Izbor glodala sa izmenljivim pločicama primenom metoda CRITIC i ROV višekriterijumskog odlučivanja

Jelena Stanojković^{1*}, Miroslav Radovanović¹

¹Mašinski fakultet, Univerzitet u Nišu, Srbija

U radu je predstavljen izbor glodala sa izmenljivim pločicama za obradu legure aluminijuma primenom metodologije višekriterijumskog odlučivanja. Na osnovu četiri kriterijuma (broj zuba, brzina rezanja, korak i cena) izvršen je izbor najbolje alternative od četiri glodala sa izmenljivim pločicama različitih proizvođača reznih alata. Za višekriterijumski izbor primenjena je ROV metoda i CRITIC metoda za određivanje težinskih koeficijenata.

Ključne reči: glodala sa izmenljivim pločicama, CRITIC, ROV, višekriterijumsko odlučivanje

1. UVOD

Glodanje je jedan od najvažnijih postupaka obrade koji se koristi u proizvodnji. To je postupak obrade odvajanjem čestica obradnih površina proizvoljnih oblika. Izvodi se na altnim mašinama, glodalicama. Obrada glodanjem je postupak obrade ravnih površina, žlebova, profilisanih kontura, površina specijalnog i složenog oblika. Glavno kretanje je obrtno kretanje definisano brzinom rezanja V_c . Pomoćno kretanje je pravolinijsko kretanje predmeta obrade $i/$ ili alata i određeno je brzinom pomoćnog kretanja V_f aksijalnim pomeranjem u jedinici, odnosno pomoćno kretanje može biti definisano korakom po zubu f_z , aksijalnim pomeranjem za jedan zub alata i korakom f , aksijalnim pomeranjem za jedan obrtaj alata

Izbor reznog alata za obradu konkretnog materijalu je složen zadatak. Izbor glodala sa izmenljivim pločicama prečnika 16 mm za obradu legure aluminijuma 6082-T6 može se olakšati korišćenjem metode višekriterijumskog odlučivanja.

Višekriterijumsko odlučivanje je jedna od najpoznatijih oblasti u teoriji odlučivanja koja koristi skup matematičkih metoda i alata za rešavanje realnih problema u različitim oblastima. Problem višekriterijumske analize uključuje veći broj kriterijuma, odnosno ciljeva koje treba uzeti u obzir prilikom donošenja odluke [1].

Rešavanje problema višekriterijumskog odlučivanja može imati sledeće ciljeve [1, 2, 3]:

- Određivanje najbolje alternative
- Grupisanje alternativa u klase
- Rangiranje alternativa prema ukupnoj preferenciji
- Opis alternativa.

Idealno rešenje je ono koje ima najbolje vrednosti atributa u odnosu na razmatrane kriterijume. Takvo rešenje je retko praksi, a njegov značaj je to što se rešavanjem problema višekriterijumskog odlučivanja zapravo teži takvom rešenju [1, 4].

U ovom radu za rešavanje problema izbora glodala sa izmenljivim pločicama za obradu legure aluminijuma primenjena je metoda CRITIC za određivanje težinskih koeficijenata i metoda ROV višekriterijumskog odlučivanja za određivanje najbolje alternative (različiti proizvođači reznih alata) na osnovu zadatih kriterijuma (broj zuba, brzina rezanja, korak i cena).

2. ODREĐIVANJE TEŽINSKIH KOEFICIJENATA PRIMENOM METODE CRITIC

Realni problemi višekriterijumskog odlučivanja najčešće nemaju kriterijume istog značaja, pa pri rešavanju problema donosilac odluke mora odrediti stepen značaja svakog kriterijuma. Stepem značaja svakog kriterijuma pri višekriterijumskom odlučivanju određuje se težinskim koeficijentom, pri čemu je suma težinskih koeficijenata jednaka jedinici.

Određivanje težinskih koeficijenata je jedan od najvažnijih problema pri višekriterijumskom odlučivanju [1]. Od metode rešavanja problema razlikuje se i uticaj težinskih koeficijenata na dobijeno rešenje, njihova mala promena može drastično da utiče na rang alternativa [5].

