنة نتائج البرنامج مع نتائج حالة سابقة منشورة لاختيار أفضل عمليات اللحام لحالة دراسية وهي المبرد المنزلي وتم اكتشاف نتائج مطابقة للعمليات المرشحة.

الكلمات المفتاحية : الأنظمة الخبيرة، اختيار عمليات اللحام، اتخاذ القرار المتعدد المعايير، طريقة التحليل الهرمي