International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. VII, No. 1 / 2015

APPLICATION OF MULTIOBJECTIVE METHODS FOR OPTIMIZATION OF MACHINING PROCESS PARAMETERS

Cătălin Gheorghiță, Vlad Gheorghiță

Politehnica University of Bucharest Romania, Department of Manufacturing Technology
Splaiul Independeței, No. 313, 060042, Bucharest, Romania

Corresponding author: Cătălin Gheorghiță: catalin.gheorghita@upb.ro

Abstract: The determination of optimal cutting parameters, is important in increasing the productivity of the machining operations.The response surface methodology which sets the relationship between factors and response, was used for developing the objective function and constraints for determine the models of power milling. The selection for a given problem is made by using methods of multiobjective decision making (MODM) to eliminate unsuitable alternatives, and to select the most suitable alternative. In this paper the methods are used to identify the best solution for the mathematical model of cutting power for milling 30Cr130 Steel.
Key words: Decision Making, SAW method, TOPSIS method, ARAS method, Multi-objective optimization, Milling.

1. INTRODUCTION

The objective of any procedure is to identify appropriate selection criteria, and obtain the most appropriate combination of criteria in relation to the actual requirement. Should identify the criteria that influence the selection choice for a given problem by using simple and logical method to eliminate unsuitable alternatives, and to select the most suitable alternative.

The selection of optimum machining parameters, such as depth of cut, cutting speed and feed, is the most important task to the process planner to achieve the low cost as well as desired quality of machined components, since the economy of machining operations plays an important role in increasing productivity and competitiveness. This purpose can be achieved using different methods: SAW method, TOPSIS method, ARAS method. The application of multiobjective optimization method was applied for solving multiple criteria optimization problem in milling process.

2. METHODOLOGY

For application of these methods were used data, according to table 1, for milling 30Cr130 Steel [1].

Table 1. Objective data of the attributes

Exp. No.	t [mm]	t_1 [mm]	s_z [mm /tooth]	v [m/min]	F_r [N]	P [kW]
1.	0.9	0.4	0.02	190	152.86	0.48
2.	2.4	0.4	0.02	275	183.26	0.84
3.	0.9	2.5	0.02	275	199.49	0.91
4.	2.4	2.5	0.02	190	198.72	0.63
5.	0.9	0.4	0.13	275	314.14	1.44
6.	2.4	0.4	0.13	190	623.35	1.97
7.	0.9	2.5	0.13	190	414.1	1.31
8.	2.4	2.5	0.13	275	659.56	3.02
9.	0.9	1	0.05	229	248.3	0.95
10.	2.4	1	0.05	229	411.03	1.57
11.	1.47	0.4	0.05	229	234.16	0.89
12.	1.47	2.5	0.05	229	354.36	1.35
13.	1.47	1	0.02	229	185.62	0.71
14.	1.47	1	0.13	229	455.66	1.74
15.	1.47	1	0.05	190	263.8	0.84
16.	1.47	1	0.05	275	305.06	1.4
17.	1.47	1	0.05	229	282.86	1.08

The weights of attributes were determined following Digital Logic Method and their values are 0.22 for "t - axial depth", 0.07 for "t_1 - radial depth", 0.1 for "s_z - feed", 0.21 for "v - cutting speed", 0.2 for "F_r - radial force" and 0.2 for "P - power".

The first four attributes are beneficial with higher values, while the others two are useful with lower values. It was argued that methods of multiobjective decision should be used only when the decision attributes can be expressed in identical units of measure.

2.1. Saw Method

Simple Additive Weighting method is also called the weighted sum method and is the simplest, and still the widest used MADM method, [2]. Each attribute is given a weight (w_j), and the sum of all weights must be 1 and each alternative is assessed with regard to every attribute. The overall or composite performance score of an alternative is given by Equation 1.

$$P_i = \sum_{j=1}^{M} w_j \cdot (m_{ij})_{normal} \quad (1)$$

If all the elements of the decision table are normalized, then SAW method can be used for any type and any number of attributes. The alternative with the highest value of P_i is considered as the best alternative.

The normalized values are presented in Table 2.

