THE USE OF ANALYTICAL HIERARCHY PROCESS (AHP) FOR WELDING PROCESS SELECTION DURING RAIL CAR MANUFACTURING

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ABSTRACT

The welding process is a complex manufacturing process, which requires the deployment of multi-criteria decision support system amidst complex and conflicting welding processes, emerging technologies and materials. The Analytical Hierarchy Process (AHP) was employed for the investigation of the most suitable welding process for the assembly of the body shell of the rail car. The process attributes ranked include; crash worthiness, structural integrity, end of life, materials and its cost, welding position and joint orientation, weld quality, thickness of part, rate of material deposition as well as the welding cycle time. The development of the decision support system starts with the development of a conceptual framework that defines the goal, criteria, welding methods as well as their interconnectivity. This was followed by the ranking of sets of alternatives and subsequent comparison by identifying the weights for each criterion while the difference between the alternatives and the ideal solution was determined. The successful completion of this work provided the integration of conceptual and mathematical support system into an organized approach for solving multi criteria decision for the rail car development. This will simplify the decision making process, promote the production effectiveness and enhance overall production cost through the deployment of the best technique.

Keywords: *AHP, Manufacturing, TOPSIS, Welding*

1 INTRODUCTION

The determination of the most appropriate welding technique to be employed for the assembly operation of sub assembly during rail car manufacturing is a critical task, which represents a multi-criteria decision based on the suitability of different types of welding processes as well as their conflicting criteria. The use of manufacturers experience in the selection of welding process without scientific justification based pairwise comparison between the selected process and its alternatives is fast becoming unreliable amidst emerging materials, dynamic production factors and the quest for increased productivity, efficiency and reliability. The combination of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytical Hierarchy Process (AHP) offers a knowledge-based multi-criteria decision support system for the determining the optimum manufacturing process amidst complex and conflicting multiple manufacturing methods, emerging technologies and materials [1-2]. While the AHP is suitable for estimating the weights of the criteria and sub criteria, the TOPSIS can sufficiently rank the alternatives [3-5]. The main criteria however lies in the production of quality and reliable structural welds, which are time and cost effective. The combination of welding process parameters as well as the characteristics of the different welding techniques often influences the structural integrity of the welded components as well as the overall welding time and cost. Commonly used welding processes include; Laser Arc Welding (LAW), Resistance Spot Welding (RSW), Metal Inert Gas (MIG) and Friction Stir Welding (FSW).

The aforementioned welding processes have their merits and demerits, which makes them suitable for some specific areas of application during the assembly operations of the railcar. The use of the knowledge based decision support system evaluates the characteristics of each welding processes as well as the total manufacturing cost with a view of determining the most appropriate process. This assist in striking the right balance between weld quality and cost. For instance, Laser Arc Welding (LAW), combines the merits of the laser method with the gas metal arc using low energy input to bring about welding operation that penetrates deeply between the materials, hence, it is a fast cavity-free welding process that produces welded structure integrity and durability. It is also suitable for joining several materials with different thickness and suitable for welding complex geometry. The limitation being the cost of installation and consumables and the fact that the welding operation often requires expensive and time consuming post welding operations [6-7].

The Friction Stir Welding (FSW) is most suitable for joining aluminum particularly for structures with low weight and high strength requirement. The process is cost effective without the need for expensive and time-consuming post welding operations producing welded structures with good appearance and mechanical properties. The limitations lie in the fact that it is slow, creates cavity-welds and difficult to use for non-linear welds and in joining materials of varying thickness [8-9]. The Metal Inert Gas (MIG) is a versatile, fast, clean and efficient welding process but limited to thin materials and inside operations because it is cumbersome coupled with the fact that it requires a shielding gas to protect the purity of the weld [10-11]. The Resistance Spot Welding (RSW), is safe, fast, efficient, cost effective and can be used to join different materials of varying thickness but if the process is not adequately controlled it can bring about the production of welded structure with poor strength and integrity [12-14].

