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A 5S Lean Strategy for a Sustainable Welding Process

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Abstract: The correct performance of the welding processes used to join metal parts or structural elements is considered to be of vital importance to guarantee the reliability of these products during their useful lives. Adequate workstation design ensures a safe environment in which an operator can perform these processes correctly. In order to guarantee the quality of welding seams, which are used to join metal parts and structural elements, a series of standards have been developed; these standards establish requirements to guarantee the correct performance of welding processes, and the inspection of the metal welds obtained. The 5S methodology has proven to be a valid tool for improving workplaces in industrial and service activities; it is a capstone methodology when companies implement lean production approaches. This work presents a framework for applying the 5S methodology in metal welding workplaces. It defines an index to evaluate the degree of implementation of the 5S methodology, and the application of the important performance analysis methodology (IPA). Fuzzy logic is used to treat the uncertainty in evaluating the different evaluation indicators proposed. This framework is applied to a real practical case, to provide an example of its use in establishing good manufacturing practices that guarantee compliance with the requirements of welding standards, and guaranteeing the correct handling and storage of the materials and tools used in welding processes for the manufacture of welded parts and structural elements.

Keywords: 5S; important performance analysis; welding; metallic structural elements

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1. Introduction

Nowadays, the joining of metal parts and structural elements through welding is widely used in sectors such as railways, shipbuilding, and the automotive and construction industries, among others. The design and development of capital goods, railway rolling stock, ships, motor vehicles, the metallic structures of buildings, and civil constructions requires a collaborative effort between all the personnel of the various technical offices and specialised engineering companies [1].

The scientific literature presents different studies on the electric arc welding process [2–5] but, even with a correct design or a design that is appropriate for the intended purpose of the unit, equipment, or projected structural element, sometimes a series of risks appear during the elements' manufacturing or execution phases, which can potentially result in the production of defective welds; these risks can undermine the reliability of the product during its operation or life cycle, and the most serious potential consequence is the breakage of the welding seams, which can lead to economic losses or the loss of human life. For this reason, a series of specialised standards have emerged in recent years to guarantee the safety and quality of welding seams in metal parts or structural elements manufactured in workshops, production plants, shipyards, etc. ISO 3834 [6], EN 15085 [7], and EN 1090 [8] are examples of specialised standards for metal welding processes for controlling the manufacture of metal products, parts, and structural elements

The risks associated with welding processes can be minimised by correctly applying these standards. To guarantee compliance with these standards, the 5S methodology [9] is recommended; this methodology can be applied in all types of companies, whether in workshops, warehouses, or offices. The 5S methodology aims to improve and maintain the organisation, order, and cleanliness of the workplace. The aim is to improve working conditions by increasing safety through the elimination or mitigation of risks. In our case, the methodology has a dual purpose: improving working conditions by reducing risk for the people involved in manufacturing the products, while at the same time reducing the risk of defective welding seams.

The application of 5S has produced good results in industrial environments [10–13], improving safety [14] and sustainability [15], and in other environments such as stores [16] and education [17]. Randhawa and Ahuja's empirical analysis, which focuses on different aspects such as productivity, quality, safety, the use and visualisation of the workplace, and Kaizen improvements [10], highlights how the application of 5S benefits the general development of the organisation. Their analysis of various studies on the application of 5S concludes that, although it appears simple to apply, in reality it is not. It also shows how 5S and its lean approach are integrated with and related to other quality tools such as TPM, the Kanban system, quality circles, Kaizen, and lean manufacturing, and that mechanisms need to be integrated in order to assess the degree of implementation of 5S [18]. In line with this approach, a systematic methodology is presented to assess the degree of implementation of the 5S methodology, to propose improvement actions, and to quantify the improvement obtained. To this end, we propose using the important performance analysis methodology (IPA) as a tool for determining improvement actions, while applying fuzzy logic to treat evaluation uncertainty. An index is also proposed for measuring the degree to which the 5S methodology has been implemented in the process. The methodology presented in this paper is intended as a framework for applying the 5S methodology in the metal welding process. This work presents a practical case that shows the results of applying this methodology in a real environment.

