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An Integrated Approach for Welding Process Selection

أسلوب تكاملي لاختيار عملية اللحام

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Welding process, FUZZY-AHP, FUZZY-TOPSIS, MCDM

الملخص العربي:- **هذا البحث يقدم ويستعرض بحالة دراسية إطار داعم ثنائي الطور لاتخاذ القرار في اختيار نوع عملية اللحام من بين أي عدد من العمليات المقترحة لغرض محدد وتحت ظروف محددة. يقوم الطور الأول باستبعاد العمليات الغير متوافقة تماماً مع التطبيق المطلوب على أساس فئة محددة من المعايير. وبعد ذلك يقوم الطور الثاني باختيار عملية اللحام الأنسب للتطبيق من بين العمليات المتبقية على أساس فئة أخرى مكملة للمعايير. والطور الثاني يدمج طريقتين، الأولي (FUZZY-AHP) والتي تقوم بزنة معايير الاختيار طبقاً للهدف، وتقوم الطريقة التالية (FUZZY-TOPSIS) بترتيب أفضلية عمليات اللحام وتقرر الأنسب من بينهم. ويتضح أن الإطار المقترح يغطي مدي أوسع من المعايير التطبيقية لعمليات للحام وبمرونة وطواعية أكثر. ولذلك فان الإطار المقترح يمكنه بسهولة تناول المشكلات الأكثر تعقيداً لاختيار عمليات اللحام في الصناعة.**

***Abstract*— A two-phase decision support framework is presented and experimented with a case study to find the level of preference of any number of welding processes under a variety of welding circumstances. First phase fathoms unapplied/inappropriate welding processes based on a set of exclusion criteria. Second phase decides the best welding process amongst those remaining according to a set of selection criteria. The second phase is an integration of two methods, FUZZY-AHP which weights the selection criteria with the goal, and FUZZY-TOPSIS which ranks such criteria and gets most suitable welding process. The proposed framework covers a wider range of practical welding criteria with more flexibility and amenability; thus, making it possible to be simply applied in the complex industrial problem.**

NOMENCLATURE

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AHP	Analytic Hierarch Process	IS	Induction soldering
BCW	Butt cold welding	LBW	Laser beam welding
BZW	Braze welding	L-MIG	Laser metal inert gas
CD-SW	Capacitor discharge stud welding	MAG	Metal active gas
CEXW	Co-extrusion welding	MCDM	Multi criteria decision making
DB	Dip brazing	MIG	Metal Inert gas
DCW	Drawing cold welding	MMAW	Manual metal arc welding
DFB	Diffusion brazing	PAW	Plasma arc welding
DFS	Diffusion soldering	PE-TIG	Penetration enhanced
DFW	Diffusion welding	P-MIG	Plasma metal inert gas
DS	Dip soldering	RB	Resistance brazing
EBW	Electron beam welding	RLW	Roll welding
EBW-NV	Electron beam welding-non-vacuum	RPW	Resistance projection welding
EBW-V	Electron beam welding-vacuum	RS	Resistance soldering
EGW	Electro gas welding	RSEW	Resistance seam welding
ESW	Electro slag welding	RSW	Resistance spot welding
EXW	Explosive welding	SAW	Submerged arc welding
FB	Furnace brazing	SMAW	Shielded metal arc welding
FCAW-G	Flux cored arc welding-gas	SW	Stud welding
FCAW-S	Flux cored arc welding-shielded	TB	Torch brazing
FGW	Forge welding	THW	Thermite welding
FRW	Friction welding	TIG	Tungsten inert gas
FS	Furnace soldering	TOPSIS	Technique for Order Preference by

			Similarity to Ideal Solution
FSW	Friction stir welding	TS	Torch soldering
FW	Flash welding	USW	Upset welding
GTAW	Gas tungsten arc welding	UV	Ultra violet
GW	Gas welding	UW	Upset welding
HFW	High frequency welding	ICW	Indentation cold welding
IB	Induction brazing		

I. INTRODUCTION

Welding is a manufacturing process used to produce an assembly or structure from parts or structural elements. There are more than 40 known welding methods applied in industry. Welding method selection depends on the manufacturing engineers experience when they are dealing with applications that they are familiar considering a few factors, mostly the discontinuity (an element of quality) and cost which may be insufficient while there will be many welding methods equally fulfill the required product [1, 2]. Therefore, specific systems should be developed for helping engineers in welding method selection depending on knowledge bases that contain all problem factors.

