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COSTWELD: A COST ESTIMATION SYSTEM OF WELDING BASED ON THE FEATURE MODEL

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Abstract:
Understanding true cost of a product during the design stage could guide the designer to obtain more competitive solutions. Therefore designers are taking interest in understanding costs of their decisions and use the cost as a design driver. This paper develops COSTWELD, a welding cost estimation model based on feature concept. The model uses a semi-analytic approach which decomposes the structure in a set of assemblies. Each assembly is modelled by one or several couples (preparation feature, welding feature). Then for each feature is generated several manufacturing processes and each process is associated with a cost model.

COSTWELD is programmed with the Visual Basic language under windows exploitation systems and operates databases which are developed through the database management “ACESS”. Depending on the company experience, databases can be improved by addition of new processes or adjustment of hourly costs and coefficients calculations values. Thus the databases represent the company knowledge library. At last, and to show the efficiency of the model, we have treated an industrial project proposed by a collaborating company. The results obtained are near to the real cost which shows the accuracy of the model we have developed.

Key Words: Concurrent Cost Engineering, Feature Model, Welded Structures, Welded Times

1. INTRODUCTION

The fierce global competition in the international markets forces manufacturers to increase productivity at reduced cost. Thus, an accurate cost-estimation has become a strategic objective, especially during early stages of the design. In this context, numerous research works have been developed to evaluate the manufacturing cost of mechanical parts [1-13].

Qian and Ben Ariech [1] have proposed a cost-estimation model that links activity-based costing (ABC) with parametric cost representations of the design and development phases of machined rotational parts. They present several parametric approaches of cost estimation using geometrical characteristics of parts. These approaches are tested on real rotational parts developed in a controlled factory environment. Klansek and Karavanja [2] have presented a tool for the estimation of welding costs (material costs, power consumption costs and labour costs) for composite and steel structures. New approximation functions are proposed for the calculation of some manufacturing times and material consumptions. Bouaziz et al. [3] have proposed a system for the manufacturing cost of tools based on a semi-analytic approach. The principle of the developed system consists in grouping the shapes to be machined into complex machining features. For each feature parameter, the system generates a typical process and consequently a model of machining time. Shehab and Abdalla [4] developed a system that has the capability of selecting a material, as well as machining process and parameters based on a set of design and production parameters and of estimating the product cost throughout the entire product development cycle including assembly cost. Jarmai and Farkas [5] proposed times of different welding and gas metal cutting technologies. In this work, the proposed welding times of the fillet and single V welds for the SMAW technology are given for weld sizes amounting up to 15 mm. Jarmai [6] also introduced times for different post welding treatments and times for hand cutting and machine grinding, in relation to the welding process.

This paper extends our previous research [7] by developing a welding cost estimation system “COSTWELD”. A cost function for the calculation of the preparation cost and the welding cost is detailed. Also the implementation of the developed data-processing tool is presented in this work.

We start at first by giving details about the principle of this system. Then we explain the modelling of assemblies using couples (preparation feature, welding feature). The modeling by features enriched the system by information related to both product and process, allowing designers to make changes targeted cost reduction. Finally we are dealing with an application for an industrial project, carried out in collaboration with the society “Mediterranean Company of Repair in Tunisia”.

2. THE IMPORTANCE OF GOOD ESTIMATES

The estimated costs of products with precision are crucial to the financial success of manufacturing firms. Both overestimates and underestimates can spell disaster. Underestimates may land a contract, but they also frequently lead to financial loss and business failure. On the other hand, overestimates of costs will cause the company to lose contracts. However, realistic estimates result in the most economical cost. They let managers to control the excess resources.

Figure 1 graphically represents the over-and underestimates relationships in the Freiman curve [8]. The graph shows that:

- The greater the underestimate, the greater the actual expenditure;
- The greater the overestimate, the greater the actual expenditure;
- The most realistic estimate results in the most economical project cost.

