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EVALUATION OF PIPE CUTTING TECHNOLOGIES IN SHIPBUILDING

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Summary

Pipes are the most significant ones of the components which constitutes the vessel body. Pipes are fabricated in piping plant at shipyard and exposed to some processes such as cutting, bending, hydrostatic tests, galvanizing and so on. Cutting operation is also vital process among the other ones since it is very crucial that the cutting surfaces are flat and the right angles. In shipyards, there are various pipe cutting methods such as plasma, oxygen, metal saw, band saw and abrasive cutting wheel. Shipyard production department desires to implement the most appropriate pipe cutting method in order to operate properly and effectively. The purpose of this study is to present the most convenient pipe cutting method according to the determined criteria. For this, fuzzy TOPSIS technique which is one of the most used fuzzy Multiple Criteria Decision Making (MCDM) methods in the literature is employed. The importance degrees of the criteria are evaluated by using fuzzy AHP. As a result of the presented study, the most appropriate pipe cutting method is determined for ship building industry.

Key words: *Pipe cutting, Fuzzy TOPSIS, Fuzzy AHP, MCDM, shipbuilding*

1. Introduction

In shipbuilding process, there are lots of cutting operations. However, quality and operation time are the most significant performance factor for cutting operations Therefore, it is a significant issue to select the best pipe cutting method since there is a tough competition environment in shipbuilding. Determining the most appropriate pipe cutting technique presents to fulfil cutting operation at highest efficiency for shipyards. Hence, this makes shipyards more competitive against their competitors.

Pipes and pipe systems are the ones of the significant components in ship fabrication. In ship production process, pipes undergo various operations such as cutting, flanging, hydrostatic tests, welding and so on. Furthermore, cutting operation is one of the major pipe processes in all. The pipes used in vessel body are mostly carbon steel and the shape of the cut is the straight cut. When pipes are exposed to cutting operation, a number of specificdimensioned pipe pieces are fabricated. Then, pipe systems are manufactured by mounting pipe pieces each other. It is necessary to achieve the smooth surfaces and right welding grooves after cutting operation so that the welding operation can be performed without any defect. If cutting surfaces and welding grooves are in undesired way, mounting process is not able to carry out properly. It means that re-work operation which is so bad in terms of costs and efficiency is required. Therefore, in the scope of this paper, pipe cutting techniques such as plasma, oxygen, metal saw, band saw, and abrasive cutting wheel used in shipbuilding industry are evaluated under the multiple and conflicting criteria in order to determine the most appropriate pipe cutting technique. In the presented study, an integrated multiple criteria decision making method including fuzzy analytic hierarchy process (AHP) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) techniques is used for the evaluation. While fuzzy AHP is used to determine importance degrees of the criteria, TOPSIS is used to rank the cutting technologies from the best to worst.

The rest of this paper is organized as follows; in Section 2, a brief explanation for cutting technologies is given. In Section 3 and Section 4, the method and its application are presented, respectively. Finally, concluding remarks are given in Section 5.

2. Cutting Technologies

In this section a brief explanation on cutting technologies is given.

2.1 Plasma cutting method

In plasma cutting process, cutting operation is carried out with plasma that is regarded as fourth condition of material. Plasma is achieved by inserting energy into the gas which is passing through torch. Today, plasma cutting method is widely used in many industries. This method has some advantages such as qualified cutting surface and less operation time. Cutting operation with plasma is frequently performed by means of CNC (computer numeric control) cutting machines. Pipes are fixed on machine and also levelled. Then, the cutting angle of torch is arranged and the pipe together with clamping mechanism begins to rotate. Meanwhile, torch cuts the pipes with plasma.

2.2 Oxy-fuel cutting method

Oxygen cutting is the most frequently employed cutting method in shipbuilding. Metal is cut by burning with pure oxygen gas jet. In this cutting operation, a chemical reaction between oxygen and metal occurs at a high temperature, which is called as exothermic reaction. This reaction releases excess energy through heat and light. In order to apply this method, the metal is required to be able to burn with oxygen.

2.3 Metal saw cutting method

Metal saw cutting operation is carried out with a circular metal saw and the pipes are cut with it. It has a collection bin to prevent metal pieces from getting into the machine.

2.4 Band saw cutting method

In band saw cutting technique, the cutting operation is carried out with saw. Here, saw tooth is removed pieces from pipe surface and by means of that, the cutting operation is performed. While band saw is moving one way, it can move two ways and vibrate according to machine’s features. Band saw material must be sharper than the pipe material to be cut.

2.5 Abrasive cutting method

Abrasive cutting wheel is a circular disk which contains abrasive materials. The circular disk is rotated by an engine in order to perform the pipe cutting operation. Abrasive cutting wheel technique can do the cutting operation faster than band saw, and it also presents more flat cutting surfaces than the others [1].

In literature, there are a few studies concerning cutting techniques. Perzel et al [2] specified the advantages and deficiencies of water jet, plasma, laser and oxygen cutting methods and compare each other according to some criteria to provide initial technical and economic information. Olsen [3] compared conventional laser cutting technique with special ray-patterned laser cutting method. McCormick [4] investigated laser, plasma, electrical discharge machining and water jet cutting technologies and compared water jet cutting with other methods with technical point of view. Yazicioglu and Yalcinkaya [5] acquainted about water jet cutting technique and compare with flame, punch press, laser, plasma and wire electro discharge machining cutting techniques technical point of view. Carlson [6] gave information about the appropriate metal saw selection. Hypertherm Inc. [7] mentioned about oxygen, plasma, laser cutting techniques in terms of various parameters. Zheng et al [8] compared laser and water jet cutting methods in terms of quality and cost. Tozan [9] implemented Fuzzy AHP in order to select appropriate water jet cutting technologies. Temuçin [10], in his master thesis, developed a decision support software and proposed a model to determine the best cutting technique to cut AISI 309 stainless steel material. This software includes ELECTRE, TOPSIS, PROMETHEE, Fuzzy ELECTRE and fuzzy TOPSIS methods. Eleren and Ersoy [11] have applied Fuzzy TOPSIS method to evaluate alternative cutting methods that used for marble cutting process. In this study, fuzzy TOPSIS method which is introduced by Chen is employed to evaluate the pipe cutting technologies that are used in shipyards. To calculate the importance degrees of criteria, fuzzy AHP method is used. The experts who we discussed about pipe cutting technologies are experienced with shipbuilding pipe works. In the literature, there is no study which evaluates pipe cutting technologies for shipbuilding industry in accordance with criteria determined in this study.