As the welding processes are alternatives and the welding factors are criteria, the problem becomes a multi-criteria decision-making problem. Thus, MCDM methods such as TOPSIS, AHP and their FUZZY versions become relevant as seen later in this paper.

There are a lot of work done to solve this selection problem such as Darwish et al. [1] who developed a knowledge-based system for determining the most suitable welding method for a given circumstances and they experimented 30 welding methods. Their system includes the factors of product type, material type, and material thickness, method of use, quality level, joint type and welding position. Their system needs to prescreen to the welding methods. Brown et al. [3] introduced a methodology for determining the most suitable joining technology where the methodology is intended to highlight candidate processes that are capable of joining under given conditions; where the selection methodology depends on criteria like joint function (load type and strength), joint technical information (joint configuration and material type), joint spatial information (material thickness and size) and economic factors (production volume and skill required). These criteria are stored in database and implemented in software. Such systems merely introduce candidate welding methods without robust selection.

More robust selection systems were introduced such as Esawi and Ashby [4] who described a methodology for joining method selection implemented in a software; where a search engine isolates the processes that meet design requirements of material, joint geometry and loading where the information about joining processes with respect to each criteria are stored in a database. After getting the isolated processes they are ranked according to relative equipment cost or by production rate; that is more relevant.

There are other methodologies that select among a given number of welding processes for a given application/situation. Jafarian and Vahdat [5] described a knowledge-base-system for determining most suitable welding method for a given circumstances. They used nine important welding processes considering the criteria of operator factor, alloy class, material thickness, capital cost, deposition rate, design application, joint configuration, welding position, equipment portability and filler metal utilization. In this methodology a FUZZY-AHP-TOPSIS method was used to compare between welding methods. This system indicated that GTAW, PAW and EBW are the most suitable welding methods for high pressure vessel. Capraz et al. [6] used AHP and TOPSIS to select a welding method for welding plain carbon stainless steel storage tank. AHP is used to get criteria weights according to experts' opinion and TOPSIS is used for ranking the welding processes. They applied to MMAW, MIG, MAG, GTAW and SAW welding processes.

The remaining of this paper is organized as follows. The welding processes those implemented here are stated in §II. The proposed framework is described and demonstrated in §III. Concluding remarks are presented in §IV. The paper also contains an Appendix.

II. WELDING PROCESSES

A group of 49 welding processes are considered in this study classified as follows based on the source/cause of coalescence between the welded parts.

- *Pressure Welding Processes*
- *Fusion welding processes*

RSW, RSEW, RPW, HFW, FW, SW, CD-SW.

- *Non-fusion welding processes*

UW, DFW, RLW, EXW, ICW, BCW, DCW, CEXW, FGW, FSW, FRW, USW.

- *Non-pressure Welding Processes*
- *Homogenous welding processes*

SMAW, MIG, FCAW-G, FCAW-S, PE-TIG, TIG, SAW, P-MIG, L-MIG, PAW, EGW, ESW, EBW-V, EBW-NV, LBW, GW.

- *Heterogeneous welding processes*

TB, DFB, DB, FB, IB, RB, BZW, TS, DFS, DS, FS, IS, RS and THW.

III. SELECTION FRAMEWORK FOR WELDING PROCESS

The proposed framework as explored clearly in Fig. 1 comprises two phases — *exclusion phase* and *selection* phase.

A. Exclusion Phase

This phase identifies the ***functional candidate*** group of welding processes amongst those submitted first and fathoms the other processes. Thus, the given welding processes are reduced to those meet working circumstances of *nine factors* including are maximum and minimum welded part volume, material type, maximum and minimum joint thickness, production volume, weld position, joint type, applicable joint configuration, weld place, and possible applications.

B. Selection Phase

In this phase, the welding processes that meet the given nine factors are ranked using FUZZY-TOPSIS method based on only *seven factors* those are welding equipment cost, operator factor, maintenance complexity of welding equipment due to machine structure, surface finish, process preparation, health & safety, and weld discontinuity free.

The MCDM problem necessarily weights/ranks the inherent criteria. Here, FUZZY-AHP method is used for criteria weighting assisted by decision engineer opinions and other information. These weights move to FUZZY-TOPSIS method to decide the preferable welding process.