Table 2. Normalized data of the attributes with SAW method

Exp. No.	t [mm]	t_1 [mm]	s_z [mm/ tooth]	v [m/min]	F_r [N]	P [kW]
1.	0.375	0.16	0.153	0.690	1	1
2.	1	0.16	0.153	1	0.834	0.571
3.	0.375	1	0.153	1	0.766	0.527
4.	1	1	0.153	0.690	0.769	0.761
5.	0.375	0.16	1	1	0.486	0.333
6.	1	0.16	1	0.690	0.245	0.243
7.	0.375	1	1	0.690	0.369	0.366
8.	1	1	1	1	0.231	0.158
9.	0.375	0.4	0.384	0.832	0.615	0.505
10.	1	0.4	0.384	0.832	0.371	0.305
11.	0.612	0.16	0.384	0.832	0.652	0.539
12.	0.612	1	0.384	0.832	0.431	0.355
13.	0.612	0.4	0.153	0.832	0.823	0.676
14.	0.612	0.4	1	0.832	0.335	0.275
15.	0.612	0.4	0.384	0.690	0.579	0.571
16.	0.612	0.4	0.384	1	0.501	0.342
17.	0.612	0.4	0.384	0.832	0.540	0.444

Table 3. The machinability index

Exp. No.	t [mm]	t_1 [mm]	S_z [mm/ tooth]	v [m/ min]	F_r [N]	P [kW]	P_i
1.	0.082	0.011	0.015	0.145	0.2	0.2	0.654
2.	0.22	0.011	0.015	0.21	0.166	0.114	0.737
3.	0.082	0.07	0.015	0.21	0.153	0.105	0.636
4.	0.22	0.07	0.015	0.145	0.153	0.152	0.756
5.	0.082	0.011	0.1	0.21	0.097	0.066	0.567
6.	0.22	0.011	0.1	0.145	0.049	0.048	0.574
7.	0.082	0.07	0.1	0.145	0.073	0.073	0.544
8.	0.22	0.07	0.1	0.21	0.046	0.031	0.678
9.	0.082	0.028	0.038	0.174	0.123	0.101	0.548
10.	0.22	0.028	0.038	0.174	0.074	0.061	0.596
11.	0.134	0.012	0.038	0.174	0.130	0.107	0.597
12.	0.134	0.07	0.038	0.174	0.086	0.071	0.575
13.	0.134	0.028	0.015	0.174	0.164	0.135	0.652
14.	0.134	0.028	0.1	0.174	0.067	0.055	0.559
15.	0.134	0.028	0.038	0.145	0.115	0.114	0.576
16.	0.134	0.028	0.038	0.21	0.100	0.068	0.579
17.	0.134	0.028	0.038	0.174	0.108	0.088	0.573

Using the weights and the normalized data of the attributes for different alternatives, the machinability index values are calculated and arranged in descending order of the index (table 3). According to SAW method, the combination of parameters number 4 emerged as the best option.

2.2. Aras Method

Additive Ratio Assessment Method is based on quantitative measurements and utility theory [3]. A utility function value determines the relative efficiency of an alternative over the other alternatives. This utility function is directly proportional to the relative effect of the criteria values and weight importance of the considered criteria. The utility value of an alternative is determined by a comparison of variant with the best alternative. The steps of ARAS method are presented as follows:

For beneficial and non-beneficial attributes, the normalization procedure follows two steps. At first, the reciprocal of each criterion with respect to all the alternatives is taken as follows:

$$x_{ij}^* = \frac{1}{x_{ij}} \quad (2)$$

In the second step, the normalized values are calculated and presented in table 4:

$$R = [r_{ij}]_{max} = \frac{x_{ij}^*}{\sum_{i=1}^{m} x_{ij}^*} \quad (3)$$

Table 4. Normalized data of the attributes with ARAS method

Exp. No.	t [mm]	t_1 [mm]	S_z [mm/ tooth]	v [m/ min]	F_r [N]	P [kW]
1.	0.090	0.116	0.117	0.070	0.105	0.125
2.	0.034	0.116	0.117	0.048	0.087	0.072
3.	0.090	0.019	0.117	0.048	0.080	0.066
4.	0.034	0.019	0.117	0.070	0.081	0.095
5.	0.090	0.116	0.018	0.048	0.051	0.042
6.	0.034	0.116	0.018	0.070	0.026	0.031
7.	0.090	0.019	0.018	0.070	0.039	0.046
8.	0.034	0.019	0.018	0.048	0.024	0.020
9.	0.090	0.047	0.047	0.058	0.064	0.063
10.	0.034	0.047	0.047	0.058	0.039	0.038
11.	0.055	0.116	0.047	0.058	0.068	0.068
12.	0.055	0.019	0.047	0.058	0.045	0.045
13.	0.055	0.047	0.117	0.058	0.086	0.085
14.	0.055	0.047	0.018	0.058	0.035	0.035
15.	0.055	0.047	0.047	0.070	0.061	0.072
16.	0.055	0.047	0.047	0.048	0.052	0.043
17.	0.055	0.047	0.047	0.058	0.057	0.056