Postoji veliki broj metoda za određivanje težinskih koeficijenata. Metode za određivanje težinskih koeficijenata mogu biti [1, 6]:

- subjektivne metode i
- objektivne metode.

Subjektivne metode zasnovane su na određivanju težinskih koeficijenata na osnovu informacija dobijene od donosioca odluke. U subjektivne metode za određivanje težinskih koeficijenata spadaju [1, 4]:

- Metoda srednjih vrednosti,
- Metoda aproksimacije,
- Metoda proporcije,
- Metoda sopstvenih vrednosti,
- Metoda aditivne normalizacije,
- Metoda modifikovane digitalne logike, i
- Metoda rangiranja.

Objektivne metode zanemaruju mišljenje donosilaca odluke i zasnovane su na određivanju težinskih koeficijenata primenom određenih matematičkih jenačina. U objektivne metode za određivanje težinskih koeficijenata spadaju [1, 4]:

- Metoda CRITIC,
- Metoda FANMA,
- Metoda standardne devijacija,
- Metoda entropije.

Problemi određivanja težinskih koeficijenata su godinama predmet istraživanja i naučnih rasprava.

*Kontakt adresa autora Aleksandra Medvedeva 14, Niš, stanojkovic.jelena89@gmail.com

Za određivanje težinskih koeficijenata potrebno je definisati alternative i kriterijume na osnovu kojih će se vršiti izbor glodala sa izmenljivim pločicama za obradu legure aluminijuma 6082-T6. U tabeli 1. predstavljene su četiri alternative (glodala sa izmenljivim pločicama od tvrdog metala različitih proizvođača reznih alata Seco,

Iscar i TeaguTec), dok su kriterijumi: broj zuba glodala, brzina rezanja, korak i cena. Cilj je izabrati glodalo sa izmenljivim pločicama koje ima maksimalni broj zuba, brzinu rezanja i korak, a minimalnu cenu.

Tabela 1: Alternative i kriterijumi

Alternative		Kriterijumi			
Glodala sa izmenljivim pločicama		C1	C2	C3	C4
		Broj zuba zn	Brzina rezanja Vc [m/min]	Korak po zubu fz [mm/zubu]	Cena [€]
		max	max	max	min
A1	R217.69-1416.0-10-2A XOEX10T308FR-E05 H15 Seco	2	580	0.19	195
A2	HM90 E90A-D16-2-C16 ADCR 1003DFE-P IC28 Iscar	2	640	0.25	220
A3	TE90AX-316-16-06 AXCT 060 204R-AL K10 TeaguTec	3	620	0.2	160
A4	R217.69-1616.0-06-3N XOEX060204FR-E03 H15 Seco	3	670	0.12	215

Metoda CRITIC (Criteria Importance Through Intercriteria Correlation) je metoda za određivanje objektivnih vrednosti težinskih koeficijenata. Metoda CRITIC zasniva se na analitičkom ispitivanju matrice odlučivanja, uključujući intenzitet kontrasta i konflikt kriterijuma koji koriste standardna odstupanje normalizovanih vrednosti atributa i alternativa, kao i koeficijenti korelacije svih parova kolona [1, 4]. Metoda CRITIC se sastoji se iz šest koraka:

1.korak: Određivanje elemenata normalizovane matrice odlučivanja primenom jednačine (1) [1,4]:

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad (1)$$

Gde su $x_j^{\max} = \max(x_{ij}, i = 1, \dots, m)$ i $x_j^{\min} = \min(x_{ij}, i = 1, \dots, m)$.

Na osnovu jednačine (1) normalizovana matrica odlučivanja prikazana je tabelom 2. Vrednost r_{ij} pokazuje koliko je neka alternativa blizu idealne vrednosti $x_j^{\max}$ i koliko udaljena od anti-idealne vrednosti $x_j^{\min}$.