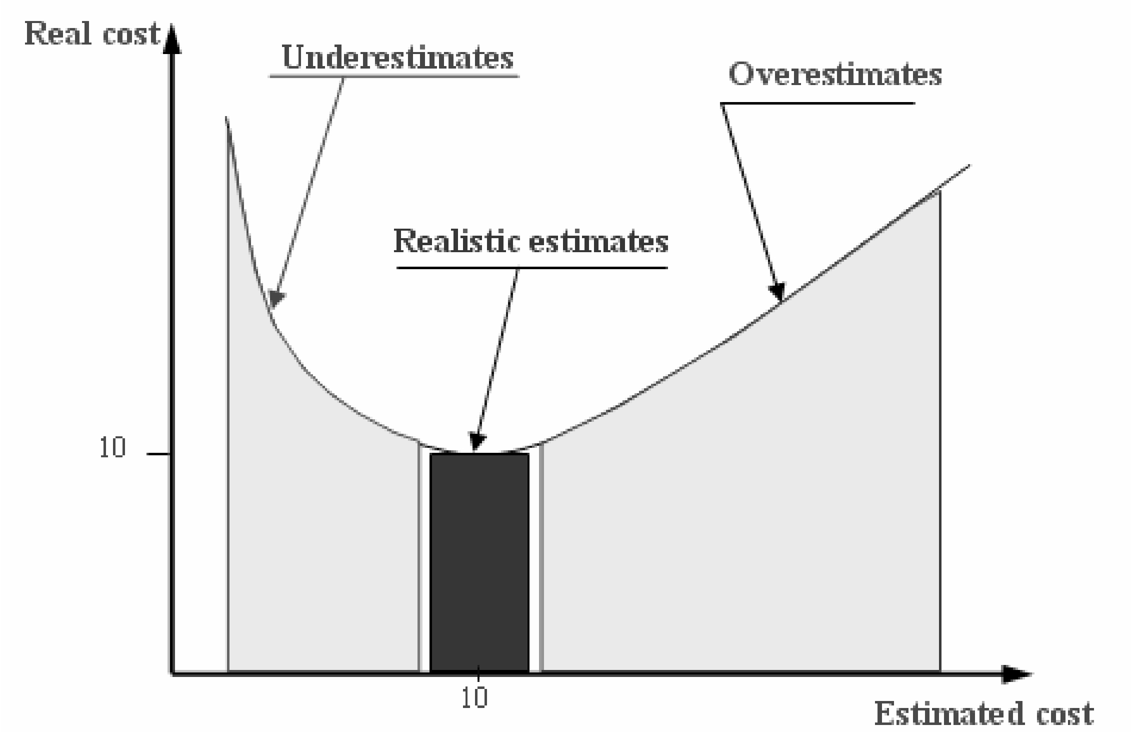


Figure 1: The Freiman curve.

3. THE PRINCIPAL OF THE DEVELOPED SYSTEM

The principle of the developed system consists of conceiving a model that integrates the information necessary to define a welding assemblage and its manufacturing process, in order to obtain a realistic estimates result. Thus the method of cost calculation is based on the use of parameterized features which associate the technological, dimensional and geometrical characteristics. The system is made up of phases described by Figure 2 :

- Identification of assemblies contained in the product (types and number of assemblies);
- Modeling each assembly by a couple (preparation feature, welding feature), taking into account the geometric and technological data of the assembly;
- Feature processing: calculating time and cost;
- Selection of the process corresponding to the minimum cost;
- Calculating time and cost of the assembly;
- The product cost is the sum total of the features costs which compose it.

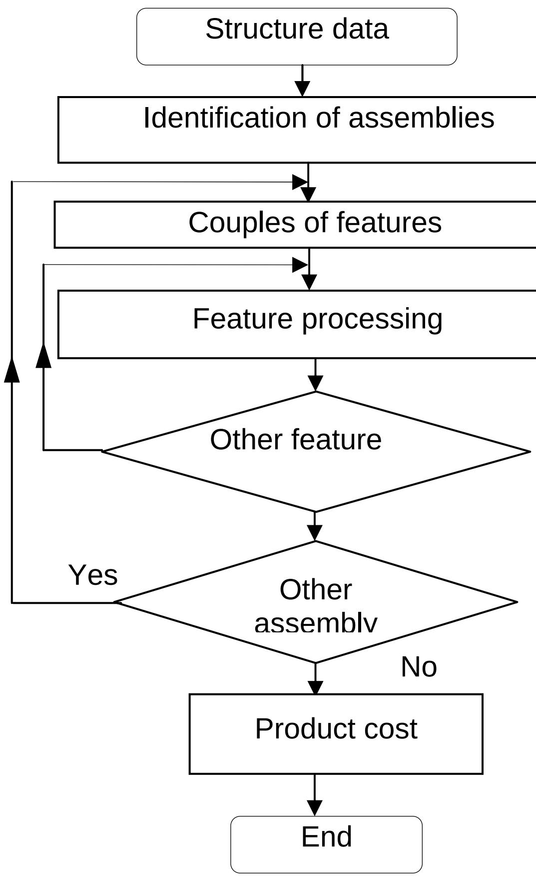


Figure 2: Flow chart of cost analyzing process.

4. MODELLING PER FEATURE

The generation of knowledge for automation costing of welds, requires a physical representation of the assembly to confine and know the different variables to handle. We interest in particular in geometrical and technological variables, which have an influence on the total cost of the product. Thus, we thought of modelling by feature. Indeed, the feature model includes knowledge related at the same time on the geometrical characteristics of the product, the manufacturing processes to be considered and the means to use.

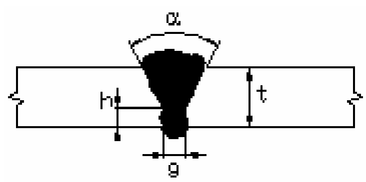
We present two concepts of features: preparation feature and welding feature, respectively for the two phases, joint preparation phase and welding phase.