One of the peculiarities of the AHP and TOPSIS is the fact that it establishes a correlating relationship among the performance goal, criteria, sub criteria and alternatives which enhances the ranking of alternatives and decision-making [15-17]. Furthermore, the relationship can be developed into a predictive model for keeping dynamic goals, alternatives and multi or sub criteria within a realistic forecast. Kumar *et al.* [18] employed the TOPSIS technique for the selection of material for optimal design while Javad and Mohammed [19] used the AHP for the selection of a primary crusher. In addition, Singaravel and Selvaraj [20] employed both the TOPSIS and AHP for the optimization of the machining parameters during a turning operation. The research findings from these works indicate that the TOPSIS and AHP is a suitable decision making tool for ranking and selection of the manufacturing process,

process factors, materials etc. The selection of the most appropriate welding process for the rail car assembly using AHP amidst existing and emerging welding processes is a Multi-Criteria Decision (MCD), which has not been sufficiently reported by the existing literature. Hence, this work provides the application of decision support framework in the quest to explore the prospect of Industry 4.0 for meeting increasing design and service requirements in the rail car industries.

2 METHODOLOGY

The welding operation is one of the methods for the assembly of the pre-assembled parts, which makes up the body shell of the rail car in the manufacturer's machine shop. The materials for the assembly of the machine parts as well as the design and finish requirements of the final assembly determines the type of welding process to be employed. The pre-assembled parts of the rail car include the underframe, body side, under side, end and roof amongst others. Notable among materials used are stainless steel, aluminum and carbon steel. Irrespective of the material used for the fabrication, the quest for a cost effective assembly process that will meet the design, finish and service requirements requires a scientific basis for selection rather than the welder's experience alone. For instance, the use of aluminum for the body side panel boast of low weight and energy conservation but requires the process of Metal Inert Gas (MIG) and Friction Stir Welding (FSW) for the production of joint with high structural integrity. The FSW of the aluminum is suitable for the pre-fabrication of the longitudinal side of the rail car body because the welding process operates below the melting point of aluminium hence it can produces welded parts with excellent mechanical properties and permissible distortion. The criteria for selecting the most suitable welding process include; the cost effectiveness of the process, robust design requirement (safety, structural strength and integrity as well as crashworthiness), end of life (dismantling, recycling, reuse to maximize the value of scrap). To ensure the development of welded part with high structural integrity, the welding process also requires a high level of skill and control. The Analytic Hierarchy Process (AHP) was considered suitable or the selection of the most suitable process for the assembly of the body shell of the railcar because it can interactively combine qualitative and quantitative factors to simplify Multi-Criteria Decision and make consistent judgement via pairwise comparison and ranking of the priorities as well as the criteria. The framework for the development of the Multi-Criteria Decision Model (MCDM) is presented in Figure 1.