Tabela 2: Normalizovana matrica odlučivanja

Alternative	Kriterijumi			
	C1	C2	C3	C4
A1	0	0	0.5384	0.5833
A2	0	0.6666	1	1
A3	1	0.4444	0.6153	0
A4	1	1	0	0.9166

2. korak: Na osnovu vrednosti r_{ij} formira se vektor kriterijuma, pri čemu svaki vektor ima standardno odstupanje σ_j primenom jednačine (2) [4, 6]:

$$\sigma_j = \sqrt{\frac{1}{n} \sum_{i=1}^n (r_{ij} - \bar{r}_{ij})^2} \quad (2)$$

Gde je n broj kriterijuma, $\bar{r}_{ij}$ je aritmetička sredina elementa normalizovane matrice. Standardno odstupanje σ_j predstavlja odstupanje alternativa u zavisnosti od kriterijuma, tabela 3 [2].

Tabela 3: Standardno odstupanje

Standardno odstupanje	Kriterijumi			
	C1	C2	C3	C4
σ_j	0.5773	0.4194	0.4118	0.4538

3. korak: Definisanje matrice $n \times n$ sa elementima R_{jk} koji predstavljaju koeficijente linearne korelacije r_j, r_k , i n predstavlja broj alternativa, primenom jednačine (3) [1]:

$$R_{ij} = \frac{n \sum r_j r_k - \sum r_j \sum r_k}{\sqrt{n \sum r_j^2 - (\sum r_j)^2} \cdot \sqrt{n \sum r_k^2 - (\sum r_k)^2}} \quad (3)$$

Na osnovu jednačine (3) koeficijenti linearne korelacije su dati u tabeli 4.

Tabela 4: Koeficijenti linearne korelacije

Kriterijumi	C1	C2	C3	C4
C1	1	0.5353	-0.6469	-0.4239
C2	0.5353	1	-0.3793	0.4620
C3	-0.6469	-0.379	1	-0.0571
C4	-0.4239	0.4620	-0.0571	1

4. korak: Određivanje mere konflikta kriterijuma primenom jednačine (4), tabela 5 [1, 4, 6]:

$$\sum_{k=1}^n (1 - R_{jk}) \quad (4)$$

Tabela 5: Mere konflikta kriterijuma

Kriterijumi	C1	C2	C3	C4
C1	0	0.4646	1.6469	1.4239
C2	0.4646	0	1.3793	0.5379

C3	1.6469	1.3793	0	1.0571
C4	1.4239	0.5379	1.0571	0

5. korak: Određivanje količine informacija u odnosu na svaki kriterijum primenom jednačine (5) data je tabelom 6 [4]:

$$C_j = \sigma_j \sum_{i=1}^m (1 - r_{ij}) \quad (5)$$

Tabela 5: Količina informacija u odnosu na svaki kriterijum

Količina informacija	Kriterijumi			
	C1	C2	C3	C4
C_j	2.0413	0.9990	1.6818	1.3703

6. korak: Određivanje težinskih koeficijenata kriterijuma normalizacijom vrednosti C_j primenom jednačine (6) data je tabelom 7 [7]:

$$w_j = \frac{C_j}{\sum_{j=1}^n C_j} \quad (6)$$

Tabela 6: Težinski koeficijenti

Težinski koeficijenti	Kriterijumi			
	C1	C2	C3	C4
w_j	0.3350	0.1639	0.2760	0.2249

3. ROV METODA

Metoda ROV (Range Of Value) je razvijena od strane Yakowitza i saradnika 1993 [8]. godine. ROV metoda sastoji se iz pet koraka za rangiranje alternativa na osnovu zadatih kriterijuma:

1.korak: Određivanje cilja i definisanje kriterijuma na osnovu kojih će se vršiti izbor najbolje alternative.

Cilj je izbor glodala sa izmenljivim pločicama za obradu aluminijuma od četiri alternative, tj. glodala različitih proizvođača reznih alata (Seco, Iscar, TeaguTec). Kriterijumi na osnovu kojih će se vršiti izbor alternative su: broj zuba, brzina rezanja, korak i cena.