2. Materials and Methods

The 5S methodology could improve the joining of metal parts and structural elements by means of electric arc welding, following 4 steps (Figure 1). In the first step, a system of indicators is defined for the production process, as well as an evaluation methodology to define both the initial state and the impact of the improvements applied to the production process. In the second step, which is centred on a 5S audit, the current process is evaluated, and proposals are made for improving the workplace. The proposed improvements are implemented in step 3. Finally, in step 4, the impact of the implemented improvement proposals is evaluated.

The first step of this proposed methodology requires knowledge of the indicators used in the scientific literature, as well as those indicators that are more directly related to the welding process. However, the study of the process, and the generation of improvement proposals and their evaluation, require the knowledge of experts. The proposed methodology models the knowledge of the experts, taking into account a certain degree of uncertainty in their assessments, and proposes a general index to evaluate the degree of implementation of the 5S methodology.

It was necessary to apply the proposed methodology in a small company in the metal sector to evaluate its first results.

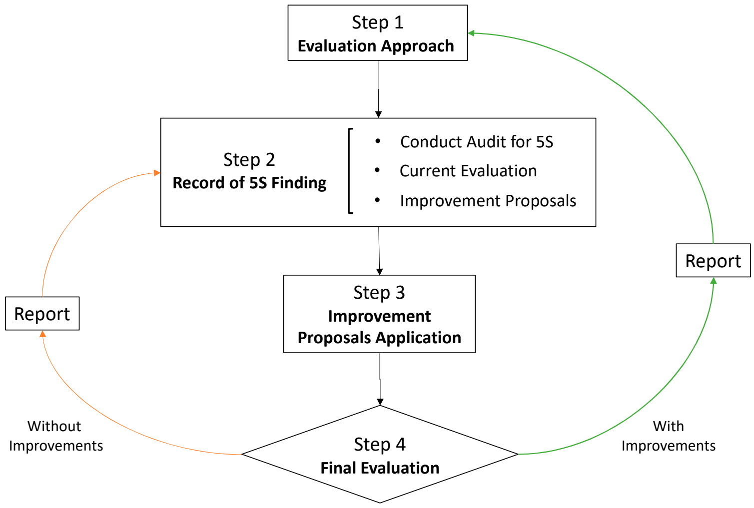


Figure 1. A 5S approach to improve the process of joining structural metal parts using electric arc welding processes.

2.1. *Establishing the 5S Methodology*

In order to improve the organisation of storage areas and the welding process itself, the 5S methodology is used as a tool for continuous improvement. The aim is to reduce the risk of producing defective welds, by increasing the safety, ergonomics, and sustainability of the workplaces where the welding processes are carried out. The 5S Methodology corresponds to the initials of five Japanese words that name each of the five phases of the methodology. These phases are:

- SEIRI—SORT: identify and separate necessary and unnecessary materials, discarding the latter.
- SEITON—SET IN ORDER: establish how the necessary materials should be located and identified so that they can be easily and quickly found, used, and replenished.
- SEISO—SHINE: identify and eliminate sources of dirt, ensuring that all equipment is always in perfect condition.
- SEIKETSUS—STANDARDISE: easily distinguish a normal situation from an abnormal one, by means of simple rules that are visible to all.
- SHITSUKES—SUSTAIN: work in accordance with what has been established in the previous phases at all times.

To implement the 5S methodology, a multidisciplinary working group should be created, comprising each of the organisation's managers. This group will be responsible for ensuring that all of organisation's staff apply the 5S methodology. Once the multidisciplinary working group has been established, both the group in question and the rest of the company's employees must receive training in the application of the 5S methodology.

Once all of the staff have been trained, it is usual to select a pilot area in which the 5S methodology is applied and which can be used to validate the methodology, as well as providing an example of application for the rest of the production and storage areas in the industrial building. An essential work plan should be established to progressively improve all of the work and storage areas.

2.2. *Performance Indicators*

A total of 16 indicators have been defined to evaluate the performance of the process. The choice of indicators takes into account the needs imposed by the ISO 9001 and EN 15085 standards, as well as the five implementation phases of the 5S methodology. There are 2 indicators related to productivity (overall activity and welding activities), 4 related to quality and its associated costs (overall no quality, no quality, no quality cost, and quality cost), 4 related to the impact of the process (total workcells, welding workcells, safety, and ergonomic), 1 indicator related to the cost of implementing improvement proposals (improvement cost) and 5 indices to measure the degree of application of each of the phases of the 5S methodology (1S index, 2S index, 3S index, 4S index and 5S index). All of these indicators are described in Table 1.