This framework is programmed in MATLAB environment and it can be introduced as a software for users with such *graphical user interface* that shown in Fig. 2. The user only feeds the information displayed on the shown interface. For each factor the user selects from a pop-up-menu.

The program is constructed to display the most preferable welding processes on solution screen cell while other results are stored internally. First, the user manually inputs the information about relative importance (pairwise comparison matrix) of the seven selection criteria in *criteria weights determination* panel based on AHP Saaty's scale {1/9, 1/8, ..., 1/2; 1, 2, ..., 9}. Other information are also manually inputted following the instructions on the interface.

The necessary information of available welding processes should be collected, arranged, and set as those data samples displayed in the Appendix. This information represents the handmaiden for constructing the built-in database.

The relationships of the welding processes with welding factors are organized from four sources, textbooks, papers, and the websites of international welding companies and the companies that use welding in EGYPT [7]. Refer to Tables 1-11 in Appendix. Tables 2-8 are collected aided with references [8-18]; Table 10 with references [2, 9, 16]; Table 11 with references [7, 9, 10, 12-15, 18-23]. In addition, Tables 9 and 11 are based on Table 1.

The program is applied to a real case having circumstances as welding low carbon steel, butt joint, vertical position, tube to tube configuration, 50 pieces, plumbing application, in site welding, 10 mm thickness and volume 0.07m^3. Table 12 in Appendix is the pairwise comparison matrix of this case. This matrix and other information are fed manually as shown in Fig. 2. The best welding process for this case is found TB (Torch Brazing) process followed by TIG and SMAW processes as recorded in Appendix, Table 13, which is found very near to the reality as appear from linguistic values of the seven selection criteria.

IV. Conclusions

This paper introduces a flexible and amenable decision framework for ***welding process selection*** avoiding several shortcomings of others. It filters the submitted processes twice through a sequence of two sets of robust criteria including new ones such as health & safety and system maintenance. This is actuated with an integrated powerful decision-making engine. Thus, it can ensure the right decision of differentiating a wider range of industrial processes whatever the complexity of products and welding processes including recent situations.

Furthermore, this framework can easily accommodate other criteria and evaluation functions since it becomes an inception for portable software.

