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Product Cost Estimation Using Fuzzy Logic

By

Sohier Mohamed Hussien Baioumy*

Abstract:

Design and development of a product in the early stage of production is based on cost estimation. This paper aims at presenting the compared results of the application of two different approaches –namely regression model and fuzzy logic for the estimation of the cost. Fuzzy cost estimation is based on data needed to estimate the cost, which sometimes is imprecise or uncertain. Also at the early stages of design, the knowledge required to estimate the cost is not available accurately to use the regression technique. Therefore, this paper investigates the possibility of applying fuzzy logic in cost estimation for producing a pressure vessel as a case study.

Keywords:

Cost Estimation, Regression Model, Fuzzy Logic Model.

* Benha High Institute of Technology, Benha University, Egypt.

1. Introduction:

Design and development of a product in the early stage of production is based on cost estimation [1,2]. Good cost estimation helps designers to modify the design to achieve proper performance. Also, it helps the high level designer take a decision when there are more than one alternative available. Overestimating can result in loss of a good customer, while underestimating may lead to a loss to the enterprise. Manufacturing engineers are interested in_cost estimation filed to get a high product quality with low cost. Therefore, cost estimation techniques become important for study. Zhang [3] introduced a feature-based cost estimation approach for packaging products. Ben-arich[4] modified the activity-based cost (ABC) method. Adnan[5] classified cost estimation based on grouping the techniques with similar features into two categories qualitative and quantitative. EL Baradie[6] applied the fuzzy-based system for machining data selection when the relationship between a given workpiece material hardness and the cutting speed is an empirical-imprecise relationship. Fuzzy logic approach is helpful to provide accurate cost estimation when dealing with the uncertainty which comes from the non-process variables or lack of knowledge. Jahan-Shahi[7] applied fuzzy logic in cost estimation to Flat Plate Processing (FPP'S). Jahan-Shahi [8] developed a new approach called Multivalued Fuzzy Sets (MVFS) to deal with non-process variables and decrease the uncertainty to an interval containing optimistic, mostlikely and pessimistic activity-time estimates. Shehab[9] introduced an intelligent system for modeling product cost at the conceptual design stage of product using a fuzzy-based system. There are works for compare between using regression and neural network techniques. Smith[10] studied the possibility of replacing a classic costing method with one based on an artificial neural network. The results obtained in the case study confirm the validity of this innovative method, giving results similar and sometimes better than classical approaches, but with the limitation of a reduced possibility of interpreting and modifying data. Shteb[11] tested and compared the accuracy of the traditional approach of regression analysis with the neural network based cost estimation model in steel pipe bending. The results of comparison provide that the neural network outperformed regression analysis. Verlinden[12] mentioned that the regression is better for sheet metal production if the number of independent input variables is limited.

In literature, cost estimation techniques can summarized to qualitative and the other quantitative [5]. Qualitative cost techniques make a decision as a result of a comparison study of a new product with another one which has been already produced by the plant. By using historical cost data the time necessary to evaluate the cost is reduced. These techniques can be classified into intuitive and analogical techniques. Among the intuitive techniques are cost-based reasoning, fuzzy-logic approach and expert systems [9, 13, 14, 15]. The back-propagation neural-network approach and regression analysis models are considered analogical techniques [10, 11, 12]. Fuzzy-logic approach is helpful to cope with human variable uncertainty. Also, the back-propagation neural-network approaches can deal with nonlinearity problems. However, these techniques can be used only when similar past design is available and it is difficult to deal with the concept "similarity" [16].Quantitative techniques are based on a detailed analysis of the product design and operation process

corresponding to design. In these techniques, cost is calculated using an analytical function of certain variables representing different product parameters or decomposing a product into elementary components (row materials, activities, labors, equipment, etc) and then sum all elements during product production cycle. Quantitative techniques can be classified to parametric [16, 17] and analytical techniques [18, 19]. However, these approaches can be used only if all the characteristics of the product and production process are well defined.
To select which technique can be used is not completely free, because each of them needs different amount of input data and knowledge.
In this paper fuzzy logic approach is investigated to use in cost estimation. This approach becomes a useful means when the knowledge required estimating the cost is not available accurately. This study applies fuzzy logic in cost estimation for producing a presser vessel as a case study.