The preparation feature is defined by the geometrical shape of the joint to which one or more manufacturing process is associated. The latter includes the whole necessary operations for the realization of this feature. In our previous work [7] we have developed seven types of preparation features: I, V, ½ V, X, K, U and J.

The welding feature represents the space to be filled with the metal deposited between the two parts whose edges are properly prepared. Each welding feature has one or more corresponding preparations features in the same type. It is characterized by data links to the assembly, the geometry, the welding operation and a difficulty factor which depend of the direction and position welding "Table I".

Each assembly can be modelled by one or several couples (Preparation feature, Welding feature). Thus, we have developed a library of features. The latter constitutes a structural element able to capitalize technological knowledge to optimize the execution of welding.

Table I: Parametring of a welding feature type V.

Data related to the assembly	
Assembling type : butt-weld, Fillet weld, Cornice type, etc.	
Welding direction: horizontal, vertical	
Welding position: flat, rising vertical, downward vertical, cornice type	
Geometrical data	
Geometrical parameters (preparation feature)	
Welding data	
Welding process : SMAW, GMAW, GTAW, FCAW, etc.	
Filler density	
Deposit rate	
Difficulty factor : φ, related to direction and position welding	

5. COST FUNCTION

We seek to enhance the operations of the manufacturing processes to estimate the production costs of each feature and thereafter the total cost of a product. The cost function can be expressed as:

$$C = C_p + C_w = \sum_i C_{Hi}.t_{pi} + \sum_j C_{Hj}.t_{wj} \qquad (1)$$

Where:

C_p is the preparation cost which includes the cost of machine utilisation and of labour and consumables cost. C_w is the welding cost. This represents the sum total of the elementary costs: the use of welding post consumption, labour, the electrode consumption, the electricity and the protecting gas consumption.

C_{Hi} and C_{Hj} are the preparation and welding operations hourly costs, respectively, t_{pi} and t_{wj} are the corresponding times. Hourly costs are known values which vary from an enterprise to another depending on the technological level, while the manufacturing times dependent to feature types.

In the following section we develop the expressions to calculate the elementary times of preparation and of welding.

5.1 Preparation time

The preparation time is essentially made up of machining, oxycutting and grinding time.

Machining time

The machining time is written as follows:

$$t_M = \sum_i (1+\alpha).(t_{ci} + t_{ri}) + t_{im} \quad (2)$$

Where t_{ci} are the cutting times which are depending on the speed linear (in the case of perpendicular cutting) or the material removal rate (in the case of chamfering), tri are the times of return-length for movement of the tool, t_{im} is the unproductive time and a is an adjustment factor.

Oxycutting time
The oxycutting time is expressed by the following equation [7]:

$$t_O = \chi.t^{\eta_r}.L.K_r \quad (3)$$

Where χ denotes the difficulty factor relative to each preparation feature, *t* the plate thickness, η_r a coefficient relating to the curve-fitting calculations, K_r a factor relative to the reduction of the blowtorch cutting speed and *L* represents the length of the preparation feature.

The grinding time
The preparation of Welding joint can be achieved by grinding if the plate thickness is low (less than 4 mm). Also we make a grinding after each oxycutting operation, so that edges of the joints will be smooth. The grinding time can be expressed by this formula:

$$t_G = \frac{L}{Q_l} \quad (4)$$

Where *L* represents the feature length and Q_l denotes the grinding linear rate, which the values are: 750, 500, 375 and 300 mm/min recommended, respectively, for the thicknesses of 10, 20, 30 and 40 mm [2].

5.2 Welding time

The welding time is essentially made up of the post functioning time, the additional time (additional fabrication actions such as changing the electrode, deslagging and chipping) and pointing time.

Post functioning time
The post functioning time is calculated with the following expression:

$$t_{pf} = \varphi.\frac{d}{D_R}.V_f \quad (5)$$

Where φ is a difficulty factor Table II, *d* is the filler density, D_R is the deposition rate and V_f is the volume of filler.

Table II: Proposed values for the difficulty factor "φ" [5].

Welds	V-weld 60°	Fillet weld 90°
Long welds, flat position	1.0	2.0
Short welds, plate, flat steel	1.5	2.5
U, L profiles, tubes	2.0	3.0
I, T profiles	2.5	4.0

Additional time
The Additional time can be estimated as follows:

$$t_{ad} = \kappa.t.L_w \quad (6)$$

Where k= $1{,}2\cdot10^{-3}$ (min/mm^2) is an adjustment factor [5], t is the plate thickness and L_w is the weld length.

Pointing time

The weld pointing assures a constant gap between the two parts to weld all along the welding length. The weld pointing time is given by the following relation:

$$t_{po} = \varphi.\frac{d}{D_R}.\frac{L}{l_b}.\frac{4}{3}.\pi.g^3 \qquad (7)$$

Where φ is the difficulty factor, *d* is the filler density, D_R is the deposition rate, *L* represents the feature length, l_b is the distance between two successive pointing points and *g* is the gap.