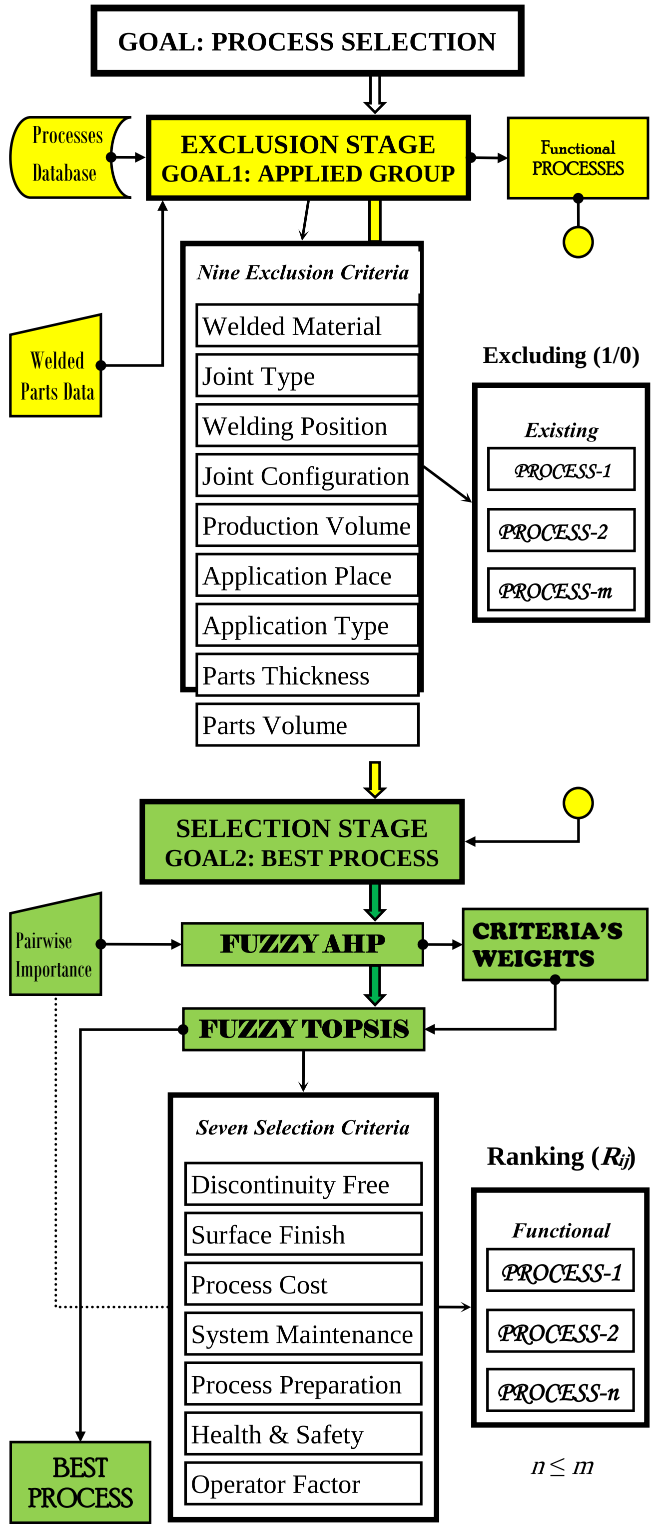

Fig. 1. Proposed framework for welding process selection.