Section 2 gives the models, section 3 shows the case study, section 4 shows the results of a case study and section 5gives conclusions.

2. Regression model and Fuzzy logic techniques:

2.1 Regression model

Cost estimation using regression model have been used from long time to support cost engineers in different areas [3, 11, 16]. There is a special equation for each case according to statistical test (best subset). This test determines the best property combination to display the relationships between the cost estimation and variables considered. The type of relationships between cost estimation and variables assumed are a prior. The correlation between variables is not acceptable in a regression model. The output results were appraised using the Absolute Relative Error (ARE) defined as;

$$ARE = \frac{|Acual\,\mathrm{cost} - Estimated\,\mathrm{cost}|}{Acual\,\mathrm{cost}} \qquad (1)$$

Using the best subset test for the data available for vessels used in the case study [20] the regression model expresses the relationships between cost and variables as

$$y_i = \lambda_0 + \sum_{k=1}^{p} \lambda_k x_{ik} + \sum_{kk}^{p} \lambda_{kk} x_{ik}^2 + \sum\sum \lambda_{kj} x_{ik} x_{ij} \qquad (2)$$

Where, p is the number of predictor variables, n is the number of sample data i =1,….,n and $\lambda_0, \lambda_1, ..., \lambda_p$ are parameters, $x_{i1,}, ..., x_{ip}$ are known constants [10]

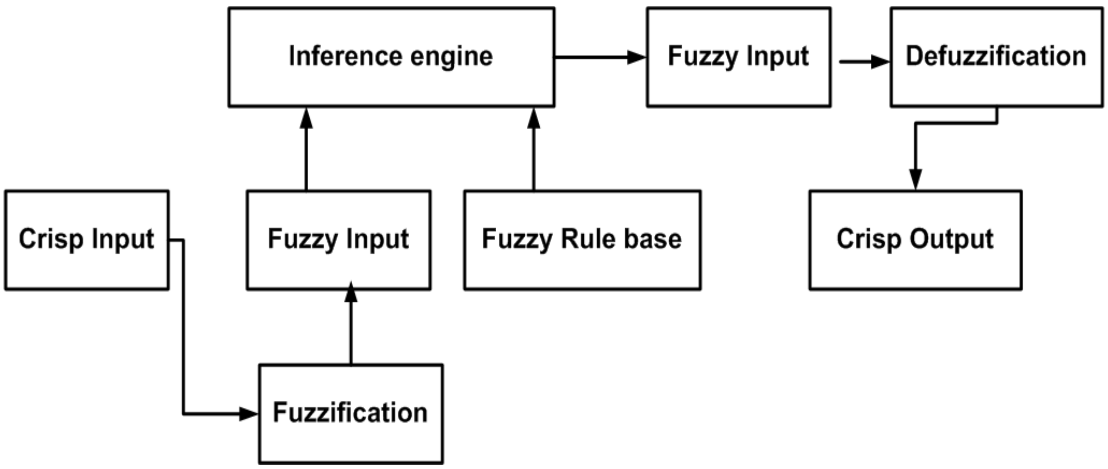
The parameters $\lambda_0, \lambda_k, \lambda_{kk}, \lambda_{kj}$ are determined through least squares regression which minimizes the sum of squares of the deviations of the predicted values $\hat{y}(x)$ from the actual values $y(x)$.

2.2 Fuzzy logic techniques:

A schematic diagram for using fuzzy logic, which is composed of four main steps namely, fuzzification, fuzzy rule base, fuzzy inference engine and defuzzification is shown in Fig 1.