6. IMPLEMENTATION OF THE DATA PROCESSING TOOL

We chose an environment implementation which is largely diffused: the Visual Basic language under windows exploitation systems. We have developed our data-processing tool (COSTWELD) thanks to the database management "ACESS". It enables us to rapidly and efficiently define important and strong data-bases.

The structure of COSTWELD is decomposed into three modules (as shown in figure 3) connected to one another and which represent the application interface.

- The product specification Module, it allows the keyboarding of product data (material type, weight and thickness structure) and working conditions (work in building site or in a workshop);
- Module for reconnaissance of the assemblies contained in the product. It makes it possible to define number and types of assemblies, the directions and the positions of welding;
- Module for costs calculation.

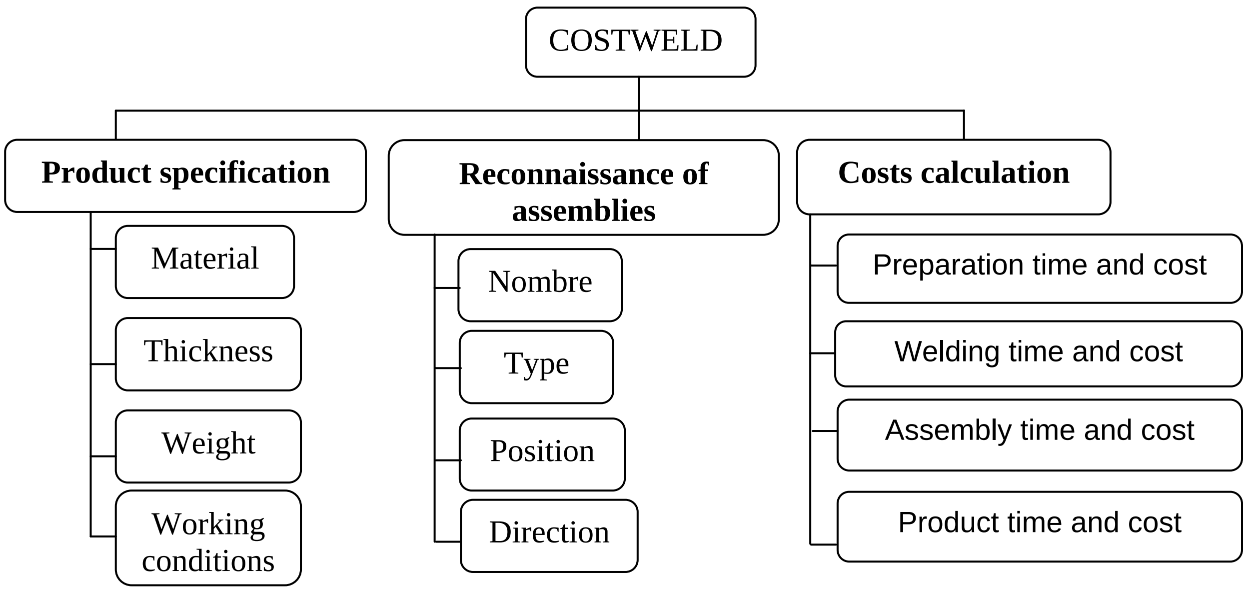


Figure 3: Data processing software architecture.

7. COST ESTIMATE PROCESS

The calculation method is decomposed according to phases described by the algorithm of Figure 4:

- Decomposing the structure into several assemblies;
- Modelling each assembly by a couple (preparation feature, welding feature);
- Calculating the preparation time and cost for each process:

  - Generating the preparation processes, taking into account the manufacturing constraints and metal cutting conditions;
  - Calculating time and cost preparation. Necessary cutting parameters and hourly costs are selected from a database;
  - Selecting the preparation process corresponding to the minimum cost.
- Calculating the welding time and cost. Necessary welding parameters and hourly costs are selected from a database;
- Calculating the assembly cost;
- Calculating the product cost;