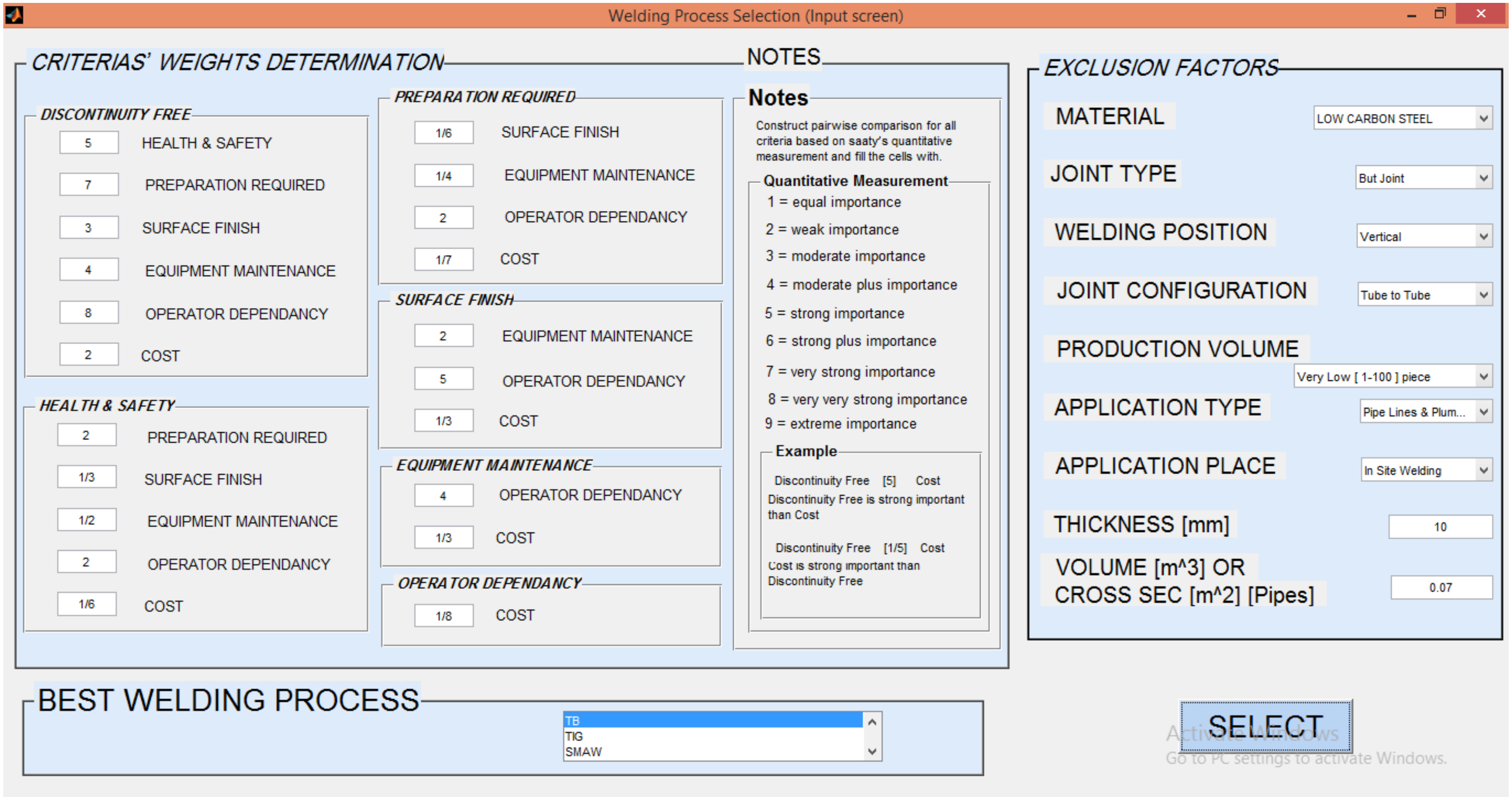

Fig. 2. The interface of the constructed program with input data of the case study.

Appendix

TABLE 1
SOME GUIDING WELDING COMPANIES.

NO.	Company	Information
1	Lincoln Electric	Equipment cost & maintenance
2	The Monty	Equipment cost & welded parts volume
3	Nelson Stud Welding	Equipment cost
4	SCIAKY INC	Equipment cost & maintenance
5	EPB Ltd.	Equipment cost
6	USA Weld	Equipment cost
7	The Welders Warehouse	Equipment cost
8	Image Industries	Equipment maintenance
9	The Fabricator	Equipment maintenance
10	Modern Welding	Equipment maintenance
11	Government of South Australia	Equipment maintenance
12	Property Maintenance (Job Insider)	Equipment maintenance
13	DBG	Equipment maintenance
14	OKUMA	Equipment maintenance
15	MTI Manufacturing Technology Inc.	Equipment maintenance
16	T.J. Snow	Welded parts volume
17	Alumbra	Welded parts volume
18	Culaser	Welded parts volume
19	TWI	Welded parts volume
20	RV Machine Tools	Welded parts volume
21	Pressure Welding Machines	Welded parts volume
22	Nabertherm	Welded parts volume
23	SOHO	Welded parts volume
24	Wincoo Machine	Equipment cost
25	NBXIN Chang	Equipment cost & welded parts volume
26	KIAIND	Equipment cost & welded parts volume
27	MORAN	Equipment cost
28	FS Welder	Equipment cost & welded parts volume

TABLE 2
MATERIALS THAT CAN BE WELDED BY SAMPLE PROCESSES.

PROCESS	Low Carbon Steel	Mild Steel	Medium Carbon Steel	High Carbon Steel
SMAW	Yes	Yes	Yes	Yes
MIG	Yes	Yes	Yes	Yes
FCAW-G	No	Yes	No	No
FCAW-S	No	Yes	No	No
PE-TIG	Yes	Yes	Yes	Yes
TIG	Yes	Yes	Yes	Yes

TABLE 3
MAXIMUM AND MINIMUM PART THICKNESS FOR SAMPLE PROCESSES.

PROCESS	Minimum Thickness (mm)	Maximum Thickness (mm)
SMAW	1.6	38
MIG	0.5	80
FCAW-G	1.5	12
FCAW-S	1.5	12
PE-TIG	0.2	30
TIG	0.2	10

TABLE 4
APPLICABILITY OF SAMPLE PROCESSES TO SOME JOINTS.

PROCESS	Butt Joint	Corner Joint	T Joint	Lap Joint	Edge Joint
SMAW	Yes	Yes	Yes	Yes	Yes
MIG	Yes	Yes	Yes	Yes	Yes
FCAW-G	Yes	Yes	Yes	Yes	Yes
FCAW-S	Yes	Yes	Yes	Yes	Yes
PE-TIG	Yes	Yes	Yes	Yes	Yes
TIG	Yes	Yes	Yes	Yes	Yes

TABLE 5
APPLICABILITY OF SAMPLE PROCESSES TO WELD POSITIONS.

PROCESS	Flat	Horizontal (2G)	Horizontal (2F)	Vertical	Overhead
SMAW	Yes	No	Yes	Yes	Yes
MIG	Yes	No	No	No	No
FCAW-G	Yes	No	Yes	Yes	Yes
FCAW-S	Yes	No	No	Yes	Yes
PE-TIG	No	No	Yes	No	Yes
TIG	No	No	No	No	Yes

TABLE 6
APPLICABILITY OF SAMPLE PROCESSES TO PART CONFIGURATIONS.