3. Method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method which is developed by Hwang and Yoon in 1981 and it is one of the most used MCDM methods. In the literature, foundation of the method is based on distances from positive and negative ideal solutions are calculated and then a ranking is made according to similarity to positive ideal solution [11].

Chen [12] introduced an approach to TOPSIS method as group decision making method in fuzzy environment in his study which published in 2000 and pointed out that this approach be able to apply for many decision problems. Furthermore, Eleren and Ersoy [11] evaluated marble cutting technologies in their study using the approach proposed by Chen.

The main structure of the algorithm this study is given in Figure 1.

The steps which are followed in this study can be summarized as below:

3.1 Initial phase (Phase I)

In this phase, basic definitions and boundaries of the problem have been defined.

3.1.1 Definition of alternatives (Step 1)

In this step, decision makers or experts determine the options that can be used for pipe cutting process.

3.1.2 Definition of criteria (Step 2)

Decision makers or experts determine the criteria which are attributive for alternatives.

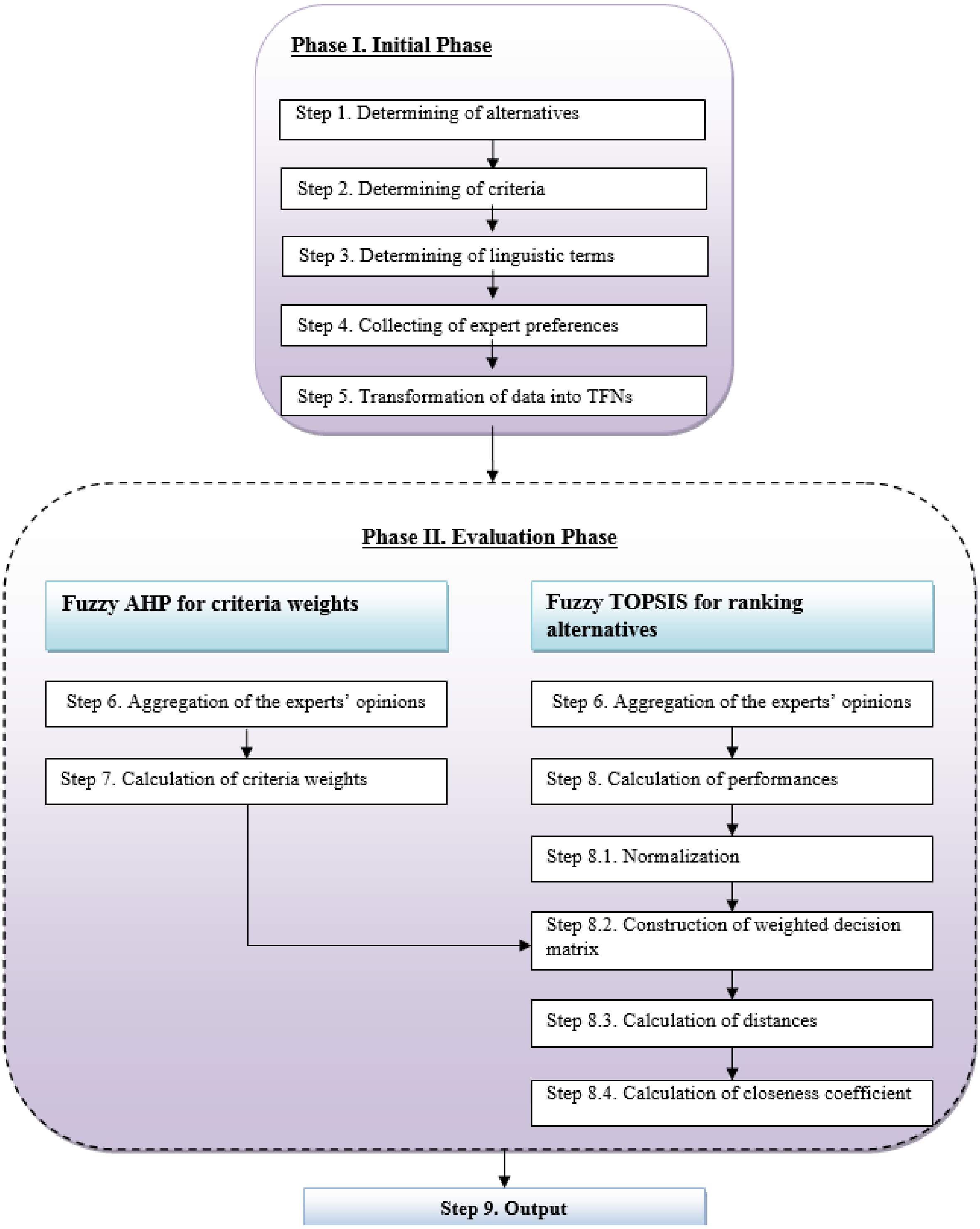

Fig. 1 Main structure of algorithm

3.1.3 Definition the linguistic terms (Step 3)

The linguistic scales and fuzzy numbers used in the study are determined from the literature.

3.1.4 Collecting of expert preferences (Step 4)

Expert preferences on the importance degrees of criteria and alternatives are pooled out using a questionnaire. At first, experts evaluate importance degrees of criteria using a pairwise comparison scale because each criterion is not same importance. Then, alternatives with respect to the defined criteria are assessed. Fuzzy decision matrices are as follows:

$$\tilde{C}^k = \begin{vmatrix} 1 & \tilde{c}_{12} & \cdots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \cdots & \tilde{c}_{2n} \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots \\ \tilde{c}_{m1} & \tilde{c}_{m2} & \cdots & 1 \end{vmatrix} \tag{1}$$

$$\tilde{c}_{ij} = \begin{cases} i > j, & \mathrm{Eq, Wk, Es, Vs, Ab} \\ i = j, & 1 \\ i < j, & 1/\mathrm{Eq}, 1/\mathrm{Wk}, 1/\mathrm{Es}, 1/\mathrm{Vs}, 1/\mathrm{Ab} \end{cases} \tag{2}$$