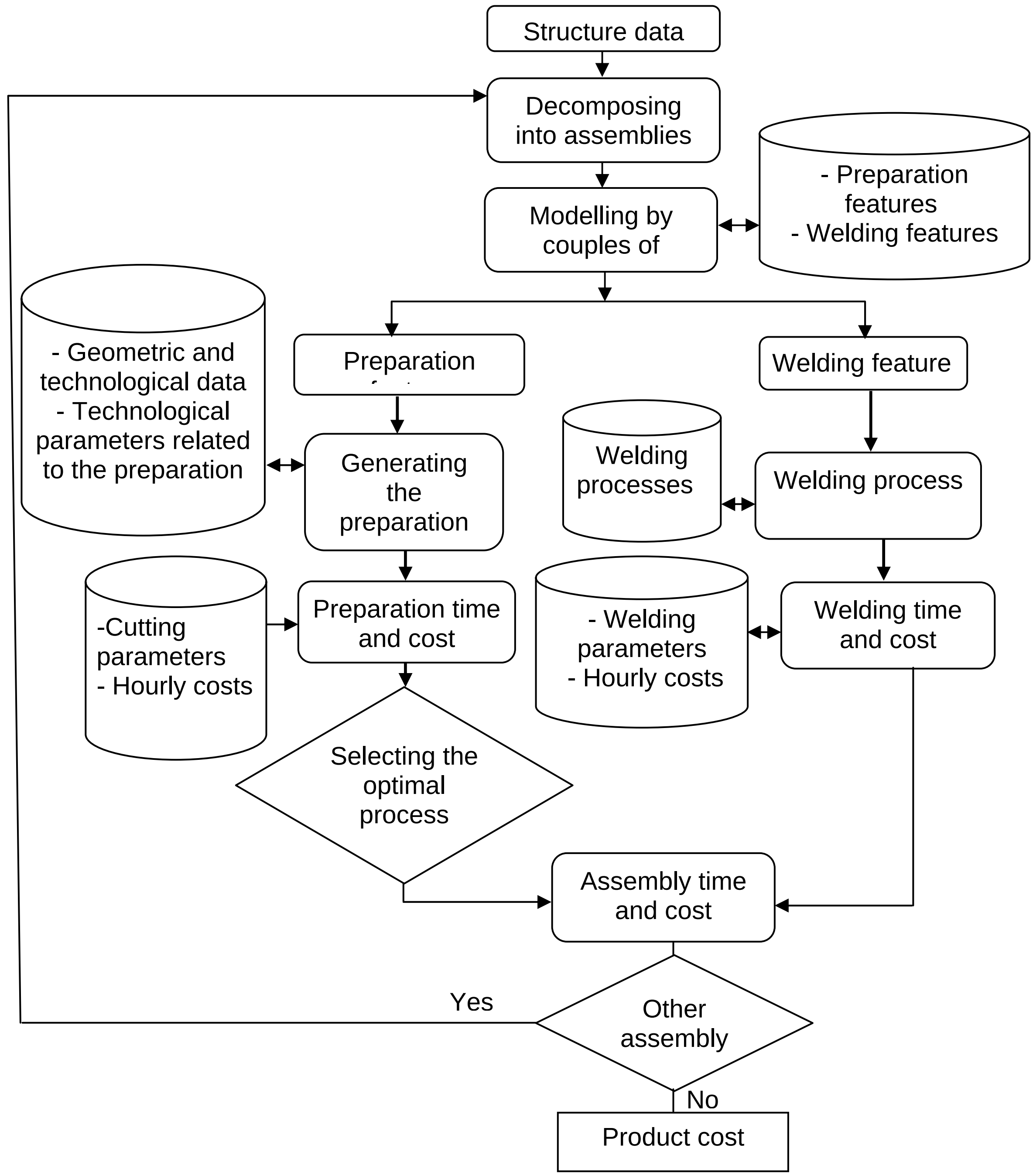


Figure 4: Algorithm of COSTWELD.

8. STUDY OF INDUSTRIAL CASE

In order to show the efficiency of the tool developed, we interpret the example of an industrial project case: structural repair of a ship illustrated in figure 5. Work to be realized is the replacement of a panel on the hull of a ship. The product is composed of four assemblies, two horizontal assemblies (assemblies 1 and 2) and two vertical assemblies (assemblies 3 and 4). The assemblies will be done by a butt weld in only one side. The metal thickness is 12 mm.