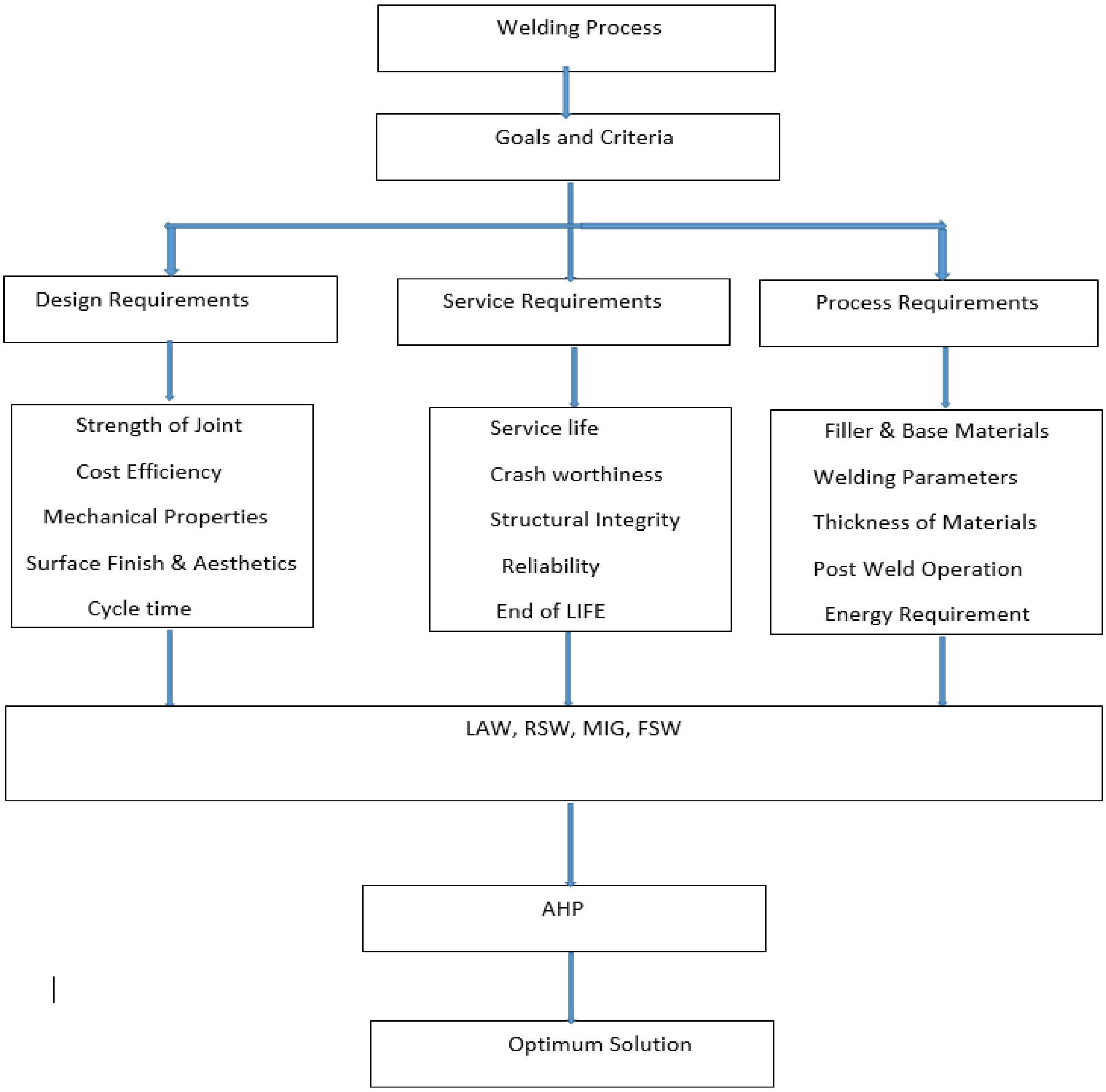

Figure 1: The framework for the development of the Multi-Criteria Decision Model (MCDM)

The Multi-Criteria Decision (MCD) was used for the development of the framework and the two levels AHP. This was followed by the generation of matrix and the pairwise comparisons among the criteria and alternatives based on competing factors. The computation of the values for the Consistency Index (CI), Consistency Ratio (CR) Eigen values and vectors and the Random Consistency Index (CI), assist in the ranking of the priorities as well as the determination of the level of consistency among the criteria and the alternatives. This was followed by the computation of the average and global weights, which forms the basis for the selection of the optimum welding process.

Figure 2 is the two levels of the AHP, which indicates the relationship among the goal, criteria and alternative choices.