The weighted normalized decision matrix D is determined in table 5.

$$D = [y_{ij}]_{max} = r_{ij} \cdot w_j \quad (4)$$

Determine the optimality function (S_i) for i-th alternative.

$$S_i = \sum_{j=1}^{n} y_{ij} \quad (5)$$

Table 5. The weighted normalized decision matrix

Exp. No.	t [mm]	t_1 [mm]	S_z [mm/tooth]	v [m/min]	F_r [N]	P [kW]
1.	0.020	0.008	0.012	0.015	0.021	0.025
2.	0.007	0.008	0.012	0.010	0.017	0.014
3.	0.020	0.001	0.012	0.010	0.016	0.013
4.	0.007	0.001	0.012	0.015	0.016	0.019
5.	0.020	0.008	0.002	0.010	0.010	0.008
6.	0.007	0.008	0.002	0.015	0.005	0.006
7.	0.020	0.001	0.002	0.015	0.008	0.009
8.	0.007	0.001	0.002	0.010	0.005	0.004
9.	0.020	0.003	0.005	0.012	0.013	0.013
10.	0.007	0.003	0.005	0.012	0.008	0.008
11.	0.012	0.008	0.005	0.012	0.014	0.014
12.	0.012	0.001	0.005	0.012	0.009	0.009
13.	0.012	0.003	0.012	0.012	0.017	0.017
14.	0.012	0.003	0.002	0.012	0.007	0.007
15.	0.012	0.003	0.005	0.015	0.012	0.014
16.	0.012	0.003	0.005	0.010	0.010	0.009
17.	0.012	0.003	0.005	0.012	0.011	0.011

Higher the S_i value, the better is the alternative. The optimality function S_i has a direct and proportional relationship with the values in the decision matrix and criteria weights.

Calculate the degree of utility (U_i) for each alternative. It is determined by a comparison of the variant with the most efficient one (S_0). The equation used for calculation of the utility degree (U_i) is given as below:

$$U_i = \frac{S_1}{S_0} \qquad (6)$$

The utility values of the alternatives range from 0% to 100%. The alternative with the highest utility value (U_{max}) is the best choice among the candidate alternatives.

Table 6. The utility value

Exp. No.	S_i	U[%]
1.	0.100	100
2.	0.069	68.99003
3.	0.072	71.94335
4.	0.070	70.11673
5.	0.058	58.21944
6.	0.043	43.18642
7.	0.054	54.31296
8.	0.029	29.42646
9.	0.065	65.24492
10.	0.042	42.87601
11.	0.064	64.1199
12.	0.048	48.08024
13.	0.073	73.21645
14.	0.043	43.16816
15.	0.061	61.02046
16.	0.049	49.12878
17.	0.054	54.52857

According to ARAS method, the combination of parameters number 1 emerged as the best option.

2.3. Topsis Method

Technique for Order Preference by Similarity to Ideal Solution method is based on the concept that the chosen alternative should have the shortest Euclidean distance from the ideal solution, and the farthest from the negative ideal solution. The ideal solution is a hypothetical solution for which all attribute values correspond to the maximum attribute values in the database comprising the satisfying solutions; the negative ideal solution is the hypothetical solution for which all attribute values correspond to the minimum attribute values in the database. The main procedure of the TOPSIS method for the selection of the best alternative from among those available is described below. In order to make a comparison between properties, the elements of the matrix are normalized as:

$$r_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \qquad (7)$$

The entropy Ej of the normalized values of a j-th attribute is defined as follows:

$$E_j = -k \sum_{i=1}^{m} r_{ij} \cdot log r_{ij} \qquad (8)$$

where $k = 1/\log m$. E_j is also in the range of (0,1). The weight factor v_j for the j-th attribute is defined as:

$$w_j = \frac{1-E_j}{\sum_{j=1}^{n}(1-E_j)} \qquad (9)$$

Table 7. Entropy and index of performance

	t [mm]	t_1 [mm]	S_z [mm/tooth]	v [m/min]	F_r [N]	P [kW]
Ej	1.201	1.138	1.133	1.226	1.190	1.185
1-Ej	-0.201	-0.138	-0.133	-0.226	-0.190	-0.185
wj	0.187	0.128	0.124	0.210	0.177	0.172
sj*wj	0.041	0.008	0.012	0.044	0.035	0.034
wj*	0.232	0.050	0.070	0.249	0.200	0.195