$$\tilde{D}^k = \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & \cdots & \tilde{d}_{1n} \\ \tilde{d}_{21} & \tilde{d}_{22} & \cdots & \tilde{d}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{d}_{m1} & \tilde{d}_{m2} & \cdots & \tilde{d}_{mn} \end{bmatrix} \tag{3}$$

where $\tilde{C}^k$ and $\tilde{D}^k$ are fuzzy decision matrices given by k^{th} expert for importance degrees of criteria and alternatives, respectively. Each member of the matrices is a triangular fuzzy number (TFN). A TFN is represented by a membership function and $\mu_{\tilde{n}}(x)$, in the range [0, 1] defines the membership degree of the fuzzy number to a fuzzy set. A triangular fuzzy number is defined as follows [13] and also demonstrated in Figure 2;

$$\mu_{\tilde{n}}(x) = \begin{cases} if \quad n_1 \le x \le n_2, & (x - n_1)/(n_2 - n_1) \\ if \quad n_2 \le x \le n_3, & (n_3 - x)/(n_3 - n_2) \\ if \quad x > n_3 \; or \; x < n_1, & 0 \end{cases} \tag{4}$$

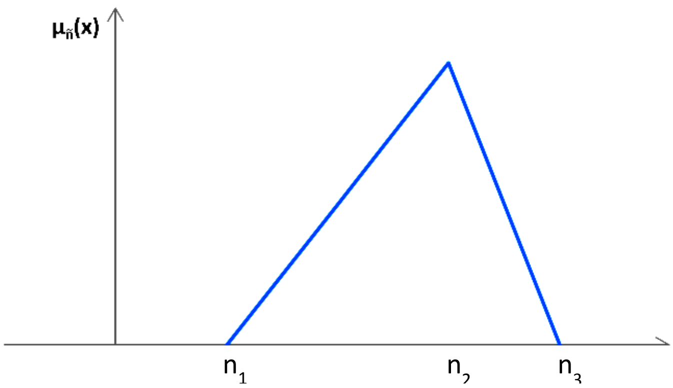

Fig. 2 ñ= (n_1, n_2, n_3) triangular fuzzy number

3.1.5 Transformation of data into triangular fuzzy numbers (TFN) (Step 5)

Linguistic evaluations must be transformed into triangular fuzzy numbers since linguistic terms are not mathematically operable.

3.2 Evaluation (Phase II)

In this phase, calculation of the importance degrees of criteria and performances of the alternatives has been conducted.

3.2.1 Aggregation of the experts' opinions (Step 6)

If there is more than one expert in the evaluation procedure, it is required to aggregate the experts' preferences. The weighted average method is the most used aggregation operator in the literature. Therefore, the weighted aggregation operator is used to obtain aggregated pair wise comparison matrix and aggregated fuzzy decision matrix.

$$\widetilde{C} = \begin{vmatrix} 1 & \widetilde{c}_{12} & \cdots & \widetilde{c}_{1n} \\ \widetilde{c}_{21} & 1 & \cdots & \widetilde{c}_{2n} \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots \\ \widetilde{c}_{m1} & \widetilde{c}_{m2} & \cdots & 1 \end{vmatrix} \tag{5}$$

$$\widetilde{D} = \begin{bmatrix} \widetilde{d}_{11} & \widetilde{d}_{12} & \cdots & \widetilde{d}_{1n} \\ \widetilde{d}_{21} & \widetilde{d}_{22} & \cdots & \widetilde{d}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{d}_{m1} & \widetilde{d}_{m2} & \cdots & \widetilde{d}_{mn} \end{bmatrix} \tag{6}$$

Where $\widetilde{C}$ and $\widetilde{D}$ are aggregated pairwise comparison matrix for importance degrees of criteria and aggregated fuzzy decision matrices for alternatives, respectively.

3.2.2 Calculation of criteria weights (Step 7)

In the presented study, Buckley's fuzzy AHP is used to find the fuzzy weights since it is easy to implement. The procedure can be summarized as follows [15].

After aggregated pair wise comparison matrix ($\widetilde{C}$) is obtained, the fuzzy weight matrix is calculated by Buckley's Method as follows:

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \otimes \ldots \otimes \tilde{c}_{in})^{1/n} \tag{7}$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 + \tilde{r}_2 + \ldots + \tilde{r}_n)^{-1} \tag{8}$$

where $\tilde{c}_{in}$ is the fuzzy comparison value of criterion *i* to criterion *n*, $\tilde{r}_i$ is the geometric mean of fuzzy comparison value of criterion *i* to each criterion.

3.2.3 Calculation of performances (Step 8)

In this step, performances of alternatives are calculated under each criterion by using Fuzzy TOPSIS [12].

3.2.3.1 Normalization (Step 8.1)

For the normalization procedure, following equation are utilized.

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn} \quad \Rightarrow \quad \tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right) \tag{9a}$$

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn} \quad \Rightarrow \quad \tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right) \tag{9b}$$

where $c_j^* = \max_i c_{ij}$ if *j* is benefit criteria and $a_j^- = \min_i a_{ij}$ if *j* is cost criteria.

3.2.3.2 Construction of weighted decision matrix (Step 8.2)

In this step the weighted normalized fuzzy decision matrix is constructed using with the following equation:

$$\begin{aligned} \tilde{V} &= [\tilde{v}_{ij}]_{mxn} \quad i = 1, 2, \cdots, m \quad j = 1, 2, \cdots, n \\ \tilde{v}_{ij} &= \tilde{r}_{ij}.\tilde{w}_j \end{aligned} \tag{10}$$

3.2.3.3 Calculation of distances (Step 8.3)

Then, the distances (d_i^*, d_i^-) of each alternative from fuzzy positive-ideal solution (*FPIS, A**) and fuzzy negative-ideal solution (*FNIS, A*$^-$) are calculated, respectively.

$$\begin{aligned} d_i^* &= \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*) \quad i = 1, 2, \cdots, m \\ d_i^- &= \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad i = 1, 2, \cdots, m \end{aligned} \tag{11}$$

For benefit attributes, *FPIS, A** and *FNIS, A*$^-$is selected as follows;

$$\begin{aligned} A^* &= (v_1^*, v_2^*, ..., v_n^*) \quad where \ v_j^* = (1,1,1) \\ A^- &= (v_1^-, v_2^-, ..., v_n^-) \ where \ v_j^- = (0,0,0) \end{aligned} \tag{12}$$

For cost attributes, *FPIS, A** and *FNIS, A*$^-$is selected as follows;

$$\begin{aligned} A^* &= (v_1^*, v_2^*, ..., v_n^*) \quad where \ v_j^* = (0,0,0) \\ A^- &= (v_1^-, v_2^-, ..., v_n^-) \ where \ v_j^- = (1,1,1) \end{aligned} \tag{13}$$

3.2.3.4 Calculation of closeness coefficient (Step 8.4)

A closeness coefficient (CC_i) is calculated by using d_i^* and d_i^- with the following equation:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad i = 1, 2, \cdots, m \tag{14}$$

3.2.4 Output (Step 9)

Hence, the alternatives are ranked via CC_i such that the alternative has the biggest CC_i value is the best in all for our goal.