In the fuzzification step, the input of numerical value maps into fuzzy sets of the linguistic associated with that value. A fuzzy set, U, defined on universe of discourse, X, the domain of the fuzzy variable is characterized by a membership function $\mu_U(x)$ which is drown from interval [0, 1] expressed as follows:

$$U = \{(x, \mu_U(x)) \setminus x \in X, \mu_U(x) \in [0,1]\} \quad (3)$$



Figure(1): *General diagram of a fuzzy system*

The membership function defined for each fuzzy set is applied on the input parameter to determine the degree of truth. In fuzzy rule base knowledge acquisition is the main concern of building of the expert system. The knowledge in the form of IF-THEN rules can be obtained from data. Several rules constitute a *fuzzy rule-based system*. Each rule has a premise (the part of the rule between the “IF” and”THEN”) and a conclusion (the part of rule following the "THEN”). The premise part is the collection of conditions connected by AND, OR and NOT logic operators.

In the fuzzy inference engine step, the truth value for the premise of each rule is computed and applied to the conclusion part of each rule. This is done for composed rules usually used the Mamdani min inference operator with the Min/Max inference technique.

The last step in the system is Defuzzification, which convert the fuzzy output sets to a crisp value. There is more than one Defuzzification method; the most common is the *Center of gravity (Centroid)* defined by [21] as:

$$centroid = \frac{\int_x \mu_U(x) x dx}{\int_x \mu_U(x) dx} \quad (4)$$

3. The Case Study:

The objective of research was to compare the result obtained from the application of cost estimation regression method with those achieved with fuzzy logic technique. Gerrard, et al. [20] reported 19 samples obtained from a manufacture of pressure vessel for cost as a function of height (H), diameter (D) and wall thickness (T). For each variable we create a collection of fuzzy sets:

- The degree of potential height determined by (HIGH, MEDIUM, and LOW) can be expressed as (H, M, L). Figure 2 display the membership function, where *m* is called the mode and α and β are called the left and right variability, respectively. Therefore each fuzzy number coefficient A_j can be defined by $A_j = (m, \alpha, \beta)$. Figure 3 shows the complete membership function of height.

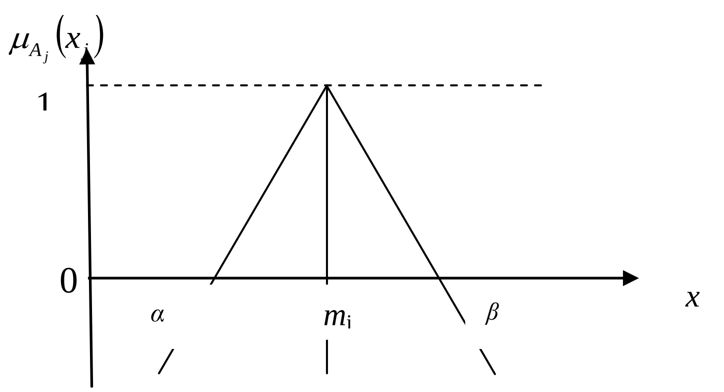
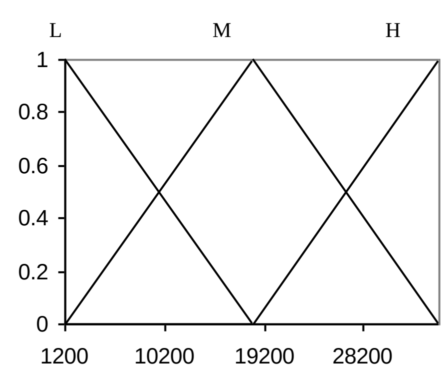


Figure (2): *Fuzzy membership function for symmetric triangular*



Figure(3): *Height membership function*

- The linguistic data of diameter consists of (LARGE (LR), MEDIUM (ME), and NARROW (N)). The membership function of this parameter is shown in Figure 4.