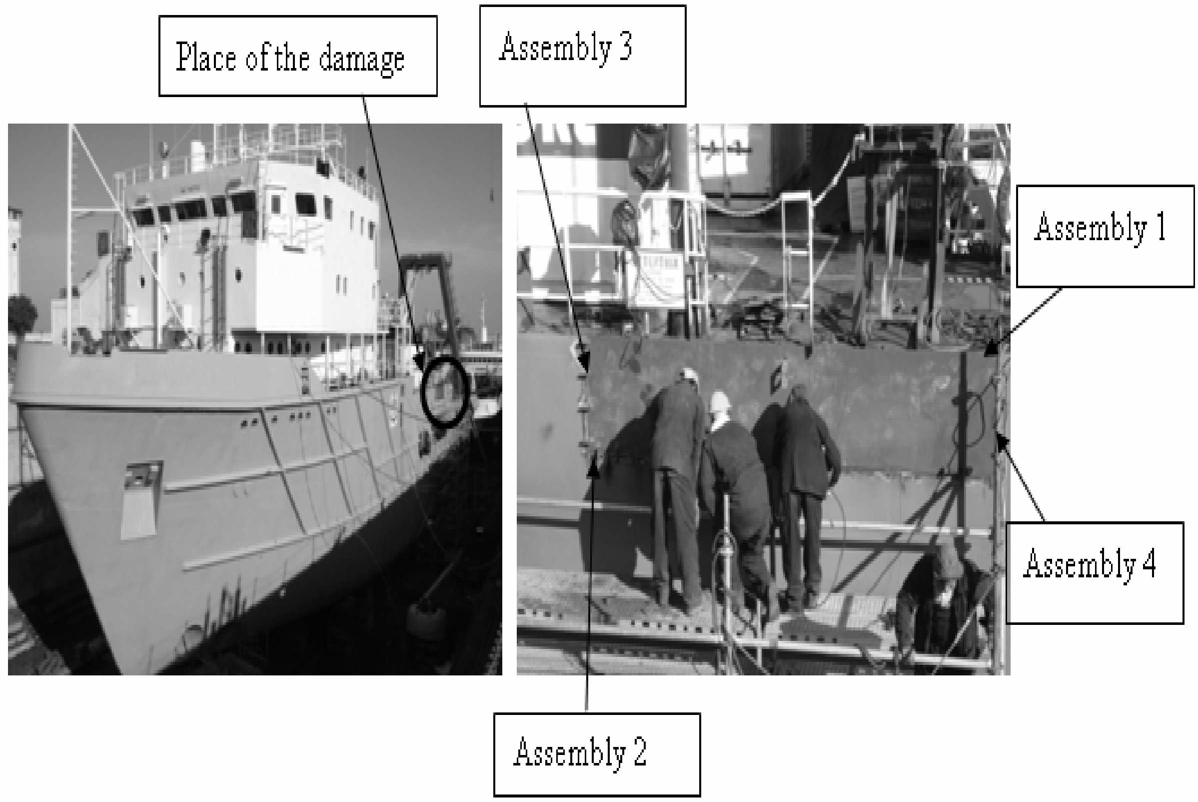


Figure 5: Structural repair of a ship .

8.1 Treatment of the preparation features

Parametrizing of the preparation features
The analysis of product data and characteristics of preparation features, defined in the scope of our approach for the elaboration of the feature mode [7], has led to model the four assemblies by preparation features type ½V whose parameters are defined in table III. The geometrical data of each preparation feature are introduced starting from user interface. While the technological data and the cutting parameters are generated automatically starting from a data base.

Table III: Parametrizing of the preparation features.

Material type	Steel marine
Profile shape	½ V
Thickness	12 mm
Groove angle	60°
Gap	2 mm
Width of a root face	01 mm
Length (assembly 1) Length (assembly 2) Length (assembly 3) Length (assembly 4)	0,5 m 0,5 m 3 m 3 m
Preparation process	**Process 1** : • Oxycutting operation to realize the plan chamfer on the edges of the panel; • Grinding operation of the edges of the panel; • Grinding operation of the panel site on the boat hull. **Process 2 :** • Machining of the plan chamfer on the edges of the panel; • Grinding operation of the panel site on the boat hull.

Selecting the optimal preparation process

In figure 6, we present an analysis of times and costs of preparation which correspond to the preparation processes mentioned in table III, we will select the process 1, which is at minimum cost.