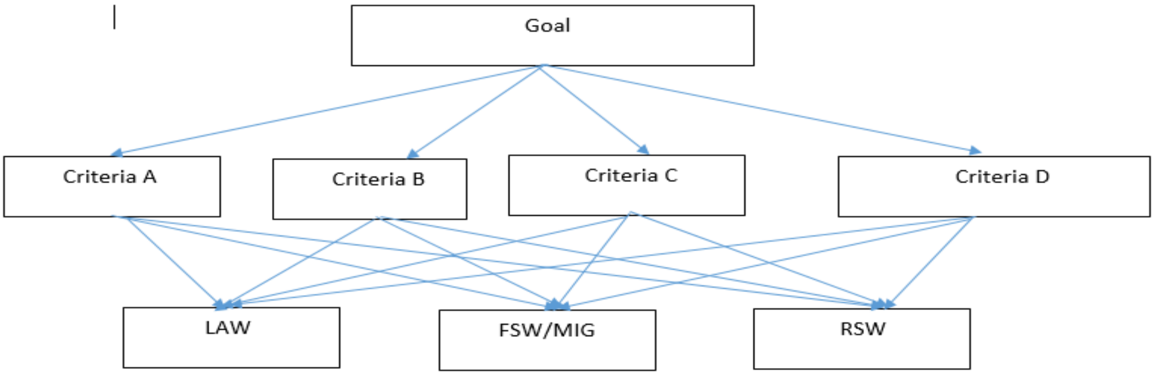

Figure 2: The two levels of the AHP

From Figure 2, the goal represents level zero while criteria 1-4 represent level 1. The different welding processes (LAW, FSW/MIG/RSW) which are the alternatives represent level 2. Level 1 has a 4×4 comparison matrix, which is made up of 3 choices and 4 factors while level 2 has 4 comparison matrix.

The sub-criteria are hidden under the criteria in order to simplify the structure of the hierarchy. The four main criteria in the order of priority and the welding processes considered are as follow;

a. Crash worthiness and structural integrity denoted as Criteria A

b. Surface finish and aesthetics denoted as Criteria B

c. Welding cycle time and operation cost denoted as Criteria C

d. Energy and consumable requirements denoted as Criteria D

e. Laser Arc Welding (LAW) denoted as welding process 1

f. Friction Stir Welding (FSW) and Metal Inert Gas (MIG) denoted as welding process 2

g. Resistance Spot Welding (RSW), denoted as welding process 3

Equation 1 and 2 expresses the Consistency Index (CI) and the Consistency Ratio (CR) respectively.

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

$$CR = \frac{CI}{RI} \quad (2)$$

Where;

λ_{max} is the largest Eigen value, n is the number of criteria and RI is the Random Consistency Index.

The matrix for the calculation of the Eigen values and vectors is as follow;

$$Ax = \lambda x \quad (3)$$

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$$

3. RESULTS AND DISCUSSION

Table 1 shows the paired comparison matrix 1 with respect to the goal. The competing criteria are paired based on their relative importance to the overall goal. The more important pair takes higher value of integer and vice versa.

Table 1: The paired comparison matrix 1 with respect to the criteria

Criteria	A	B	C	D	Priority Vector (%)
A	1.00	5.00	7.00	9.00	46.30
B	0.35	1.00	5.00	7.00	30.90
C	0.33	0.35	0.90	2.00	13.50
D	0.22	0.50	0.24	1.00	9.300
Sum	1.90	6.85	15.40	20.00	100

The Eigen values and vectors presented in Table 2 was used in ranking the criteria in the order of their priorities

Table 2: The Eigen values and vectors for the criteria

x_i/λ_i	λ_1	λ_2	λ_3	λ_4
Eigen value λ	5.472	∞	0.1629	0.1629
Eigen vector x				
x_1	0.4030	1	0.9190	-0.9190
x_2	0.3690	0	-0.1585	0.1585
x_3	0.1350	0	0.2802	-0.2802
x_4	0.0930	0	-0.2271	0.2271

The maximum Eigen value λ_{max} is calculated thus;

$$\lambda_{max} = (0.4630)(1.90) + (0.3090)(6.85) + (0.1350)(15.40) + (0.0930)(20) = 6.920$$

The $CI = 0.97$, $RI = 0.99, CR = 9.83\%$

Since $CR = 9.83\%$ is less than 10%, the level of consistency is said to be high.

Table 3: The paired comparison matrix 2 with respect to the welding processes

Welding Process	1	2	3	Priority Vector (%)
1	1.00	1.00	9.00	57.69
2	1.00	0.90	2.00	34.4
3	0.50	0.24	0.10	7.91
Sum	2.50	2.14	11.10	100

Table 4: The Eigen values and vectors for the welding processes

x_i/λ_i	λ_1	λ_2	λ_3
Eigen value λ	3.659	-1.1184	0.3591
Eigen vector x			
x_1	-0.8637	0.9416	0.471
x_2	-0.4608	-0.2774	0.344
x_3	-0.2039	-0.1908	0.07911

The maximum Eigen value λ_{max} is calculated thus;

$\lambda_{max} = (0.5769)(2.50) + (0.344)(2.14) + (0.07911)(11.10) = 3.056$

The $CI = 0.0281$, $RI = 0.31, CR = 8.94\%$

Since $CR = 8.94\%$ is less than 10%, the level of consistency is said to be high.