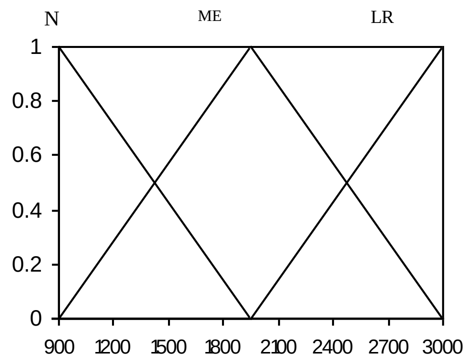


Figure (4): *Diameter membership function*

- The membership function for thickness determines by WIDTH (W), MEDIUM (MD), and THIN (T) is shown in Figure 5.

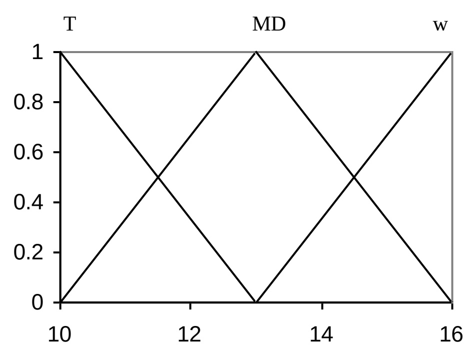


Figure (5): *Thickness membership function*

The three inputs are denoted as:

$\mu_H(A)$, where *A*= (H, M, L) (5)

$\mu_D(B)$, where *B*= (N, ME, LR) (6)

$\mu_T(C)$, where *C*= (W, MD, T) (7)

The output consisting of three membership functions determined by (EXPENSIVE, MEDIUM, SMALL) expressed as (EX, MD, S). Figure 6 shows the complete triangular membership function for the cost estimation.

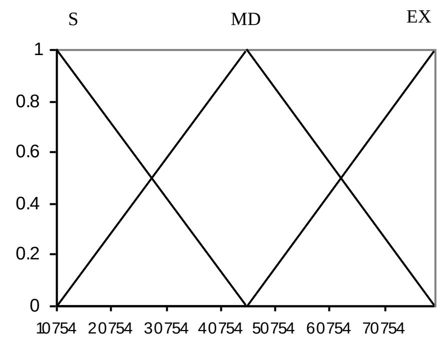


Figure 6: *Cost estimation membership function*

For fuzzy technique, with three input variables each of which consists of three membership functions, a (3x3x3) decision table with 27 rules is constructed. Decision tables provide a means for system rules which can be used to indicate the relationships between the input and output variables of the fuzzy logic system. Table 1 shows the inputs and the output of the fuzzy-rule-base system. A sample of a decision table for cost estimation is illustrated in Table 2.

Table (1): *shows the inputs and the output of fuzzy –rule-based system*.

	Variable	Membership function
Input	Height	High(H) Medium(M) Low(L)
	Diameter	Large(LR) Medium(ME) Narrow(N)
	Thickness	Width(W) Medium(MD) Thin(T)
Output	Cost	Expensive (EX) Medium(M) Small(S)

Table (2): *A sample of a decision table for cost estimation*

Height	Diameter	Thickness	Cost
H	LR	W	EX
M	N	MD	M
H	N	T	S
L	LR	W	EX

The set of rules from the above decision table is:

Rule #1 If [Height is H and Diameter is LR and Thickness is W] Then cost is EX.

Rule #2 If [Height is M and Diameter is N and Thickness is MD] Then cost is MD.

Rule #3 If [Height is H and Diameter is N and Thickness is T] Then cost is S.

Rule #4 If [Height is L and Diameter is LR and Thickness is W] Then cost is EX.

The inference engine will access the fuzzy rule base of the fuzzy expert system to derive linguistic values for the intermediate as well as the output linguistic variables. Aggregation and composition are the main steps in the inference process. During aggregation, each condition in the IF part of the rule is assigned a degree of truth based on the membership function of the corresponding linguistic term. Then to hold the degree of the truth of IF part computes the minimum (MIN) or product (PROD) of the degree of truth.