2.korak: Na osnovu vrednosti kriterijuma za date alternative definiše se matrica odlučivanja X (7) [1, 9, 10]:

$$X = [x_{ij}] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (7)$$

Gde je x_{ij} performansa i -te alternative u odnosu na j -ti kriterijum, m je broj alternativa i n je broj kriterijuma.

Matrica odlučivanja (8) za izbor glodala na osnovu tabele 1:

$$X = [x_{ij}] = \begin{bmatrix} 2 & 580 & 0.19 & 195 \\ 2 & 640 & 0.25 & 220 \\ 3 & 620 & 0.2 & 160 \\ 3 & 670 & 0.12 & 215 \end{bmatrix} \quad (8)$$

3.korak: Određivanje normalizovane matrice odlučivanja pri čemu se elementi za maksimalne kriterijume određuju primenom jednačine (9), dok se

elementi za minimalne kriterijume određuju primenom jednačina (10) [1, 9]:

$$r_{ij} = \frac{x_{ij} - x_{ij}^{\min}}{x_{ij}^{\max} - x_{ij}^{\min}} \quad (9)$$

$$r_{ij} = \frac{x_{ij}^{\max} - x_{ij}}{x_{ij}^{\max} - x_{ij}^{\min}} \quad (10)$$

Normalizovana matrica odlučivanja primenom jednačina (9) i (10) za izbor glodala sa izmenljivim pločicama prikazana je tabelom 8.

Tabela 8: Normalizovana matrica odlučivanja

Alternative	Kriterijumi			
	C1	C2	C3	C4
A1	0	0	0.5384	0.4166
A2	0	0.6666	1	0
A3	1	0.4444	0.6153	1
A4	1	1	0	0.0833

4.korak: Određivanje vrednosti funkcija korisnosti svih alternativa u odnosu na maksimalne i minimalne kriterijume.

Za maksimalne kriterijume, funkcija korisnosti se određuje primenom jednačine (11), dok se za minimalne kriterijume koristi jednačina (12) [1, 4]:

$$u_i^+ = \sum_{j=1}^n r_{ij} \cdot w_j \quad (11)$$

$$u_i^- = \sum_{j=1}^n r_{ij} \cdot w_j \quad (12)$$

Gde w_j predstavlja težinske koeficijente koji su određeni primenom metode CRITIC. Funkcije korisnosti primenom jednačina (10) i (11) prikazana je tabelom 9.

Tabela 9: Funkcija korisnosti

Alternative	u_i^+	u_i^-
A1	0.2217	0.1891
A2	0.6914	0
A3	1.0172	0.4538
A4	0.9967	0.0378

5.korak: Određivanje srednje vrednosti funkcije korisnosti alternativa primenom jednačine (13) [10]:

$$u_i = \frac{u_i^+ + u_i^-}{2} \quad (13)$$

Srednja vrednost funkcije korisnosti alternative se koristi kako bi se uočila razlika između performansi alternativa. Na osnovu srednje vrednosti funkcija korisnosti alternativa vrši se rangiranje alternativa, najveća vrednost u_i predstavlja najbolju alternativu. Srednja vrednost funkcije korisnosti kao i rangiranje alternativa prikazano je tabelom 10.

Tabela 10: Rangiranje alternativa

Alternative	u_i	Rang
A1	0.2054	4
A2	0.3457	3
A3	0.7355	1
A4	0.5173	2

Primenom ROV metode višekriterijumskog odlučivanja za izbor glodala sa izmenljivim pločicama za obradu legure aluminijuma pokazuje da na osnovu srednje vrednosti funkcije korisnosti alternatija, na prvom mestu je alternativa A3 tj. glodalo TE90AX-316-16-06 sa pločicom AXCT 060 204R-AL K10 proizvođača TeaguTec.