If r_{ij} for an index has wide scatter, that yields a small value of E_j, which gives the large weight factor in turn. If one wants to add the subjective weight s_j (Digital Logic Method), particular constraints of design, and so on, the weight factor is revised as:

$$w_j^* = \frac{s_j \cdot w_j}{\sum_{j=1}^{n} s_j \cdot w_j} \tag{10}$$

With the weight factors, the cutting parameters matrix is reconstructed in table 8:

$$v_{ij} = w_j^* \cdot r_{ij} \tag{11}$$

Table 8. The matrix with the weight factors

Exp. No.	t [mm]	t_1 [mm]	S_z [mm/ tooth]	v [m/ min]	F_r [N]	P [kW]
1.	0.0078	0.0009	0.0012	0.0120	0.0055	0.0044
2.	0.0208	0.0009	0.0012	0.0174	0.0066	0.0077
3.	0.0078	0.0059	0.0012	0.0174	0.0072	0.0084
4.	0.0208	0.0059	0.0012	0.0120	0.0072	0.0058
5.	0.0078	0.0009	0.0082	0.0174	0.0114	0.0133
6.	0.0208	0.0009	0.0082	0.0120	0.0227	0.0182
7.	0.0078	0.0059	0.0082	0.0120	0.0151	0.0121
8.	0.0208	0.0059	0.0082	0.0174	0.0241	0.0279
9.	0.0078	0.0023	0.0031	0.0145	0.0090	0.0087
10.	0.0208	0.0023	0.0031	0.0145	0.0150	0.0145
11.	0.0127	0.0009	0.0031	0.0145	0.0085	0.0082
12.	0.0127	0.0059	0.0031	0.0145	0.0129	0.0124
13.	0.0127	0.0023	0.0012	0.0145	0.0067	0.0065
14.	0.0127	0.0023	0.0082	0.0145	0.0166	0.0161
15.	0.0127	0.0023	0.0031	0.0120	0.0096	0.0077
16.	0.0127	0.0023	0.0031	0.0174	0.0111	0.0129
17.	0.0127	0.0023	0.0031	0.0145	0.0103	0.0099

The basic idea of TOPSIS is that the best decision should be made to be closest to the ideal and farthest from the non-ideal. The element with the most preferred value for the *j*-th attribute is defined as the ideal v_j^+, and the element with the least preferred value is defined as the non-ideal v_j^-.
For the *i*-th combination of cutting parameters, the separation measures which indicate distances from the ideal and the non-ideal, are defined as:

$$s_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \tag{12}$$

$$s_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{13}$$

Finally, selection of combination should be made upon the separation measures, S_i^+ and S_i^- in table 9, the ideal combination has a maximum S_i^- and minimum S_i^+. For the purpose the relative closeness C_i^+ is introduced and defined as follows:

$$C_i^+ = \frac{s_i^-}{s_i^+ + s_i^-} \tag{14}$$

where C_i^+ is close to 1, the combination is regarded as ideal; and when C_i^+ is close to 0, the combination is regarded as non-ideal.

Table 9. The separation measures and the relative closeness

Exp. No.	S_i+	S_i-	C_i+
1.	0.01653	0.029931	0.64422
2.	0.009292	0.030159	0.764468
3.	0.015428	0.0268	0.634641
4.	0.009126	0.031111	0.773193
5.	0.017562	0.021257	0.547594
6.	0.023234	0.017763	0.433279
7.	0.018693	0.020127	0.518475
8.	0.029931	0.01653	0.35578
9.	0.015758	0.024596	0.609504
10.	0.01543	0.021084	0.577422
11.	0.012162	0.025786	0.679505
12.	0.014801	0.020555	0.581368
13.	0.011907	0.028108	0.702438
14.	0.018575	0.016673	0.473014
15.	0.012681	0.025431	0.667267
16.	0.014405	0.021266	0.596173
17.	0.012885	0.02342	0.645096

According to TOPSIS method, the combination of parameters number 4 emerged as the best option.

3. RESULTS AND DISCUSSIONS

These methods have been implemented into Matlab application that allows: the choice of multiobjective methods (figure 1), determining the type of parameters and their definition (figure 2 and figure 3), and getting data from file or manual data entry (figure 4).