Rule #1 MIN [Height is H and Diameter is LR and Thickness is W].

The last step is to determine the degrees of truth of each linguistic term of the output of linguistic variable, by computing the maximum (MAX) of the degree of the truth of the rules with the same linguistic terms in the THEN parts. This inference method is called the min-max method. After obtaining the output fuzzy set, it is defuzzified by the center of area method.

4. Experimental results analysis:

The regression and fuzzy logic models have been investigated and validated by comparing the result with the actual costs of nineteen samples available [20]. The statistical analysis indicated the superiority of the second degree order of regression model. The absolute relative error (ARE) for regression is 9.9%. Figure 6 shows the compared estimation cost of the two models with the actual cost. The Table 3 indicates that the maximum and minimum absolute errors of the regression model are 34.33% and 0.32% respectively. Also the maximum and minimum absolute errors of fuzzy model are 140.08% and 0.40% respectively.

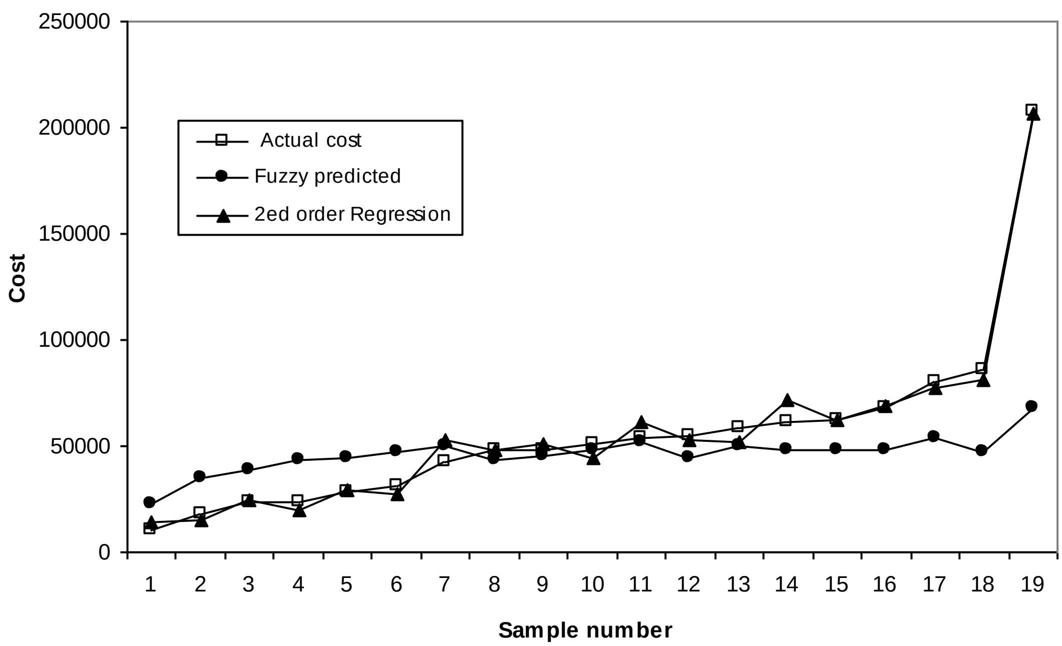


***Figure (6):*A** *comparison between actual cost and estimated cost using fuzzy logic and regression models*

Table (3):*The estimation costs of fuzzy logic and regression models compared to the actual cost*