4. ZAKLJUČAK

Izbor reznog alata za obradu konkretnog materijala predstavlja složen zadatak. Postoji veliki broj metoda višekriterijumskog odlučivanja koje koriste skup matematičkih alata za jednostavniji način izbora najbolje alternative. Za izbor glodala sa izmenljivim pločicama za obradu legure aluminijuma korišćena je metoda ROV višekriterijumskog odlučivanja. Za određivanje težinskih koeficijenata, tj. stepena značaja svakog kriterijuma korišćena je metoda CRITIC. Na osnovu četiri kriterijuma (broj zuba, brzina rezanja, korak i cena) pomoću ROV metode dobijen je redosled rangiranih alternatija A3-A4-A2-A1. Prvi izbor je glodalo TE90AX-316-16-06 sa pločicom AXCT 060 204R-AL K10 (TeaguTec), zatim glodalo R217.69-1616.0-06-3N sa pločicom XOEX060204FR-E03 H15 (Seco), HM90 E90A-D16-2-C16 sa pločicom ADCR 1003DFE-P IC28 (Iscar) i na kraju glodalo R217.69-1416.0-10-2A sa pločicom XOEX10T308FR-E05 H15 (Seco).

ZAHVALNICA

Rad predstavlja deo istraživanja obavljen u okviru projekta TR 35034. Autori se zahvaljuju Ministarstvu prosvete, nauke i tehnološkog razvoja Republike Srbije

LITERATURA

[1] M. Madić, B. Nedić, M. Radovanović, "Poslovno i inženjersko odlučivanje primenom metoda

višekriterijumskog odlučivanja", Univerzitet u Kragujevcu, Fakultet Inženjerskih nauka, (2015)

[2] A. Ishizaka, O. Nemerz, "Multi-Criteria Decision Analysis Methods and Software", John Wiley and Sons, (2013)

[3] E. Jacquet, Y. Siskos, "Preference disaggregation: 20 years of MCDM experience", European Journal of the Operational Research, Vol. 21 (3), pp. 233-245, (2011)

[4] M. Milić, G. Župac, "Objektivni pristup određivanju težina kriterijuma", Vojnotehnički glasnik, Vol. 60 (1), pp. 39-56, (2012)

[5] D. Diakoulaki, G. Mavrotas, L. Papayannakis, "Determining objective weights in multiple criteria problems: The critic method", Vol. 22 (7), pp. 763-770, (1995).

[6] J. Stanković, T. Stevanović, "Utvrdjivanje relevantnih kriterijuma za višekriterijumsko rangiranje banaka", SYM OP IS, Vol. 16 (19), Zlatibor (Srbija), pp. 213-2016, (2007)

[7] A. Jahan, K. L. Edwards, "Multicriteria decision analysis for supporting the selection of engineering materials in product design", Elsevier, (2014),

[8] D. Diakoulaki, G. Mavrotas, L. Papayannakis, "Determining objective weights in multiple criteria problems: The critic method", Vol. 22 (7), pp. 763-770, (1995).

[9] D. S. Yakowitz, L. J. Lane, F. Szidarovszky, "Multi-attribute decision making: dominance with respect to an importance order of attributes", Applied Mathematics and Computation, Vol. 54 (10), pp. 167-181, (1993)

[10] M. Madić, M. Radovanović, M. Manić, "Application of the ROV method for the selection of cutting fluids", Decision Science Letters, Vol. 5, pp. 245-254. (2016)

Selection of Indexable Milling Cutter Using CRITIC and ROV Multi Criteria Decision Method

Jelena Stanojković^{1*}, Miroslav Radovanović¹

¹Faculty of Mechanical Engineering, University of Niš, Serbia

In this paper, the selection of indexable milling cutter for machining aluminum 6082-T6 is presented using multi criteria decision making method. Based on the four criteria (number of teeth, cutting speed, feed per tooth and the price) has been chosen the best alternative of the four indexable milling cutters from different manufacturers. For multi-criteria decision making is using ROV method and for determining the weight coefficients is using CRITIC method.