Table 1. Indicators defined for the evaluation process.

#	Identifier	Description
1	Overall activity	Total number of work orders completed
2	Welding activities	% of work orders requiring welding per year
3	Overall no quality	Total number of non-conformities per year
4	No quality	Total number of non-conformities originating from welding process
5	No quality cost	Non-quality costs
6	Quality cost	Quality costs
7	Improvement cost	Cost of improvements implemented
8	Total workcells	Total number of jobs affected by improvements
9	Welding labour	Total number of workers in the company affected by the improvements
10	Safety	Degree of safety in the workplace
11	Ergonomic	Degree of ergonomics in the workplace
12	1S index	Degree of implementation 1S: SEIRI—SORT
13	2S index	Degree of implementation 2S: SEITON—SET IN ORDER
14	3S index	Degree of implementation 3S: SEISO—SHINE
15	4S index	Degree of implementation 4S: SEIKETSUS—STANDARDISE
16	5S index	Degree of implementation 5S: SHITSUKE—SUSTAIN

These indicators were considered a basic component of the company's management scorecard, with the company's quality manager responsible for recording the values of the indicators in the scorecard. The non-quality costs indicator refers to the costs associated with repairing non-compliant manufactured products. Also included are the costs associated with transport between the company and its customers for the removal of non-compliant products, and the delivery of repaired or re-manufactured products. The indicator quality costs refer to the costs associated with hiring an engineer for the position of quality manager, the costs of consultancy services, and the purchase and calibration of measuring equipment, as well as the costs of ISO 9001 and EN 15085 system certification. The safety and ergonomics indicators relate to the number of process-related accidents and injuries, as well as the opinion of the operators, and the technical evaluation by the company's engineering department, of working conditions at the workstation.

The indicators corresponding to the indices of each of the 5S methodology phases (1S index to 5S index) are related to the 5S audit methodology proposed by Ho [5], which is based on his checklist [19].

2.3. Evaluation Procedure

Once the working methodology and the performance indicator systems have been defined, a procedure must be established for evaluating the initial process performance, as well as the performance of the process incorporating the proposed improvements. To this end, a double analysis is carried out (Figure 2). Indicators 1 to 11 and the important performance analysis methodology (IPA) [20] were used to classify the process's performance according to the performance of the welding process, and according to the selected indicators and the importance that each of these indicators has for the organisation. The IPA methodology has shown good results for analysing cost saving solutions [21], customer satisfaction [22,23], customer loyalty [24], supplier selection [25], health awareness [26], service quality [27,28], experience of service and products [29,30], and security incident management [31]. The scientific literature shows different approaches to the IPA methodology [32,33] that divide the different fields of the IPA matrix [27,32–36], some of them integrating fuzzy logic [37,38]. In this case, we propose using the approach described by Wyród-Wróbel and Biesok [32], which divides the IPA matrix into 6 distinct zones: keep up the good work, warning, concentrate here, improve, low priority, and possible overkill—leave.