Sample	Height	Diameter	Thickness	Actual cost	Fuzzy predicted	2ed order Regression predicted	Fuzzy ARE%	2ed order Regression ARE%
1	1200	1066	10	10754	22544	14446	109.63	34.33
2	4500	1526	15	18172	43627	15274	140.08	15.95
3	6500	1500	16	23605	43627	24569	84.82	4.08
4	12250	1200	12	23956	40014	20153	67.03	15.87
5	21800	1050	12	28400	32816	29326	15.55	3.26
6	23300	900	14	31400	47184	27387	50.27	12.78
7	26700	1500	15	42200	50231	52439	19.03	24.26
8	12100	3000	11	47970	37880	47815	21.03	0.32
9	17500	2400	12	48000	44112	50729	8.10	5.69
10	26500	1348	14	51000	47488	43910	6.89	13.90
11	28300	1800	14	53900	47848	60954	11.23	13.09
12	14700	2400	10	54600	23781	52527	56.44	3.80
13	26600	1500	15	58040	51195	52271	11.79	9.94
14	24800	2500	13	61790	45377	72043	26.56	16.59
15	25000	2100	14	61800	47297	62701	23.47	1.46
16	24700	2000	16	67460	67190	68977	0.40	2.25
17	29500	2250	13	80400	45377	76943	43.56	4.30
18	21900	3150	12	85750	37674	80952	56.06	5.60
19	32300	5100	17	207800	68204	206597	67.18	0.58

To analyze and compare the actual and estimated costs ANOVA (Analysis Of Variance) at α equal 5% was used over all experiments. From the p-value of ANOVA in table 4, result proved statistically insignificant for the regression models. The R-square and adjusted R-square in table 4 are more than 99% this confirm the result are very reliable. Also table 5 give p-value of the application fuzzy in cost estimation it is not statistically significant this indicate that fuzzy can used cost estimation. To validate this observation, T-test was used to test the null hyposis that the fuzzy estimated cost is equal regression estimated cost estimated cost. The results are summarized in table 6. The result of the T- test indicated that based on the sample data there is no statistically significant difference between the two methods at level 1%.

Table (4): *Analysis of Variance between actual cost and predicated cost of regression model*

Source of Variation	DF	SS	MS	F	P
Sample	18	63474147352	3526341520	283.07	0.000
Cost level	1	239182	239182	0.02	0.891
Error	18	224235947	12457553		
Total	37	63698622482			

S = 3529.53 R-Sq = 99.65% R-Sq(adj) = 99.28%

Table (5): *Analysis of Variance between actual cost and predicated cost of fuzzy logic model*

Source of Variation	DF	SS	MS	F	p
Sample	18	22323203166	1240177954	1.86	0.099
Cost level	1	1199861913	1199861913	1.80	0.197
Error	18	12023131516	667951751		
Total	37	35546196595			

S = 25844.8 R-Sq = 66.18% R-Sq(adj) = 30.47%

Table(6): **T**-*test for the null hypothesis that the predicated cost of regression model is equal the predicated cost for fuzzy logic model*

Variable	Number of pairs	Mean	St.Dev.
Fuzzy predicated	19	44393.0	11428.5
2ed order regression		55790.1	41967.6

T-value=-1.37 p-value=0.188

5. Conclusions:

This paper compares two different methods for cost estimation. These methods are the regression model and the fuzzy logic method. A simple regression model of the second order was chosen because it is easily applied. The Fuzzy technique has the advantage when the available data required for cost estimation are not accurate enough to use regression method. The comparison revealed that when sufficient data regarding previous production history is available, Fuzzy logic is unable to predict cost as accurate as linear regression. The comparison revealed that the fuzzy logic over predicted the cost in comparison to regression analysis. However, it is expected that fuzzy logic can be used when the available data are imprecise or uncertain in the early stages of design. A model based of on fuzzy logic designed to estimate the cost of repetitive operations in a typical manufacturing environment could support design to cost

References:

[1] French, M., *Conceptual design for engineers*, Springer ,London ,Great Britain, 1999.

[2] Elgh,F., and Cederfeldt,M., *concurrent cost estimation as a tool for enhanced producibility- system development and applicability for producibility studies*, Int.J.Production Economics,109, P.12-26,2007.

[3] Zhang, Y.F.,Fuh,J.Y.H.,and Chan,W.T., *Feature-based cost estimation for packaging products using neural networks,*Computers in Industry, Vol.32, P.95-113,1996.