PROCESS	Plate to Plate	Bar to Bar	Bar to Tube	Bar to Plate	Tube to Tube	Tube to Plate
SMAW	Yes	Yes	Yes	Yes	Yes	Yes
MIG	Yes	No	Yes	Yes	Yes	Yes
FCAW-G	Yes	No	Yes	Yes	Yes	Yes
FCAW-S	Yes	No	Yes	Yes	Yes	Yes
PE-TIG	Yes	No	Yes	No	Yes	Yes
TIG	Yes	Yes	Yes	Yes	Yes	Yes

TABLE 7
APPLICATIONS OF SOME PROCESSES.

PROCESS	Ship Construction	Bridge Construction	Pressure Vessels	Heavy Machinery	Pipelines/ Plumbing
SMAW	Yes	No	Yes	Yes	Yes
MIG	Yes	No	No	No	No
FCAW-G	Yes	No	Yes	Yes	Yes
FCAW-S	Yes	No	No	Yes	Yes
PE-TIG	No	No	Yes	No	Yes
TIG	No	No	No	No	Yes

TABLE 8
APPLICABILITY OF SAMPLE PROCESSES TO SOME PLACES.

PROCESS	In Site	Movable Parts	Continuous Welding
SMAW	Yes	Yes	No
MIG	Yes	Yes	Yes
FCAW-G	Yes	Yes	Yes
FCAW-S	Yes	Yes	Yes
PE-TIG	Yes	Yes	Yes
TIG	Yes	Yes	Yes

TABLE 9
MAXIMUM PART VOLUME/SECTION AREA FOR SAMPLE PROCESSES.

PROCESS	VOLUME/AREA (M3 OR M2)
RPW	0.52272
HFW	5.76
FW	0.1
UW	0.001024
DFW	550.3992324
RLW	8.55
EXW	66
ICW	0.00189
BCW	0.0009

TABLE 10

PRODUCTION VOLUME FOR SAMPLE PROCESSES.

PROCESS	Very Low	Low	Medium	High	Very High
SMAW	Yes	Yes	No	No	No
MIG	No	No	Yes	Yes	No
FCAW-G	No	No	Yes	Yes	No
FCAW-S	No	No	Yes	Yes	No
PE-TIG	No	No	Yes	No	No
TIG	Yes	Yes	No	No	No

TABLE 11

SAMPLE PROCESSES WEIGHTED RELATIVE TO THE SELECTION CRITERIA.

PROCESS	System Cost	Operator Factor	System Maintenance	Surface Finish	Preparation	Health & Safety	Discontinuity Free
SMAW	V. Low	V. High	V. Low	Med.	Med.	V. High	V. Low
MIG	Low	High	High	High	High	V. High	Low
FCAW-G	Low	High	High	High	High	High	Low
FCAW-S	Low	High	Med.	High	Med.	High	Low
PE-TIG	V. Low	Low	Med.	V. High	High	V. High	Low
TIG	V. Low	V. High	Med.	V. High	High	V. High	Low

TABLE 12

PAIRWISE COMPARISON MATRIX OF SELECTION CRITERIA FOR THE CASE.

CRITERIA	System Cost	Operator Factor	System Maintenance	Surface Finish	Preparation	Health & Safety	Discontinuity Free
Equipment Cost	1	8	3	3	7	8	1/2
Operator Factor	1/8	1	1/4	1/5	1/2	1/2	1/8
Maintenance	1/3	4	1	1/2	4	2	1/4
Surface Finish	1/3	5	2	1	6	3	1/3
Preparation	1/7	2	1/4	1/6	1	1/2	1/7
Health & Safety	1/8	2	1/2	1/3	2	1	1/5
Discontinuity Free	2	8	4	3	7	5	1

TABLE 13

THE FIRST THREE PREFERABLE PROCESSES FOR THE CASE APPLICATION.

PROCESSE PRIORITY	System Cost	Operator Factor	System Maintenance	Surface Finish	Preparation	Health & Safety	Discontinuity Free
1. TB	V. Low	Med.	Low	High	V. High	V. High	High
2. TIG	V. Low	V. High	Med.	V. High	High	V. High	Low
3. SMAW	V. Low	V. High	V. Low	Med.	Med.	V. High	V. Low

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