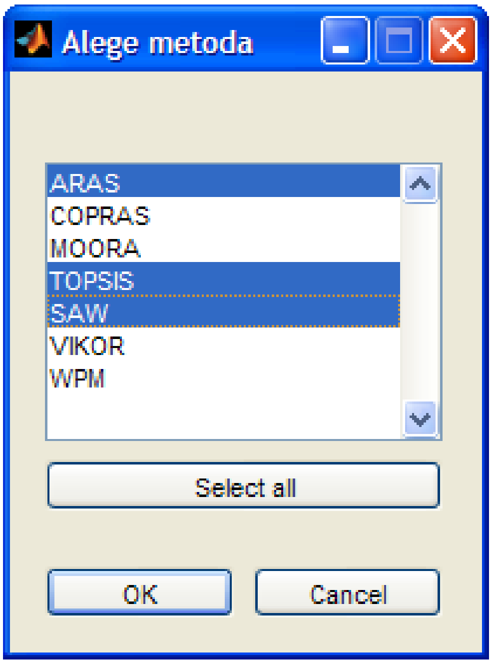


Fig. 1. The choice of multiobjective methods

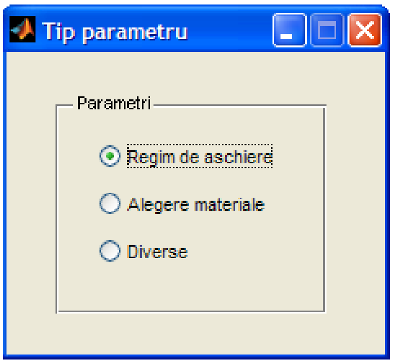


Fig. 2. Parameter type

Fig. 3. Defining parameters

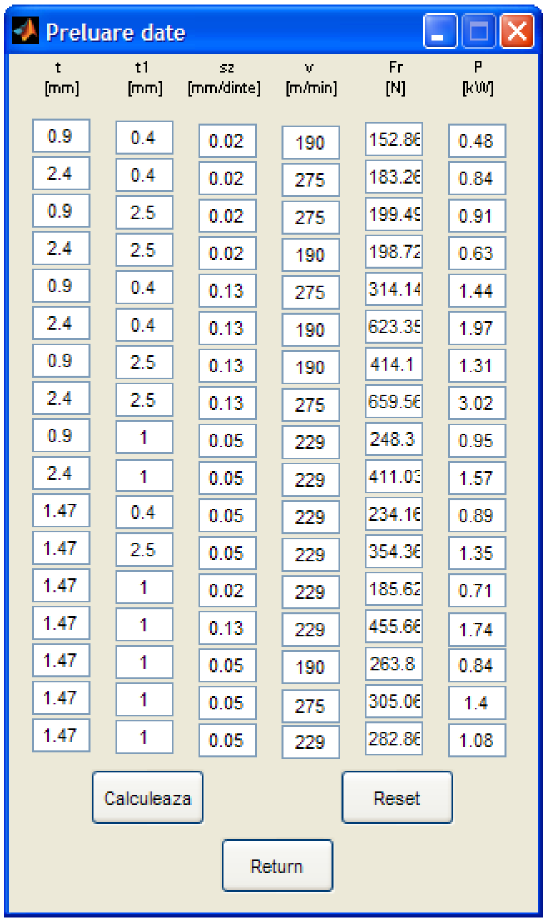


Fig. 4. Data from files

The weights are assigned to each attribute as shown in figure 5.