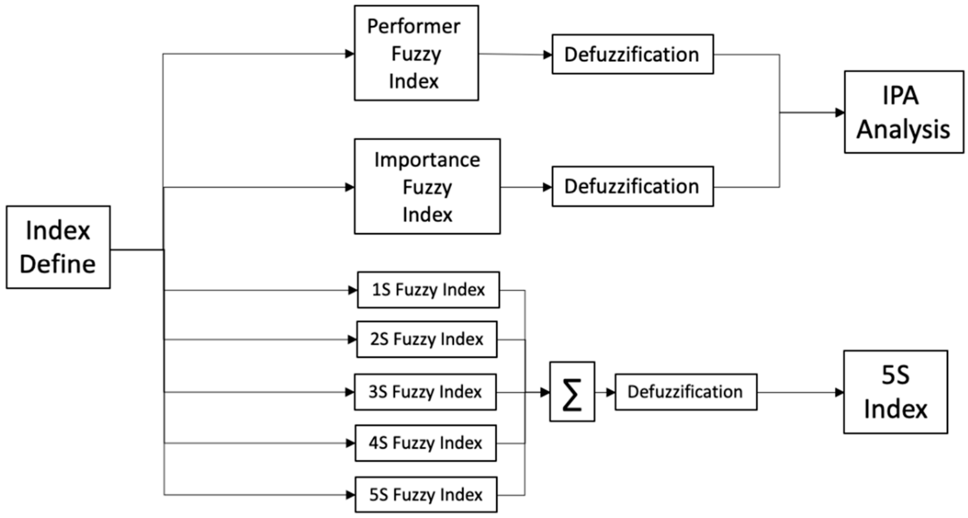
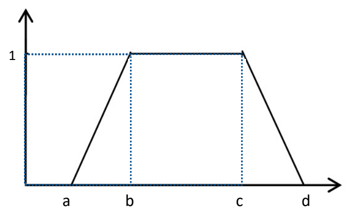


Figure 2. Evaluation procedure and performance indicators.

Fuzzy logic was used to incorporate uncertainty in evaluating the importance of indicators 1 to 12, and in evaluating the process performance according to all indicators described in Table 1. The evaluation was carried out using a 5-level Likert scale with a trapezoidal function associated with each level [39], as shown in Table 2. Fuzzification was performed using the max –min method. Defuzzification was performed using the centre of gravity method [40].

Table 2. Form functions for indicator evaluations.

Type	Parameters	Linguistic Term
	{ a, b, c, d} {3.93, 4.29, 4.75, 5.00}	Very good
	{2.86, 3.21, 3.93, 4.29}	Good
	{1.79, 2.15, 2.86, 3.21]	Fair
	{0.72, 1.07, 1.79, 2.15}	Poor
	{0.00, 0.36, 0.72, 1.07}	Very poor

In this study, a holistic approach was used to evaluate 5S implementation, defining a global index as the arithmetic mean of the values obtained for the 1S to 5S indices. Using the value obtained when calculating this average, Table 3 defines the level of implementation of the 5S methodology and the improvement actions that the process may require.

Table 3. Level of implementation and actions to be taken, according to the value of the global 5S implementation index.

Value	Level	Action
>4.5	Level 5: Very good	Implementation is correct
>3.5–4.5	Level 4: Good	Continue actions to improve implementation in the medium term
>2.5–3.5	Level 3: Fair	Continue actions to improve implementation in the short-term
>1–2.5	Level 2: Poor	Continue implementation improvement actions immediately
0–1	Level 1: Very poor	Implementation is not correct or has not been carried out

3. Results

The proposed methodology was applied in a real case in a small company in the metal sector, dedicated to building metal structures. The main types of metallic materials used are carbon steels, stainless steels, and aluminium alloys, in their different standardised formats, such as sheets and metal sections. The company has a staff of 11 workers, 3 of whom are exclusively dedicated to the arc welding process. The work team consists of three engineers. The indicators were measured by an engineer from the company's quality department (see Value column, Table 4). In total, two engineers from the company's engineering department made proposals for improving and implementing the 5S methodology. All of the indicators were evaluated, applying the methodology described in the previous section, by all members of the work team. The individual scores for each indicator were synthesised using the geometric mean [41].

Table 4. Value of indicators: initial state.

Index	Initial State		
	Value	Evaluation	
		Performance	Importance
Overall productivity	611	1.62	4.57
Welding activities	367	2.30	4.21
Overall no quality	5	0.54	4.01
No quality	Not evaluated	0.21	4.57
No quality cost	Not evaluated	0.10	0.89
Quality cost	Not evaluated	0.10	2.26
Improvement cost	Not evaluated		
Total workcells	3		
Welding labour	3		
Safety	No accidents	3.03	3.74
Ergonomic	No injuries	2.61	3.50

3.1. Initial State

Table 4 shows the indicator values in the initial situation. The indicators were evaluated with respect to their behaviour and importance, according to the methodology described in the previous section. The workstations had not set up a logical ordering of materials, parts, and tools, or a system for the identification and general cleanliness of the workstation resources. Nor was there a single procedure for action among the operators. Although the workplaces did not have the best safety and ergonomic conditions, no accidents or injuries had been recorded in the company. Not all of the quality costs and quality incidents are recorded.