4. Application

In this study, the preferences of three engineer experts who have experience with pipe works in shipyard are collected.

4.1 Initial phase (Phase I)

4.1.1 Definition of alternatives (Step 1)

The alternatives, which are used in the study, are oxy-fuel (A1), plasma (A2), metal saw (A3), band saw (A4), and abrasive cutting wheel (A5) technologies.

4.1.2 Definition of criteria (Step 2)

The criteria used in this study consist of three main criteria. Those are *performance*, *risk*, and *cost* criteria. Performance criteria include *set up time*, (The time that elapsed to make the machine be ready for cutting process), *operation time* (The time that elapsed while cutting process), *flexibility* (The applicability of the system for each type and size of parts), *adaptability* (The applicability of system to each type of the shipyard), *ease of use* (The system's ease of use), *quality* (The surface quality obtained from after the process), *sensitivity* (Performing the required precision in the cutting process), and *qualification* (Presence or absence of the need to make an extra operation on part after cutting process). *Risk criteria* involve *environmental effect* (Environmental damage caused by the cutting process) and *worker safety* (Risk of accidents that may damage to the worker during the cutting process).

And, cost criteria consist of *initial cost* (The money that spent to buy the cutting machine and all other required components), *operation cost* (The money that spent to carry out the cutting process), *maintenance cost* (The money that spent for upkeep operations), and *laborer cost* (The money that paid to the workers to perform cutting operation).

Figure 3 shows criteria and sub criteria all together.

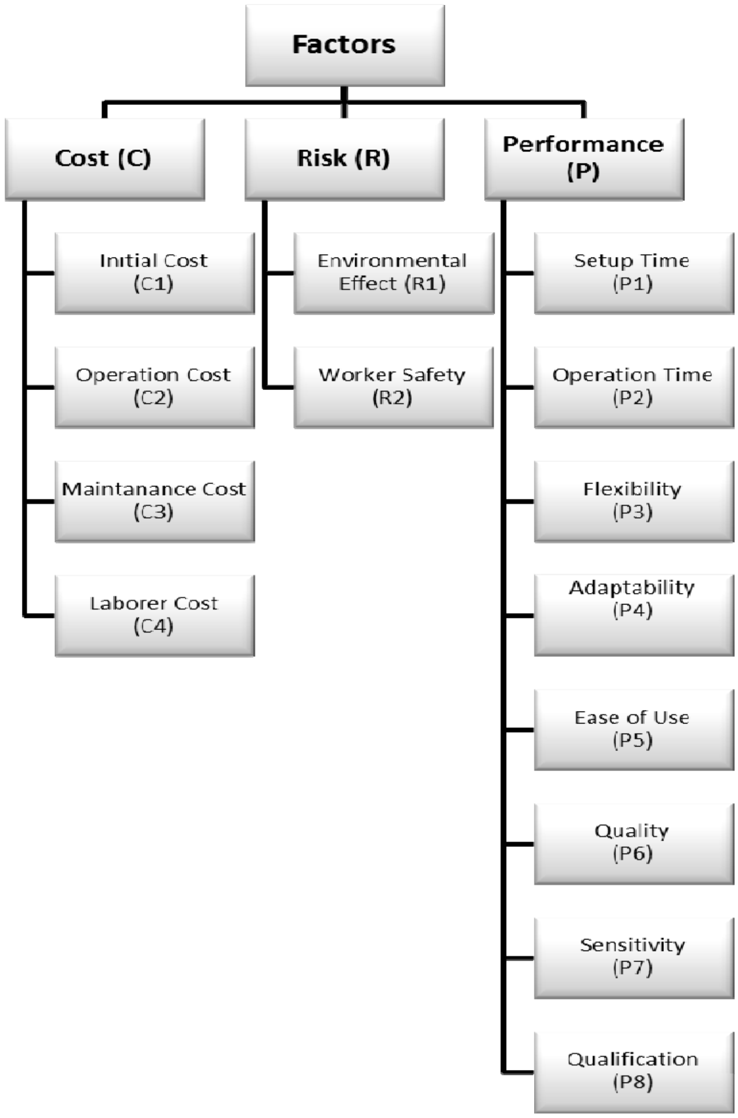

Fig. 3 Evaluation criteria for pipe cutting technologies

4.1.3 Definition of the linguistic terms (Step 3)

Linguistic terms and their fuzzy numbers used in the study are given in Table 1 [14] and Table 2.

Table 1 Linguistic terms that used to evaluate criteria among them

Equal important	Eq	(1,1,3)
Weak important	Wk	(1,3,5)
Essential important	Es	(3,5,7)
Very strong important	Vs	(5,7,9)
Absolutely important	As	(7,9,9)

Table 2 Linguistic terms that used for alternatives' ratings

Very low	VL	(0,0,3)
Low	L	(0,2.5,5)
Fair	F	(2.5,5,7.5)
High	H	(5,7.5,10)
Very high	VH	(7,10,10)

4.1.4 Collecting of expert preferences (Step 4)

Expert preferences on the importance degrees of criteria and alternatives' ratings are pooled out using a questionnaire. To illustrate the collected data, the preferences of Expert 1 for importance degree of cost criteria and alternatives' ratings have been presented in Table 3 and Table 4, respectively.