[4] Ben-arich ,d.,and qian, l., *Activity-based cost management for design and development stage*, Int.J.Production Economics,Vol. 83, P.169-183,2003.

[5] Adnan Niazi, Jian S. Dai, Stavroula Balabani, and Lakmal Seneviratne, *Product cost estimation:technique classification and methodology review*, J. Manufacturing Science and Engineering, Vol. 128, P.563-575, 2006.

[6] EL Baradie,M.A., *A fuzzy logic model for machining data selection*, Int.J.Mach. Tools Manufact., Vol. 37,No. 9,P.1353-1372,1997.

[7] H.Jahan-Shahi, E.shayan and S.Masood, *Cost estimation in flat plate processing using fuzzy sets*, I.J.Computer and Industrial Engineering, Vol. 37, P.485-488,1999.

[8] H.Jahan-Shahi, E.shayan and S.Masood, *Multivalued fuzzy sets in cost/time estimation of flat plate processing*, Int.J.Advanced Manufacturing Technology, Vol. 17, p.751-759, 2001.

[9] Shehab,E.M.,Abdalla,H.S., *Manufacturing cost modeling for concurrent product development*, robotics and computer integrated manufacturing, Vol. 17, P.341-353,2001.

[10] A. E. Smith and A. K. Mason, *Cost estimation predictive modeling: regression versus neural network*, Engineering Economist, Vol. 42,P.137-161, 1996.

[11] Shtub,A.,and Versano,R, *Estimating the cost of steel pipe bending ,A comparison between neural networks and regression analysis* Int.J.Production Economics, Vol. 62, P.201-207,1999.

[12] Verlinden, B.,Duflou, J.R., Collin,P., and Cattrysse,D., *Cost estimation for sheet metal parts using multiple regression and artificial neural networks: a case study* Int.J.Production Economics,Vol.111,P.484-492,2008

[13] Rchman,S., and Guenov,M.D*., A methodology for modeling manufacturing costs at conccptual design*, Comput.Ind.Eng., Vol. 35, P.623-626,1998.

[14] Li-Hua, X., and Yun-Feng,W., *Research on rapid cost evolution based on case-based reasoning*, Integr. Manuf.system., Vol. 10,No. 12,P. 1605-1609,2004.

[15] Ficko,M., Drstvensck, I.,Brezocnik,M.,Balic,J.,and Vaupotic,B., *Prediction of total manufacturing costs for stamping tool on the basis of CAD-model of finished product*, J.Mater.Process. Technol., Vols.164-165, P.1327-1335, May2005.

[16] Cavalieri,S.,Maccarrone,P., and Pinto,R., *Parameteric vs.neural network models for the estimation of production costs: a case study in the automotive industry*, Int.J.Production Economics, Vol. 91, P.165-177,September 2004.

[17] Dewhurst,P.,and Boothroyd,G., *Early cost estimating in product design*, J.Manuf.Syst., Vol.7, No .3,P.183-191,1988.

[18] Jung,J.Y., *Manufacturing cost estimation for machined parts based on manufacturing features*, J.Intell. Manuf., Vol.13, No .4,P.227-238,2002.

[19] Madan,J.,Rao,P.V.M.,and Kundra,T.K.,"*System for early cost estimation of die-cast parts*, Int.J.Produc.Research, Vol. 45, No .20,P.4823-4847,2007.

[20] J. Brass, A.M. Gerrard and D. Peel, *Estimating vessel cost via neural networks*, Proceedings of the 13th International Cost Engineering Congress, London, 1994

[21] Gunadi,W.,Nurcahyo and Siti Mariyam Shamsuddin,Rose Alinda, Noor Md. Sap,

Selection of Defuzzification Method to Obtain Crisp Value for Representing Uncertain Data in a Modified Sweep Algorithm,J. Computer Science and Technology , Vol.3, No. 2,P.22-28,October 2003