The IPA matrix (Figure 3) shows that the recording of quality-associated costs is an area for improvement; it also recommends that special attention be paid to process safety and ergonomics, and a focus be put on increasing production and activity in welding processes. The evaluation of 5S methodology implementation levels shows insufficient or non-existent use of the 5S methodology in the production process (Table 5).

Table 5. Initial evaluation of the degree of implementation of the 5S methodology.

Index	Initial Evaluation
1S index	1.21
2S index	0.73
3S index	1.24
4S index	1.01
5S index	0.51
Global 5S index	0.94
Action	Level 1

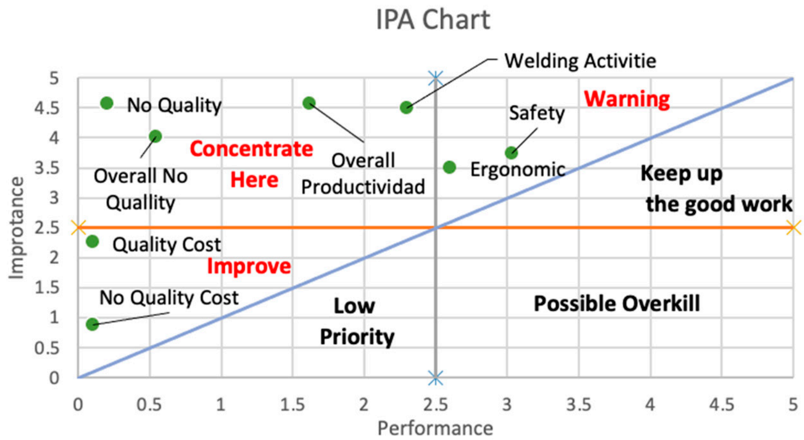


Figure 3. IPA matrix evaluation: initial state.

3.2. Improvement Proposals and 5S Mehtodology Application

Taking into account the results shown in the previous section, the 5S methodology is implemented in the company's welding stations. Following the five phases, in the organisation phase, unnecessary tools and materials will be separated from those that are necessary, eliminating all those materials and tools that are no longer useful. In the order phase, the various workstations and storage areas are organised in the best possible way so as to avoid unnecessary movement and transport, allowing tools and materials to be located quickly. In this phase, tools and all work and storage areas will also be identified using labels, cards, and signs, establishing a colour code that allows tools and materials to be quickly identified. Once the workstations, tools, and storage areas have been organised, the cleaning phase begins, establishing cleaning rules that must be followed by all staff. What is to be cleaned, the frequency of cleaning, who is to clean, and what cleaning resources or materials are to be used, must all be established. To ensure compliance with organisation and cleanliness, the visual control phase is applied by placing charts and photographs that indicate the organisation and cleanliness achieved in each work and storage area, to avoid returning to previous situations in which there was a lack of organisation and cleanliness. To guarantee compliance with the established organisation and cleanliness, this phase must include a periodic 5S audit to guarantee compliance with what has been established in the previous phases, visiting each of the work and storage areas of the industrial building in order to evaluate compliance with the methodology. Finally, the discipline and habit phase will be applied by raising staff awareness, which is a very important requirement to guarantee compliance and the maintenance of the 5S methodology over time.

An improvement sheet has been created to facilitate improvements, which identifies the current situation to be improved, the improvement proposal, and the improvement implemented. Figure 4 shows an example of an improvement sheet (Figure 4).

The proposal is to implement improvements for the storage and handling of products, and for the prevention of contamination during the bending process, as well as for the organisation of the process itself in the welding stations. Table 6 shows objectives and recommendations for the storage and handling of products. These recommendations were developed as shown in Figures 5 and 6.

	IMPROVEMENT DOCUMENT		
	Number: 0919		
Workplace	Workstation 001		
Proposed by		**Date**	
Reviewed by		**Date**	
INITIAL STATE			
IMPROVEMENT PROPOSAL:			
Human Resources			
Technical Resources			
Implantation Leader			
Manager			
Time			
IMPROVEMENT PROPOSAL			
Improvement Cost			
Closed by		**Date**	
Manager		**Date**	

Figure 4. Example of an improvement sheet for applying the 5S methodology.