Keywords: Indexable milling cutter, CRITIC, ROV, Multi criteria decision making,

1. INTRODUCTION

Milling is one of the most important machining process, that uses a milling cutter to remove material from the surface of a workpiece. Milling is the process of machining various non-rotational surfaces such as flat surfaces, grooves, profile surfaces, complex shaped surfaces and all other non-rotational shape surfaces. The main movement is rotational and it is performed by the cutting tool. It is defined by the cutting speed V_c . The feeding movement is translated and it is performed by the workpiece. It is defined by the feed per tooth f_t .

The selection of cutting tools for concrete material is a complex task. The selection of indexable milling cutter with a diameter of 16 mm for machining aluminum 6082-T6 can be facilitated by using multi-criteria decision method.

Multiple criteria decision method is one of the most popular areas of decision theory which using a set of mathematical methods and tools for solving real problems in different areas. The problem of multi criteria analysis involves a number of criteria and objectives to be taken into consideration when making a decision [1].

Solving the problem of multi-criteria decision-making has the following objectives [1, 2, 3]:

- Determine the best alternative
- Grouping alternative in classes
- Ranking of alternatives to total preference
- Description of alternatives.

The ideal solution is one that has the best value of the attribute in relation to the criteria considered. Such a solution is a rare practice, and his character is that solving the problem of multi criteria decision making endeavors such a solution [1, 4]:

In this paper the selection of indexable milling cutters for machining Al 6082-T4 is presented using CRITIC method for determining the objective weights and ROV multi-criteria decision making method for determining the best alternative (different manufacturers of cutting tools) based on defined criteria (number of teeth, cutting speed, feed per tooth and price).

2. CRITIC METHOD FOR DETERMINING THE OBJECTIVE WEIGHTS

The real problems of multi-criteria decision making usually do not have the same character of criteria, but for solving the problem of the decision maker must determine the degree of importance for each criterion. The degree of importance for each criterion in multi- is determined by weighting coefficient, where the sum of the weight coefficients equal to one.

Determination of weights is one of the most important problems in multi criteria decision making [1]. From problem solving methods and the impact of different weights of the obtained solution, their small change can dramatically affect the ranking of alternatives [5].

There are many methods for determining the weight coefficients. Methods for determining the weight coefficients can be [1, 6]:

- Subjective methods and
- Objective methods.

Subjective methods are based on determining the weighting coefficients on information obtained from decision makers]. The subjective methods for determining the weight coefficients are [1, 4]:

- Method of averages
- Approximation method,
- Method proportions,
- Method own values,
- Additive normalization method,
- Method modified digital logic and
- Ranking method

Objective methods ignored the opinion of decision makers and are based on determining the weight coefficients by using certain mathematical equations [1, 4]. The objective methods for determining the weight coefficients are [1, 4]:

- CRITIC method
- FANMA method
- Standard deviation method and
- Entropy method

Problems of determining the weight coefficients were subject of research and scientific debate for years.

To determine the weight coefficients is necessary to define alternatives and the criteria for selection of

indexable milling cutters for machining Al 6082-T4. In Table 1 are presented four alternatives, indexable milling cutter with inserts of different manufacturers (Seco, Iscar, TeaguTec), and four criteria, number of teeth, cutting speed, feed per tooth and price. The goal for selection of

indexable milling cutters is to choose the milling cutter which has a maximum number of teeth, cutting speed and feed per tooth and a minimum price.

Table 1: Alternatives and criteria

Alternatives		Criteria			
Indexable milling cutter		C1	C2	C3	C4
		Number of teeth z_n	Cutting speed V_c [m/min]	Feed per tooth f_z [mm/tooth]	Price [€]
		max	max	max	min
A ₁	R217.69-1416.0-10-2A XOEX10T308FR-E05 H15 Seco	2	580	0.19	195
A ₂	HM90 E90A-D16-2-C16 ADCR 1003DFE-P IC28 Iscar	2	640	0.25	220
A ₃	TE90AX-316-16-06 AXCT 060 204R-AL K10 TeaguTec	3	620	0.2	160
A ₄	R217.69-1616.0-06-3N XOEX060204FR-E03 H15 Seco	3	670	0.12	215