Table 3 Linguistic terms that used for alternatives' ratings

	Initial cost	Operation cost	Maintenance cost	Laborer cost
Initial cost	-	Vs	Vs	Ab
Operation cost	1/Vs	-	Es	Es
Maintenance cost	1/Vs	1/Es	-	1/Wk
Laborer cost	1/Ab	1/Es	Wk	-

Table 4 Evaluation of alternatives

	Cost	Performance	Risk	Environmental effect	Worker safety	Initial cost	Operation cost	Maintenance cost	Laborer cost	Set up time	Operation time	Flexibility	Adaptability	Ease of use	Quality	Sensitivity	Qualification
Oxy-fuel	F	F	H	F	F	F	F	L	F	L	H	F	F	F	L	VL	L
Plasma	VH	H	L	L	F	H	H	H	L	H	L	H	H	F	H	H	H
Metal saw	L	F	H	H	VL	L	L	L	F	L	H	F	H	F	L	VL	L
Band saw	L	F	H	H	L	F	L	L	L	L	L	L	L	F	L	L	L
Abrasive cutting wheel	L	L	VH	H	VL	L	L	L	F	L	L	F	H	F	L	VL	L

4.1.5 Transformation of data into triangular fuzzy numbers (TFN) (Step 5)

In this paper, linguistic scale given in Table 1 and Table 2 are used for pairwise comparisons and evaluation of alternatives, respectively. Linguistic terms are transformed into triangular fuzzy numbers by using these scales.

4.2 Evaluation (Phase II)

4.2.1 Aggregation of the experts' opinions (Step 6)

There are three experts in the evaluation procedure and it is assumed that each expert has the same impact on final decision. The aggregated fuzzy decision matrices have been given in Table 5 and Table 6:

Table 5 Aggregated pair wise comparisons

	Cost (C)	Performance (P)	Risk (R)	
C	(1,1,1)	(0.44,0.49,1.40)	(0.14,0.21,0.47)	
P	(0.71,2.03,2.29)	(1,1,1)	(0.44,0.49,1.40)	
R	(2.14,4.85,7.11)	(0.71,2.03,2.29)	(1,1,1)	
	Initial cost (C1)	Operation cost (C2)	Maintenance cost (C3)	Laborer cost (C4)
C1	(1,1,1)	(2.05,2.73,4.11)	(4.33,6.33,7.67)	(4.78,6.33,6.33)
C2	(0.24,0.37,0.49)	(1,1,1)	(1.38,2.73,4.11)	(1.4,2.11,3.67)
C3	(0.13,0.16,0.23)	(0.24,0.37,0.72)	(1,1,1)	(0.2,0.33,1)
C4	(0.16,0.16,0.21)	(0.27,0.47,0.71)	(1,3,5)	(1,1,1)
	Environmental effect (R1)	Worker safety (R2)		
R1	(1,1,1)	(0.42,0.44,1.16)		
R2	(0.86,2.29,2.39)	(1,1,1)		
	Set up time (P1)	Operation time (P2)	Flexibility (P3)	Adaptability (P4)
P1	(1,1,1)	(0.71,1.4,2.78)	(0.15,0.21,0.49)	(0.47,1.22,2.33)
P2	(0.36,0.71,1.4)	(1,1,1)	(0.51,0.78,1.67)	(0.71,1.4,2.78)
P3	(2.03,4.66,6.61)	(0.6,1.29,1.96)	((1,1,1)	(1,2.33,4.33)
P4	(0.43,0.82,2.14)	(0.36,0.71,1.4)	(0.23,0.43,1)	(1,1,1)
P5	(0.69,1.96,2.23)	(0.33,0.69,1.36)	(0.27,0.6,1)	(1.4,2.08,4.66)
P6	(1.8,4.09,6.18)	(0.43,1.29,1.36)	(1,3,5)	(2.03,4.66,6.61)
P7	(1.96,4.44,6.61)	(0.43,1,1.29)	(1.8,4.09,6.18)	(3.46,5.53,7.56)
P8	(1.96,4.44,6.61)	(0.43,1.29,1.36)	(1.8,4.09,6.18)	(1.29,3.46,5.53)
	Ease of use (P5)	Quality (P6)	Sensitivity (P7)	Qualification (P8)
P1	(0.45,0.51,1.44)	(0.16,0.24,0.56)	(0.15,0.23,0.51)	(0.15,0.23,0.51)
P2	(0.73,1.44,3)	(0.73,0.78,2.33)	(0.78,1,2.33)	(0.73,0.78,2.33)
P3	(1,1.67,3.67)	(0.2,0.33,1)	(0.16,0.24,0.56)	(0.16,0.24,0.56)
P4	(0.21,0.48,0.71)	(0.15,0.21,0.49)	(0.13,0.18,0.29)	(0.18,0.29,0.78)
P5	(1,1,1)	(2.73,3.44,4.33)	(2.73,3.44,4.33)	(2.73,3.44,4.33)
P6	(0.23,0.29,0.37)	(1,1,1)	(0.78,1,2.33)	(1,1.67,3.67)
P7	(0.23,0.29,0.37)	(0.43,1,1.29)	(1,1,1)	(1.67,2.33,4.33)
P8	(0.23,0.29,0.37)	(0.27,0.6,1)	(0.23,0.43,0.6)	(1,1,1)