Table 6. Improvement proposals: objectives and recommendations for the storage and handling of products.

Scope	Objective	Recommendations
Storage and handling of products	• To avoid contamination between different types of materials. • To prevent the risk of contaminating elements during or after manufacturing • To avoid possible contamination of the materials during their storage.	• If there is limited space available, and the carbon steels, stainless steels, and aluminium alloys materials must be stored on the same shelf, they should be grouped by type on each shelf in the following order: aluminium alloys on the top, stainless steels in the middle section, and carbon steels at the bottom (Figure 5). • A colour code shall also be used for each material. Thus, blue will be used for aluminium alloys, yellow for stainless steels, and green for carbon steels. The same colour code must be used to identify work tools, in order to associate the tools with each type of material • Specialised storage facilities must be established for each manufacturing sector, such as rail, shipbuilding, or construction (Figure 5) • All racks and structural elements for the storage of materials, such as metal sheets and profiles, must be protected by a coating of paint • During storage, metal sheets and sections shall be identified with a label or with a copy of the casting certificate; in both cases, the casting number associated with the stored material shall be visible (Figure 6) • Filler materials, such as wire spools or rods, must comply with the requirements of standard EN 13479 with regard to the product's CE marking (Figure 6) • Spools of wire and bundles of rods must be stored in shelves and cabinets at a stable temperature, following the same criteria established for the storage of base materials. Each shelf should identify the type of input material stored (Figure 6)

(**a**)

(**b**)

(**c**)

Figure 5. (**a**) Storage of metal sheets, (**b**) Structure for the storage of metal profiles for railway products, (**c**) Example of identifying hand tools for the manufacture of stainless-steel products with the colour yellow.

(**a**)

(**b**)

(**c**)

(**d**)

Figure 6. (**a**) Casting certificate of a metallic material, (**b**) CE marking of spools of wire, (**c**) Storage of spools of wire, (**d**) Storage of rod packages.

Table 7 shows objectives and recommendations for the manufacturing process. Figures 7–10 show their implementation.

Table 7. Improvement proposals: objectives and recommendations for the manufacturing process.

Scope	Objective	Recommendations
Manufacturing process	• To facilitate the production process by reducing travel times • Prevention of contamination during the bending process	• The semi-finished products are stored on worktables or in containers next to the machines (Figure 7) • Production and storage areas must be identified with corresponding signs (Figure 8) • Bending tools (dies and counter-dies) must be cleaned with acetone and a cloth (Figure 9a) • To place instructions on the press brake with photographs showing the cleaning sequence indicated (Figure 9b) • Parts to be welded must be completely clean and free of impurities, so the welder should clean them with a brush or with a cloth and acetone, depending on the type of material to be welded (Figure 9c) • In the case of welding processes with wire feed as the filler material, the shielding gas must be prepared in advance, regulating the gas flow that will come out of the nozzle of the welding gun. Once the flow has been regulated, the gas can be opened. A test flow meter must be used to check that the gas arrives and leaves the nozzle of the welding gun in sufficient quantities to guarantee the metallurgical protection of the weld bead obtained • The humidity conditions and the ambient temperature must be controlled in order to improve the welding process. The thermometers and hygrometers must be checked at least every three months. In the case of TIG (tungsten inert gas) welding, the sharpness and cleanliness of the tungsten electrode must be checked. The discs used for regrinding materials should be identified according to the material type and stored in separate drawers • In all types of welding processes, the welding mass shall be taken as close as possible to the weld bead. Welders must use a thermal pencil to inspect the pre-heating temperatures and for the welding of welding seams on the base material • Welding stations must be organised to comply with the 5S methodology (Figure 10)

(**a**) (**b**)

Figure 7. (**a**) Storage of products in containers, (**b**) Storage of press brake tools with 5S visual control signage.

(**a**) (**b**) (**c**)

Figure 8. (**a**) Area for welding aluminium alloy materials, (**b**) Storage of materials and auxiliary products for manufacturing and packaging, (**c**) Example of documentation accompanying the product during manufacture.