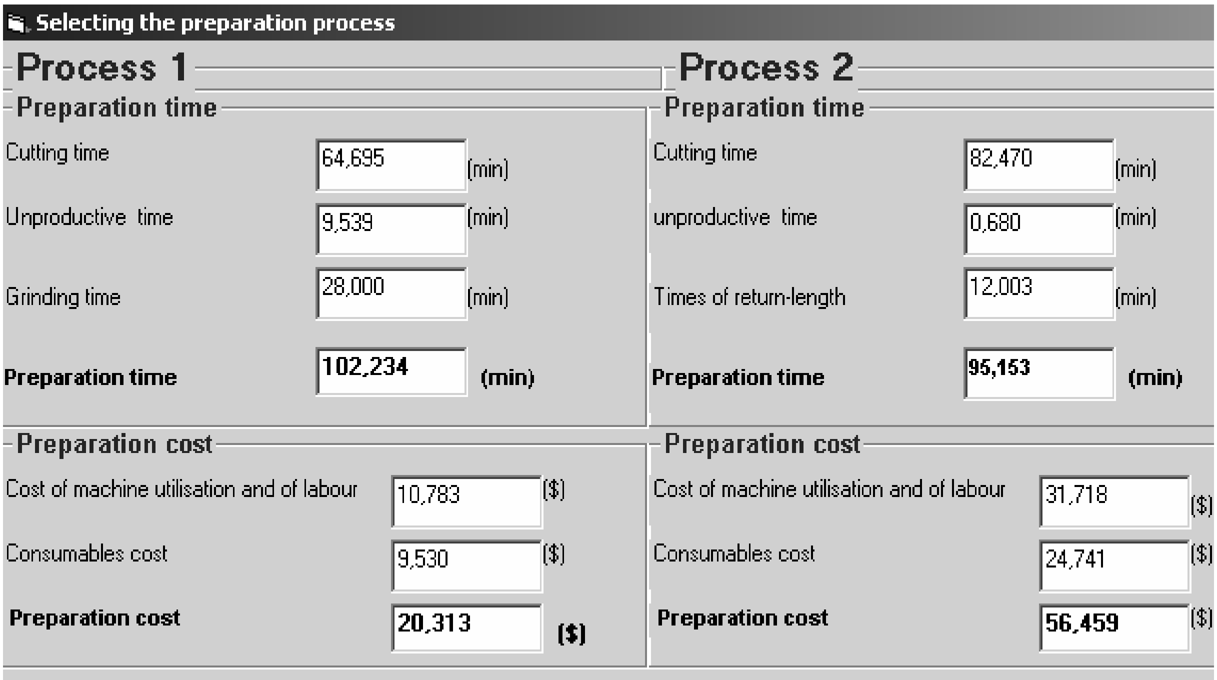


Figure 6: Selecting of the preparation process at minimum cost.

8.2 Treatment of the welding features

Each welding feature has corresponding preparation feature in the same type. The studied product is modelled by the four welding features ½V whose parameters are grouped in table

IV. Starting from the user interface Figure 7, the estimator entered data of the welding feature. Then, welding parameters will be automatically extracted of a database.

Table IV: Data of the welding features.

	Assemblies 1 or 2	**Assemblies 3 or 4**
Welding direction	horizontal	Vertical
Welding position	Cornice	Rising vertical
Correspondent preparation feature	½ V	½ V
Welding process	SMAW	SMAW
Filler density	7,85 kg/dm^3	7,85 kg/dm^3
Deposit rate	2.18 kg/h	1.4 kg/h
Difficulty factor	1,5	2,5
Protection Gas	Acetylene	Acetylene

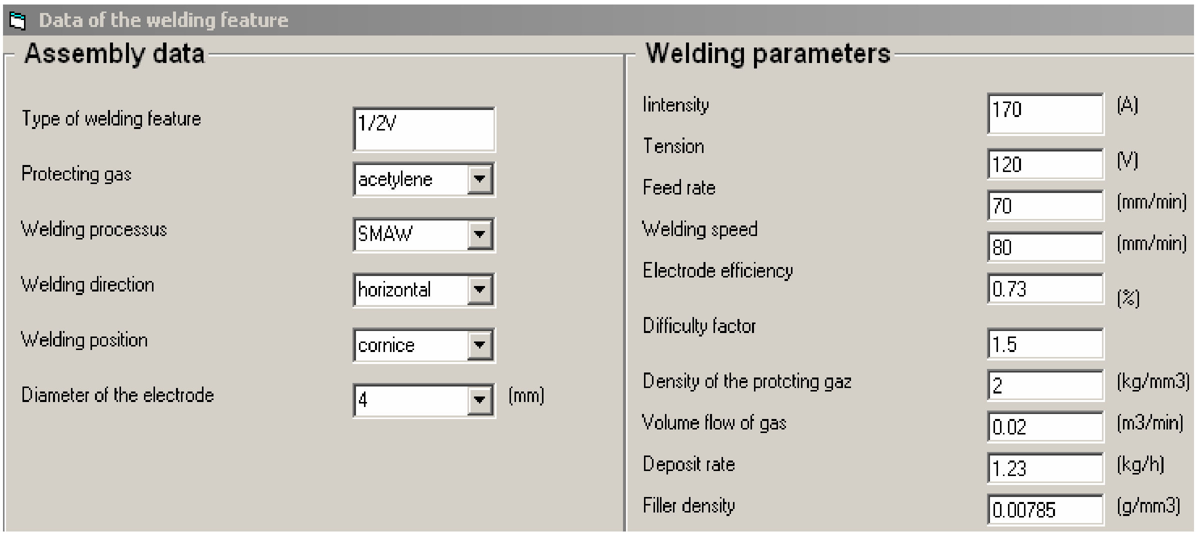


Figure 7: Data of the welding feature type ½ V (assemblies 1 or 2).

8.3 Results and discussion

Results found by COSTWELD

In figure 8, we present an analysis of the calculation results of time and costs of the product:

- Preparation time;
- Preparation cost includes costs of machine utilization, labour and consumables cost;
- Welding time which is made up of post functioning time, additional time and pointing time;
- The welding cost includes costs of welding post utilization, labour, electrode consumption, electricity consumption and protecting gas consumption.