Table 6 Aggregated preferences for alternatives

	Environmental effect	Worker safety	Initial cost	Operation cost
Oxy-fuel	(1.667,3.333,6)	(0.833,1.667,4.5)	(2.5,5,7.5)	(4.167,6.667,9.167)
Plasma	(0,1.667,4.333)	(4.833,7.5,9.167)	(4.833,7.5,9.167)	(3.333,5.833,8.333)
Metal saw	(3.333,5.833,8.333)	(0,0.833,3.667)	(0.833,3.333,5.833)	(1.667,4.167,6.667)
Band saw	(3.333,5.833,8.333)	(0.833,2.5,5.167)	(1.667,4.167,6.667)	(1.667,4.167,6.667)
Abrasive cutting wheel	(2.5,5,7.5)	(0,0.833,3.667)	(0,1.667,4.333)	(1.667,4.167,6.667)
	Maintenance cost	Laborer cost	Set up time	Operation time
Oxy-fuel	(0,1.667,4.333)	(2.5,5,7.5)	(2.333,4.167,6)	(3.333,5.833,8.333)
Plasma	(3.333,5.833,8.333)	(0.833,2.5,5.167)	(3.333,5.833,8.333)	(1.667,3.333,6)
Metal saw	(0.833,3.333,5.833)	(1.667,4.167,6.667)	(1.667,4.167,6.667)	(5,7.5,10)
Band saw	(0.833,3.333,5.833)	(0.833,3.333,5.833)	(1.667,4.167,6.667)	(2.5,5,7.5)
Abrasive cutting wheel	(0.833,2.5,5.167)	(3.333,5.833,8.333)	(1.667,4.167,6.667)	(4.667,7.5,8.333)
	Flexibility	Adaptability	Ease of use	Quality
Oxy-fuel	(3.167,5.833,7.5)	(3.167,5.833,7.5)	(5.5,8.333,9.167)	(0,0.833,3.667)
Plasma	(4.167,6.667,9.167)	(5.667,8.333,10)	(4.167,6.667,9.167)	(5,7.5,10)
Metal saw	(0.833,2.5,5.167)	(4.833,7.5,9.167)	(4,6.667,8.333)	(1.667,4.167,6.667)
Band saw	(0,1.667,4.333)	(2.333,5,6.667)	(4,6.667,8.333)	(1.667,4.167,6.667)
Abrasive cutting wheel	(4,6.667,8.333)	(4.833,7.5,9.167)	(4.833,7.5,9.167)	(2.5,5,7.5)
	Sensitivity	Qualification		
Oxy-fuel	(1.667,2.5,5.333)	(3.167,5.833,7.5)		
Plasma	(4.167,6.667,9.167)	(3.333,5,7.667)		
Metal saw	(0.833,2.5,5.167)	(0.833,3.333,5.833)		
Band saw	(1.667,4.167,6.667)	(0,2.5,5)		
Abrasive cutting wheel	(1.667,3.333,6)	(0.833,3.333,5.833)		

4.2.2 Calculation of criteria weights (Step 7)

The importance degrees of criteria which calculated by Buckley's Fuzzy AHP are given in Table 7:

Table 7 The fuzzy importance degrees of criteria

Symbol	**Factors**	**Overall Weights**	**Relative Weights**
P	Performance Factors	(0.139,0.277,0.662)	
P1	Set up time	(0.022,0.052,0.178)	(0.003,0.014,0.118)
P2	Operation time	(0.047,0.106,0.373)	(0.007,0.029,0.247)
P3	Flexibility	(0.037,0.101,0.315)	(0.005,0.028,0.209)
P4	Adaptability	(0.019,0.049,0.157)	(0.003,0.014,0.104)
P5	Ease of use	(0.076,0.189,0.453)	(0.011,0.052,0.300)
P6	Quality	(0.060,0.174,0.437)	(0.008,0.048,0.290)
P7	Sensitivity	(0.069,0.189,0.433)	(0.010,0.052,0.287)
P8	Qualification	(0.045,0.139,0.318)	(0.006,0.039,0.210)

R	Risk Factors	(0.236,0.594,1.138)	
R1	Environmental effect	(0.246,0.304,0.683)	(0.058,0.181,0.778)
R2	Worker safety	(0.354,0.696,0.982)	(0.084,0.413,1.117)
C	Cost Factors	(0.081,0.129,0.390)	
C1	Initial cost	(0.366,0.588,0.913)	(0.030,0.076,0.356)
C2	Operation cost	(0.119,0.219,0.400)	(0.010,0.028,0.156)
C3	Maintenance cost	(0.040,0.068,0.155)	(0.003,0.009,0.061)
C4	Laborer cost	(0.065,0.125,0.226)	(0.005,0.016,0.088)

According to defuzzified criteria weights, importance degrees of criteria are given in Figure 4.