(**a**)

(**b**) (**c**)

Figure 9. (**a**) Bending tool cleaning sequence, (**b**) Instructions for cleaning the bending tools placed on the press brake, (**c**) Cleaning the workpiece with acetone.

Figure 10. Organisation of the welding station.

3.3. Final Evaluation

Table 8 shows the values and evaluation of the different indicators after implementing the improvements proposed by the 5S methodology. An analysis of the IPA matrix (Figure 11) shows that implementing the proposed improvements raises most of the indicators into the "keep up the good work" zone. The application of the IPA methodology shows that special attention must be paid to recording quality parameters and their costs, as well as to safety conditions and the activity of welding stations.

Table 8. Value of indicators and their evaluation after the proposed improvements following the 5S methodology.

Index	Final State		
	Value	Evaluation	
	Performance	Importance	
Overall productivity	780	4.22	4.57
Welding activities	468	3.90	4.50
Overall no quality	18	0.20	4.01
No quality	3	1.02	4.57
No quality cost	Not evaluated	0.10	0.89
Quality cost	€2800	0.23	2.26
Improvement cost	€2500	2.80	2.83
Total workcells	5	3.50	3.19
Welding labour	3	4.21	4.10
Safety	No accidents	3.50	3.74
Ergonomic	No injuries	3.50	3.50

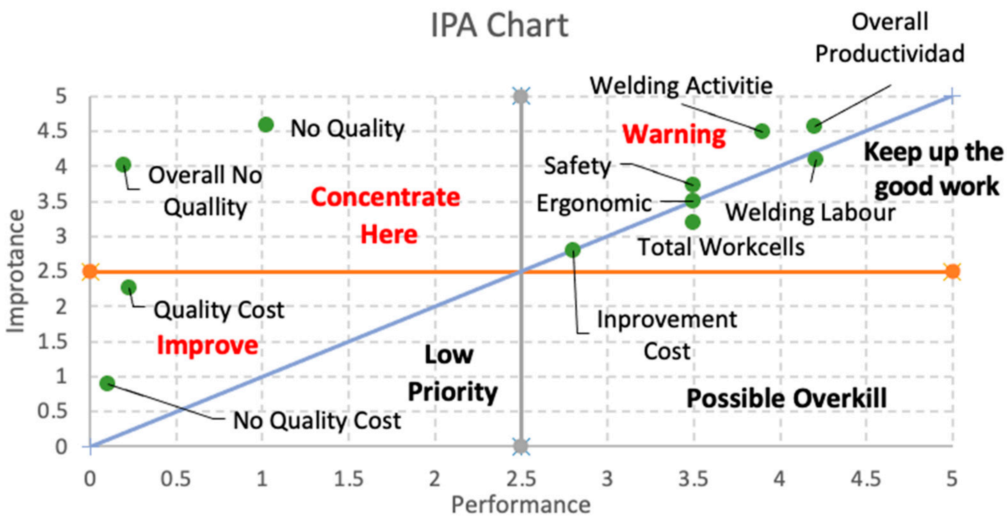


Figure 11. IPA matrix evaluation: final state.

The indicator for the degree of implementation of the 5S methodology after implementing the proposed recommendations shows a level of action in which 5S has been correctly applied in the workplace, suggesting improvements to be made in the medium term (Table 9). The improvements will mainly be aimed at the indicators that are outside the zone marked "keep up the good work" (Figure 11).

Table 9. Final evaluation of the degree of implementation of the 5S methodology.

Index	Final Evaluation
1S index	4.12
2S index	4.22
3S index	3.21
4S index	4.13
5S index	2.12
Global 5S index	3.56
Action	Level 4

4. Discussion

The methodology presented is a systematic approach that can be used to quantify the level of implementation of the 5S methodology, as well as to plan and evaluate improvement proposals in metal welding workplaces. The methodology requires the measurement of various indicators, followed by an evaluation of their performance and importance. These indicators were selected from scientific literature [10,42–45], taking into account the development of processes in metal welding workplaces. The proposed 5S index could be consistent with other metrics and indexes proposed for the evaluation of the 5S methodology in different processes [46,47]. The described approach could be used in industrial process design engineering to evaluate different process improvement alternatives, by using the advantages that simulation tools offer [48,49]