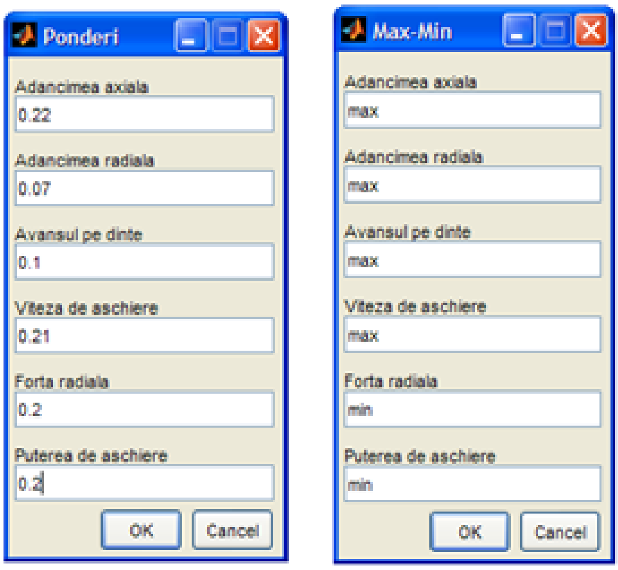
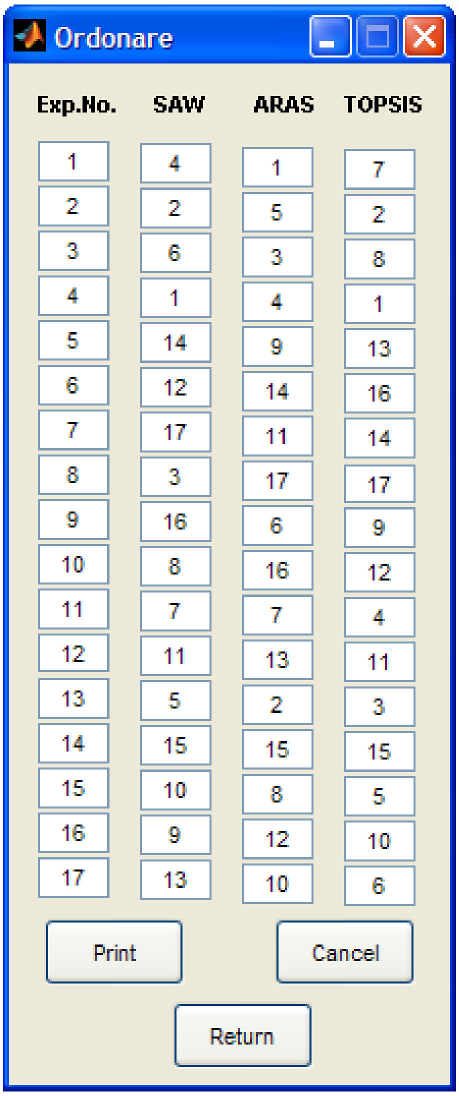


Fig. 5. Property information

Then with the help of the application, the values required for each method are calculated in order to achieve a hierarchy. The ranking with all 3 chosen methods are presented in figure 6.



Exp.No.	SAW	ARAS	TOPSIS
1	4	1	7
2	2	5	2
3	6	3	8
4	1	4	1
5	14	9	13
6	12	14	16
7	17	11	14
8	3	17	17
9	16	6	9
10	8	16	12
11	7	7	4
12	11	13	11
13	5	2	3
14	15	15	15
15	10	8	5
16	9	12	10
17	13	10	6

Fig. 6. The ranking of methods

To determine power model for milling 30Cr130 Steel, cutting parameters (axial depth, radial depth, feed, cutting speed, radial force) were considered independent variables and the cutting power was dependent variable.

The suitable model for the range of parameters values was the first order power prediction model. This model is simple and would be used for optimization of the milling process, [1].

Two of the ranking methods used (SAW, TOPSIS) determined that the best option is the combination of the following parameters: $t = 2.4$ [mm], $t_1 = 2.5$ [mm], $s_z = 0.02$ [mm/tooth], $v=190$ [m/min], $F_r = 198.72$ [N], $P=0.63$ [kW]. The cutting parameters established determine a higher productivity of processing.

4. CONCLUSIONS

To select the optimum machining parameters, the multi-objective optimization methods can be used. The methods can be applied for any type of decision problem involving any number of criteria.

Matlab application allows a quick and easy calculation and a rapid modification of a combination of parameters.

5. REFERENCES

1. Gheorghiță C. (2011). *Determination of the Mathematical model of Power for Milling 30Cr130 Steel*, Modtech Publishing House, 453-456, ISSN 2069-6736, Chișinău.

2. Venkata Rao R. (2007). *Decision Making in the Manufacturing Environment*, Springer, 27-35 ISBN-978-1-84628-818-0, London.

3. Chatterjee P., Chakraborty S. (2013). *Gear material selection using complex proportional assessment and additive ratio assessment-based approaches: a comparative study*, International Journal of Materials, Science and Engineering, Vol I, 104-111, ISSN 2315-4527.

4. Gheorghiță C. (2005). *Entropy concept in materials selection*, The 4th International Conference on Advanced Manufacturing Technologies, Editura Academiei Române, 45-48, ISBN 973-27-1254-6, Bucharest.

5. Holly M. (2012) *Matlab for Engineers Third Edition*, Pearson Education, 581-598, ISBN-10: 0-13-210325-7, New Jersey.

Received: February 26, 2015 / Accepted: June 15, 2015 / Paper available online: June 20, 2015 © International Journal of Modern Manufacturing Technologies.