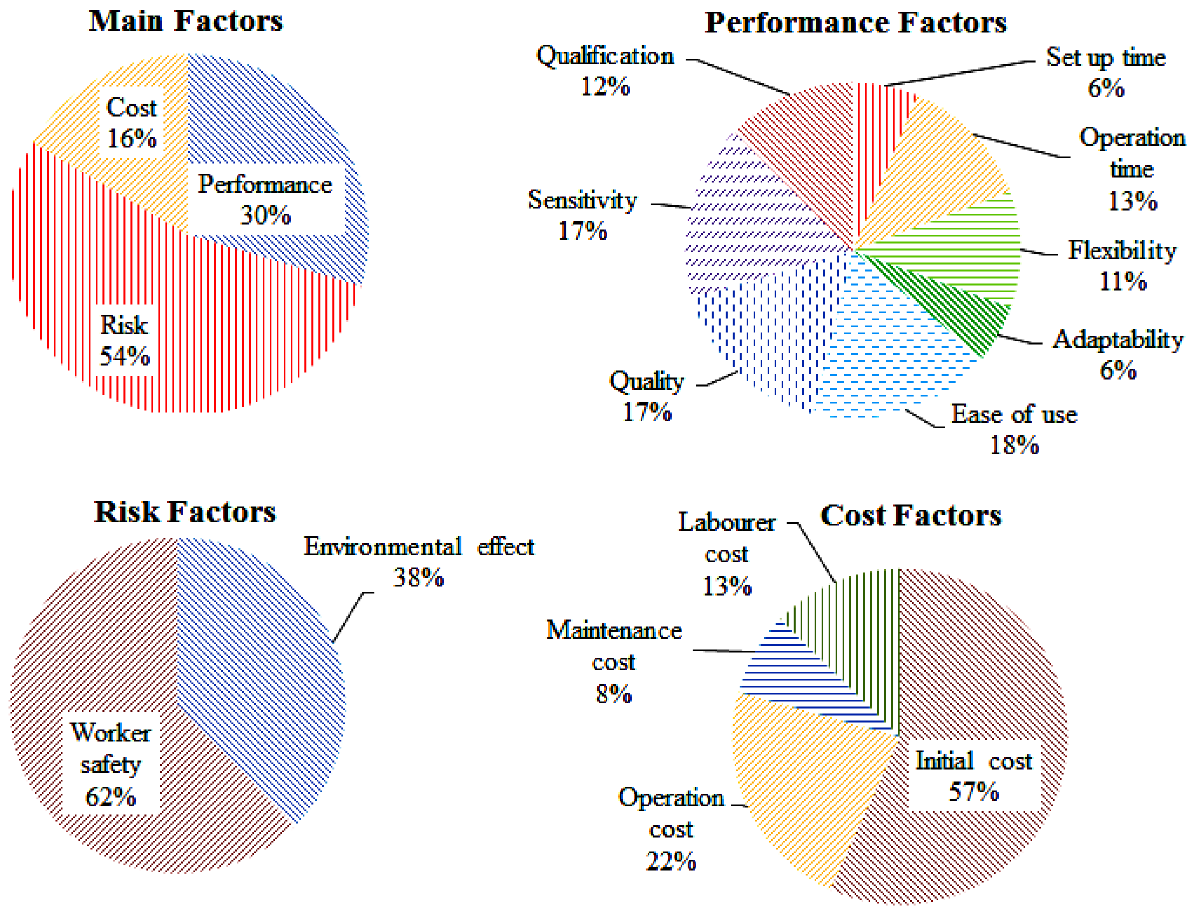

Fig. 4 Importance degrees of evaluation factors

In first part of the figure, main factors' importance degrees are observed. As given in the figure, *risk* factor is the most important factor for pipe cutting process in shipyard. *Performance* and *cost* factors follow risk factor by turns. It is concluded that *performance* factor is two times important from *cost* factor. Likewise, *risk* factor is two times important from *performance* factor approximately.

In the second part of the figure, *performance* factors are evaluated within their own. The most important performance criterion is "*ease of use*" with the value of 18%. "*Quality*" and "*sensitivity*" criteria have same importance degree and very close to "*ease of use*" with the value of 17%. "*Operation time*", "*qualification*", "*flexibility*", "*adaptability*" and "*setup time*" follow these criteria by turns. "*Adaptability*" and "*setup time*" criteria have same importance degree with the value of 6%.

According to the third part of the figure "*worker safety*" criteria is 62% important as "*environmental effect*" is 38% within the risk factors.

The last part of the figure presents cost factors' importance degrees. The "*initial cost*" criterion has an absolute importance compared to others. The least significant cost factor is "*maintenance cost*" criterion. Cost factors are ranked as "*initial cost*", "*operation cost*", "*laborer cost*", and "*maintenance cost*".

4.2.3 Calculation of performances (Step 8)

4.2.3.1 Normalization (Step 8.1)

Fuzzy decision matrix is normalized using with Eq. 9a. Thus all fuzzy values' ranges belong to the interval [0,1] [12]. Differ from the Chen's approach, the inverse of the linguistic scale for cost attributes is taken, and then; Eq. 9a is used for all criteria. Table 8 shows normalized fuzzy decision matrix:

Table 8 Normalized fuzzy decision matrix

	Environmental effect	Worker safety	Initial cost	Operation cost
Oxy-fuel	(0.4,0.667,0.833)	(0.091,0.182,0.491)	(0.25,0.5,0.75)	(0.1,0.4,0.7)
Plasma	(0.567,0.833,1)	(0.527,0.818,1)	(0.083,0.25,0.517)	(0.2,0.5,0.8)
Metal saw	(0.167,0.417,0.667)	(0,0.091,0.4)	(0.417,0.667,0.917)	(0.4,0.7,1)
Band saw	(0.167,0.417,0.667)	(0.091,0.273,0.564)	(0.333,0.583,0.833)	(0.4,0.7,1)
Abrasive cutting wheel	(0.25,0.5,0.75)	(0,0.091,0.4)	(0.567,0.833,1)	(0.4,0.7,1)
	Maintenance cost	Laborer cost	Set up time	Operation time
Oxy-fuel	(0.567,0.833,1)	(0.273,0.545,0.818)	(0.48,0.7,0.92)	(0.2,0.5,0.8)
Plasma	(0.167,0.417,0.667)	(0.527,0.818,1)	(0.2,0.5,0.8)	(0.48,0.8,1)
Metal saw	(0.417,0.667,0.917)	(0.364,0.636,0.909)	(0.4,0.7,1)	(0,0.3,0.6)
Band saw	(0.417,0.667,0.917)	(0.455,0.727,1)	(0.4,0.7,1)	(0.3,0.6,0.9)
Abrasive cutting wheel	(0.483,0.75,0.917)	(0.182,0.455,0.727)	(0.4,0.7,1)	(0.2,0.3,0.64)
	Flexibility	Adaptability	Ease of use	Quality
Oxy-fuel	(0.345,0.636,0.818)	(0.317,0.583,0.75)	(0.6,0.909,1)	(0,0.083,0.367)
Plasma	(0.455,0.727,1)	(0.567,0.833,1)	(0.455,0.727,1)	(0.5,0.75,1)
Metal saw	(0.091,0.273,0.564)	(0.483,0.75,0.917)	(0.436,0.727,0.909)	(0.167,0.417,0.667)
Band saw	(0,0.182,0.473)	(0.233,0.5,0.667)	(0.436,0.727,0.909)	(0.167,0.417,0.667)
Abrasive cutting wheel	(0.436,0.727,0.909)	(0.483,0.75,0.917)	(0.527,0.818,1)	(0.25,0.5,0.75)
	Sensitivity	Qualification		
Oxy-fuel	(0.182,0.273,0.582)	(0.413,0.761,0.978)		
Plasma	(0.455,0.727,1)	(0.435,0.652,1)		
Metal saw	(0.091,0.273,0.564)	(0.109,0.435,0.761)		
Band saw	(0.182,0.455,0.727)	(0,0.326,0.652)		
Abrasive cutting wheel	(0.182,0.364,0.655)	(0.109,0.435,0.761)		

4.2.3.2 Construction of weighted decision matrix (Step 8.2)

The weighted decision matrix is calculated using with Eq.10 and has been presented in Table 9:

Table 9 Weighted fuzzy decision matrix

	Environmental effect	Worker safety	Initial cost	Operation cost
Oxy-fuel	(0.023,0.12,0.648)	(0.008,0.075,0.549)	(0.007,0.038,0.267)	(0.001,0.011,0.109)
Plasma	(0.033,0.15,0.778)	(0.044,0.338,1.117)	(0.002,0.019,0.184)	(0.002,0.014,0.125)
Metal saw	(0.01,0.075,0.518)	(0,0.038,0.447)	(0.012,0.051,0.326)	(0.004,0.02,0.156)
Band saw	(0.01,0.075,0.518)	(0.008,0.113,0.63)	(0.01,0.044,0.297)	(0.004,0.02,0.156)
Abrasive cutting wheel	(0.015,0.09,0.583)	(0,0.038,0.447)	(0.017,0.063,0.356)	(0.004,0.02,0.156)
	Maintenance cost	Laborer cost	Set up time	Operation time
Oxy-fuel	(0.002,0.007,0.061)	(0.001,0.009,0.072)	(0.001,0.01,0.109)	(0.001,0.015,0.198)
Plasma	(0.001,0.004,0.04)	(0.003,0.013,0.088)	(0.001,0.007,0.095)	(0.003,0.024,0.247)
Metal saw	(0.001,0.006,0.055)	(0.002,0.01,0.08)	(0.001,0.01,0.118)	(0,0.009,0.148)
Band saw	(0.001,0.006,0.055)	(0.002,0.012,0.088)	(0.001,0.01,0.118)	(0.002,0.018,0.223)
Abrasive cutting wheel	(0.002,0.007,0.055)	(0.001,0.007,0.064)	(0.001,0.01,0.118)	(0.001,0.009,0.158)
	Flexibility	Adaptability	Ease of use	Quality
Oxy-fuel	(0.002,0.018,0.171)	(0.001,0.008,0.078)	(0.006,0.048,0.3)	(0,0.004,0.106)
Plasma	(0.002,0.02,0.209)	(0.001,0.011,0.104)	(0.005,0.038,0.3)	(0.004,0.036,0.29)
Metal saw	(0,0.008,0.118)	(0.001,0.01,0.095)	(0.005,0.038,0.273)	(0.001,0.02,0.193)
Band saw	(0,0.005,0.099)	(0.001,0.007,0.069)	(0.005,0.038,0.273)	(0.001,0.02,0.193)
Abrasive cutting wheel	(0.002,0.02,0.19)	(0.001,0.01,0.095)	(0.006,0.043,0.3)	(0.002,0.024,0.217)
	Sensitivity	Qualification		
Oxy-fuel	(0.002,0.014,0.167)	(0.003,0.029,0.206)		
Plasma	(0.004,0.038,0.287)	(0.003,0.025,0.21)		
Metal saw	(0.001,0.014,0.162)	(0.001,0.017,0.16)		
Band saw	(0.002,0.024,0.209)	(0,0.013,0.137)		
Abrasive cutting wheel	(0.002,0.019,0.188)	(0.001,0.017,0.16)		

4.2.3.3 Calculation of distances (Step 8.3)

Distances to *FPIS* A^* and *FNIS* A^- are calculated using with vertex method, respectively. Table 10 and Table 11 present the calculated distances:

4.2.3.4 Calculation of closeness coefficient (Step 8.4)

The closeness coefficients are calculated according to Eq. 14, respectively. Calculated values have been showed in Table 12:

4.3 Output (Step 9)

Hence the rank of the alternatives is: A2 (Plasma Cutting), A5 (Abrasive Cutting Wheel), A4 (Band Saw), A1 (Oxy-fuel Cutting), A3 (Metal Saw).

Table 10 Distances to FPIS A^*

	R1	R2	C1	C2	C3	C4	P1	P2
Oxy-fuel	0.786	0.825	0.903	0.961	0.977	0.973	0.961	0.933
Plasma	0.754	0.675	0.935	0.955	0.985	0.966	0.967	0.915
Metal saw	0.83	0.863	0.881	0.943	0.979	0.97	0.958	0.95
Band saw	0.83	0.798	0.892	0.943	0.979	0.967	0.958	0.925
Abrasive cutting wheel	0.811	0.863	0.868	0.943	0.979	0.976	0.958	0.947
	P3	**P4**	**P5**	**P6**	**P7**	**P8**	A*	
Oxy-fuel	0.94	0.972	0.892	0.965	0.942	0.925	12.95	
Plasma	0.928	0.962	0.895	0.899	0.899	0.925	12.66	
Metal saw	0.96	0.965	0.903	0.932	0.944	0.944	13.02	
Band saw	0.966	0.975	0.903	0.932	0.927	0.952	12.95	
Abrasive cutting wheel	0.933	0.965	0.894	0.924	0.934	0.944	12.94	

Table 11 Distances to FPIS A^-

	R1	R2	C1	C2	C3	C4	P1	P2
Oxy-fuel	0.381	0.32	0.156	0.063	0.035	0.042	0.063	0.115
Plasma	0.458	0.675	0.107	0.073	0.023	0.051	0.055	0.143
Metal saw	0.303	0.259	0.191	0.091	0.032	0.047	0.068	0.086
Band saw	0.303	0.369	0.173	0.091	0.032	0.051	0.068	0.129
Abrasive cutting wheel	0.341	0.259	0.209	0.091	0.032	0.037	0.068	0.092
	P3	**P4**	**P5**	**P6**	**P7**	**P8**	A^-	
Oxy-fuel	0.099	0.045	0.175	0.061	0.097	0.12	1.772	
Plasma	0.121	0.06	0.175	0.169	0.167	0.122	2.399	
Metal saw	0.068	0.055	0.159	0.112	0.094	0.093	1.657	
Band saw	0.057	0.04	0.159	0.112	0.121	0.08	1.786	
Abrasive cutting wheel	0.11	0.055	0.175	0.126	0.109	0.093	1.798	

Table 12 Closeness coefficients for each alternative

A1	0.120
A2	0.159
A3	0.113
A4	0.121
A5	0.122

5. Conclusions

In this study, pipe cutting techniques for straight cut of carbon steel pipes employed in shipyards were evaluated in accordance with the criteria which consist of three main factors and fourteen sub-factors. The evaluation, an integrated method including fuzzy AHP and fuzzy TOPSIS techniques is used. As a result of this study, in accordance with criteria determined, plasma cutting is found to be the most appropriate pipe cutting technique for straight cut of carbon steel pipes. If they have no chance to implement plasma technology in pipe cutting operation due to various reasons, it is recommended that the shipyards may prefer abrasive cutting wheel technique. In the presented study, oxy-fuel cutting and metal saw techniques are found to be inconvenient according to the determined criteria.

Finally, employing plasma cutting technique among the cutting activities satisfies the criteria and the pipe cutting operations of the shipyards may be more effective. It is believed that the shipyards are able to obtain a competitive advantage as they employ plasma cutting in pipe cutting operation.

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