Regarding the results of the practical case, the application of the 5S methodology allowed good manufacturing, storage, and handling practices to be established for the products used in welding processes for manufacturing metal parts and structural elements. The company has managed to prevent possible manufacturing defects, thereby avoiding the risk of weld seam breakage caused by defects and cracks that could have appeared if the 5S methodology had not been followed. The established indicators show an increase in the number of work orders. The percentage of work orders requiring welding processes is the same before and after the proposed improvements were applied. The number of nonconformities increased with respect to its initial level. This is because the non-conformities detected after implementing the 5S methodology had not been initially recorded, as previously there was no habit of doing so. In the final situation, 18 non-conformities were detected across all production orders and, of these, only 3 corresponded to orders involving welding. The company's management considers this figure to be acceptable. Due to this low number of non-conformities considered by the company, it was not deemed necessary to measure the cost of non-conformities. The task of measuring the cost of these non-conformities was entrusted to the company's management, as recommended by the interpretation of the IPA matrix.

The interpretation of the IPA matrix prompted the decision to start measuring quality costs from now on. This action has been extended not only to the welding stations, but to all workstations in the company. Table 8 shows the costs of the improvements implemented in the material store and in the welding stations. The costs of improvements to be implemented in future will become one of the indicators of the company management's scorecard. It is important to note that, in the initial situation, the costs of non-quality caused by non-conformities in the work orders were not known, nor were they measured while the improvements were being implemented. The results of this study have also led the company management to authorise that non-quality costs be measured on a systematic basis. The total number of employees in the production department remained constant during the study period. Of the total of 11 workers, 3 of them were responsible for welding. The number of welding posts has increased from three to five in the current situation, maintaining three posts dedicated to welding carbon steel parts, one post for welding stainless steel parts, and one post for welding aluminium alloy parts. This new organisation has been set up as a result of implementing the 5S methodology. By implementing the improvement proposals, the number of work orders could be increased while maintaining the same number of workstations and the required levels of quality, safety, and ergonomics.

The limitations of the proposed work are related to the selection and evaluation of the proposed indicators. Although fuzzy logic has been used to treat uncertainty in the evaluation of the indicators, these methodologies are limited by the very nature of this approach. The scientific literature shows numerous examples of the use of trapezoidal functions in different applications of fuzzy logic [50–53]. The fuzzy sets of this study are in line with these studies. Although the triangular functions are simpler, the trapezoidal functions allow for the evaluation of each level of the Likert scale in a given closed interval [54,55] (for example, Table 2 shows the interval [3.21, 3.93]) to evaluate the linguistic term "good". Trapezoidal functions could show a correct performance in the definition of the input and output variables of the fuzzy model [56–58]. An expert knowledge approach was used to develop the trapezoidal functions; the use of a data-centric approach is proposed as a future line of study [59]. In addition, this work has not evaluated the degree of consensus among experts regarding the evaluation of these indicators, which, in some cases, could be considered as limiting the results obtained from applying the proposed methodology. It is proposed that, to further develop our approach, this consensus be evaluated in future, following different developments to synthesise the experts' assessments [60].

5. Conclusions

A 5S lean strategy for a sustainable welding process has been developed using the important performance analysis methodology (IPA). Sixteen indicators were selected from the scientific literature, and fuzzy logic was used to consider uncertainty in the evaluation of these proposed indicators. The approach defined a novel index to evaluate the degree of implementation of the 5S methodology, and it can be used by researchers and practitioners in the application of the 5S lean methodology. The results could open research lines in relation to the definition of the proposed fuzzy model and its incorporation as a tool to analyse alternatives in process simulation methodologies.

The results of the case study show that the methodological framework presented in this work can be useful for applying the 5S methodology, and allowing good working practices to be guaranteed in the welding of metal structural parts and elements. The 5S methodology is an effective tool for improving working conditions, preventing manufacturing risks, and guaranteeing compliance with the welding standards ISO 3834, EN 15085, and EN 1090.

The systematic methodology presented here can be applied to workshops and companies in which welding processes are carried out on parts and structural metal elements made of aluminium alloys, stainless steels, and carbon steels. These alloys are the main materials used in the application of the aforementioned standards. Moreover, the proposed methodology could be adapted for other industrial process.

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