Table 5: The paired comparison matrix 3 with respect to the welding processes

Welding Process	1	2	3	Priority Vector (%)
1	1.00	0.35	5.00	10.34
2	5.00	1.00	5.00	69.44
3	3.00	0.35	1.00	20.22
Sum	9.00	1.7	11.00	100

Table 6: The Eigen values and vectors for the welding processes

x_i/λ_i	λ_1	λ_2	λ_3
Eigen value λ	5.6387	-2.856	0.2173
Eigen vector x			
x_1	0.1034	0.7746	0.1019
x_2	0.6944	-0.2527	-0.9933
x_3	0.2022	-0.5797	0.0535

The maximum Eigen value λ_{max} is calculated thus;

$\lambda_{max} = (0.1034)(9.0) + (0.6944)(1.70) + (0.2022)(11) = 4.3352$

The $CI = 0.667$, $RI = 0.88, CR = 7.50\%$

Since $CR = 8.94\%$ is less than 10%, the level of consistency is said to be high.

The adjusted weight for Criteria A, B, C, and D are 0.5997, 0.400, 0.304 and 0.407 respectively. Table 7 shows the average and overall weight computed from the adjusted weight of the criteria for the welding processes.

Table 7: The average and overall weight

Welding Process	Weight	Overall weight
1	38.7326	34.015
2	48.732	51.92
3	13.640	14.065

From Figure 3, the welding process 2, Friction Stir Welding (FSW) and Metal Inert Gas (MIG) is considered most suitable process for the assembly operation of the rail car body with the highest values of the followed by the welding process 1 Laser Arc Welding (LAW) and the Resistance Spot Welding (RSW) which has the lowest values of the average and overall weight. The non-suitability of the RSW is connected with its characteristics of producing low strength thus failing to meet the crash worthiness and structural integrity denoted as Criteria A.

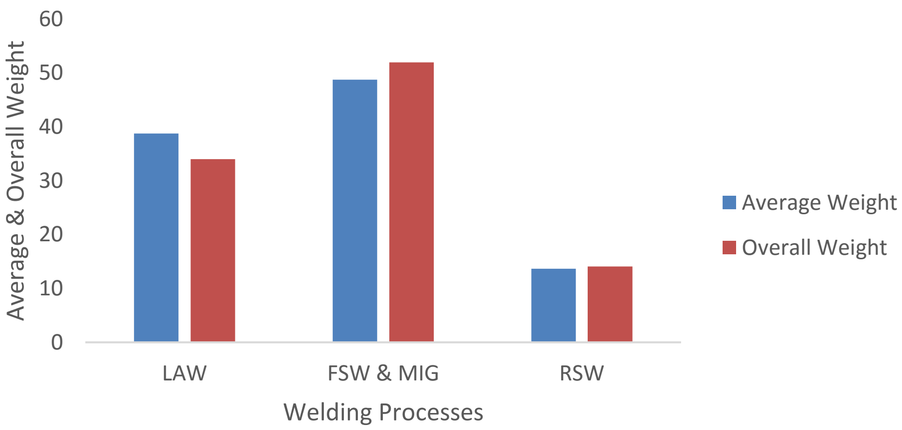

Figure 3: Average and overall weight for the welding processes

3 CONCLUSION

This study presents a scientific based methodology for evaluating and choosing the most suitable welding process for the rail car body shell. Based on the design, service and process requirements, the AHP was employed for structuring the Multi-Criteria Decision problem into hierarchy and ranking of the criteria with respect to the goals and alternatives. The Friction Stir Welding (FSW) and Metal Inert Gas (MIG) welding process was ranked first and considered most suitable for the rail car body shell assembly because of the weld features it presents such as the excellent mechanical properties and good surface finish which is in line with the selection criteria. The work also provides a decision support system as well as a framework for solving Multi-Criteria Decision Problem (MCDP) and sorting out alternatives according to their relative importance to the overall goal during the manufacturing operations of the rail car.

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