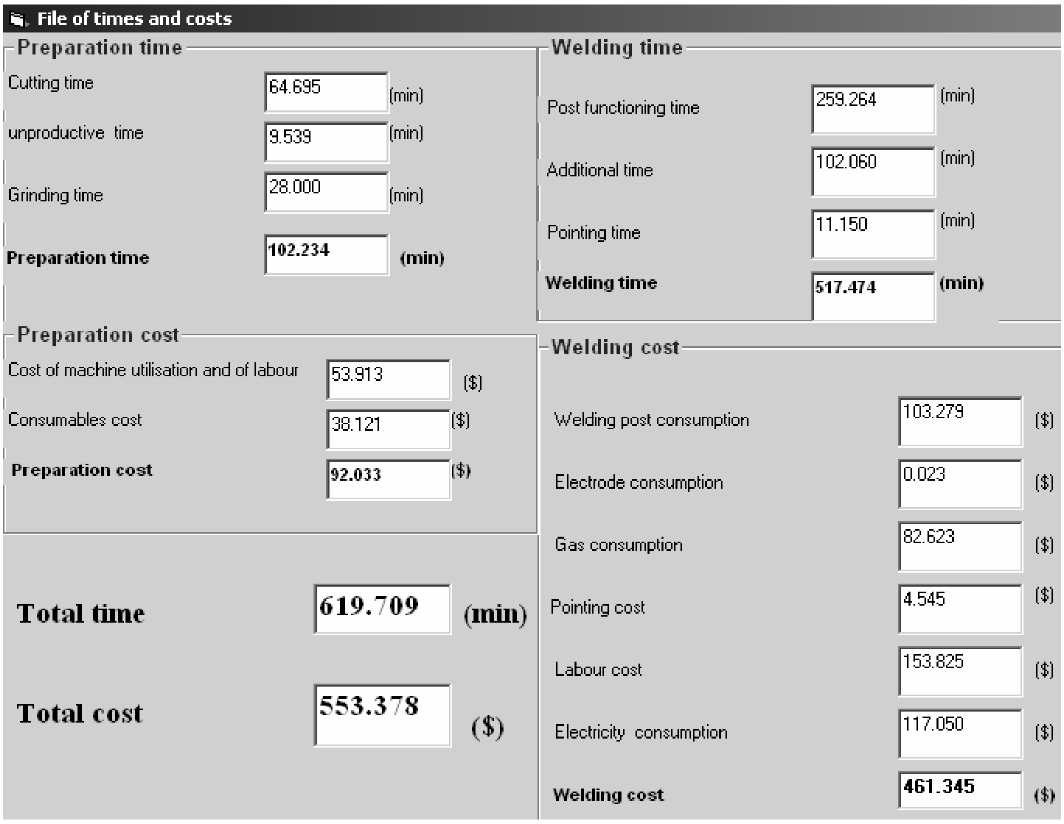


Figure 8: Results of times and costs found by COSTWELD.

Real time

The real times obtained by timing when achievements of this product are as follows:

- Preparation time = 03.13 hr (188 min);
- Post functioning time = 04.97 hr (298 min);
- Pointing time = 25 min;
- Total time = 7.52 hr (511 min).

We note that the error obtained between the time calculated by COSTWELD and the welding time is 12% in this case. This difference is in the interval of the realistic estimates (Figure 1: Freiman curve) which shows the accuracy of our calculating approach.

The calculation of total time of this application is about 08 min, which proves the rapidity of our system.

Results found by CMRT

Under the same working conditions, this product is carried out by CMRT (Mediterranean Company of Repair in Tunisia). The total welding time is estimated at 10.5 hr. This time is obtained by multiplying the total length (panel perimeter = 7 m) by a linear rate (90 min/m). The latter is determined in an intuitive way by an experienced.

We note that the error obtained between the time calculated by CMRT and the real time is grate. It is equal to 39% that is an overestimate that can lead to a refusal by the customer.

The expertise that we have done within the company has enabled us to determine the causes of overestimate:

- The time estimation is based on a global linear rate which can not produce results accurate;
- The procedure is not studied in order to know the operations which have more influence on the overall cost, which necessitates changes targeted cost reduction;
- The techniques used in workshops are not always controlled because of operators training.

Solutions proposed by our model

The solutions suggested by our model to avoid the overestimate of the welding costs are:

- A detailed study of the procedure during both phases of preparation and welding;
- The choice of the preparation process corresponding to the minimum cost;
- The integration of some adjustment factors in the models for calculating time. These factors allow companies to continually adjust their calculations based on the experience.

9. CONCLUSION

In the field of the integrated design, we proposed a system that is capable of estimating the manufacturing times and costs of welded structure at the early stage of design. The system is therefore an important tool for decision-making which allows the designer to choose the competing manufacturing process.

In this paper we presented the functional architecture of COSTWELD. This system is based on an approach by feature that integrates information necessary to define the product and manufacturing process, in order to ensure realistic cost estimation. The various technological parameters (cutting parameters, welding parameters, hourly costs, etc.) are automatically generated from databases.

At the end of this article, the developed study of the industrial case shows that obtained results compared to real time made by welding staff prove the efficiency and the rapidity of our model. Also, COSTWELD is both validated and verified by the company as being a potent system for welding cost estimation.

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