CRITIC (Criteria Importance Through Intercriteria Correlation) method for determining the objective weights, proposed by Diakoulaki in 1995 [5]. CRITIC method is based on analytical examination of the decision making matrix, including the intensity of contrast and conflict criteria using standard deviation normalized attribute value and alternatives, as well as the correlation coefficients of all pairs of columns [1, 4]. CRITIC method is performed by applying six steps:

Step 1: Determine element of normalized decision matrix, equation (1) [1, 4]:

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad (1)$$

Where: $x_j^{\max} = \max(x_{ij}, i = 1, \dots, m)$ and $x_j^{\min} = \min(x_{ij}, i = 1, \dots, m)$.

Base on the equation (1) normalized decision matrix is shown in Table 2. The value of r_{ij} shows how an alternative close to the ideal value $x_j^{\max}$ and how much far to the anti-ideal values.

Table 2: Normalized decision matrix

Alternative	Criteria			
	C1	C2	C3	C4
A1	0	0	0.5384	0.5833
A2	0	0.6666	1	1
A3	1	0.4444	0.6153	0
A4	1	1	0	0.9166

Step 2: Based on the values r_{ij} is possible to form a vector of criteria, each vector has a standard deviation σ_j , equation (2) [4, 6]:

$$\sigma_j = \sqrt{\frac{1}{n} \sum_{i=1}^n (r_{ij} - \bar{r}_{ij})^2} \quad (2)$$

Where are: n is a number of elements and $\bar{r}$ is an arithmetic mean. Standard deviation σ_j is a degree of deviation an alternative to giving criterion, Table 3. [2].

Table 3: Standard deviation of criteria

Standard deviation	Criteria			
	C1	C2	C3	C4
σ_j	0.5773	0.4194	0.4118	0.4538

Step 3: Determine a matrix $n \times n$ with elements R_{ij} , which represents a linear correlation coefficient r_j , r_k , and n is a number of alternatives, equation (3) [1]:

$$R_{ij} = \frac{n \sum r_j r_k - \sum r_j \sum r_k}{\sqrt{n \sum r_j^2 - (\sum r_j)^2} \cdot \sqrt{n \sum r_k^2 - (\sum r_k)^2}} \quad (3)$$

Base on the equation (3) coefficients of the linear correlation is shown in Table 4.

Table 4: Coefficients of linear correlation

Criteria	C1	C2	C3	C4
C1	1	0.5353	-0.6469	-0.4239
C2	0.5353	1	-0.3793	0.4620
C3	-0.6469	-0.379	1	-0.0571
C4	-0.4239	0.4620	-0.0571	1

Step 4: Determine the rates of the conflict criteria using the equation (4), Table 5 [1, 4, 6]:

$$\sum_{k=1}^n (1 - R_{jk}) \quad (4)$$

Table 5: Rates of conflict criteria

Criteria	C1	C2	C3	C4
C1	0	0.4646	1.6469	1.4239
C2	0.4646	0	1.3793	0.5379
C3	1.6469	1.3793	0	1.0571
C4	1.4239	0.5379	1.0571	0

Step 5: Determine the quantity of the information in relation to each criterion using the equation (5), Table 6 [4]:

$$C_j = \sigma_j \sum_{i=1}^m (1 - r_{ij}) \quad (5)$$

Table 6: Quantity of the information in relation to each criterion

Quantity of the information	Criteria			
	C1	C2	C3	C4
C_j	2.0413	0.9990	1.6818	1.3703

Step 6: Determine the objective weight coefficients by normalizing value C_j using the equation 6, Table 7 [7]:

$$w_j = \frac{C_j}{\sum_{j=1}^n C_j} \quad (6)$$

Table 7: Objective weight coefficients

Weights coefficients	Criteria			
	C1	C2	C3	C4
w_j	0.3350	0.1639	0.2760	0.2249

3. ROV METHOD

ROV (Range Of Value) method was developed by Yakowitz et al in 1993 [8]. ROV method is performed by applying five steps for ranking alternatives based on defined criteria.

Step 1: Determine the objective and definition criteria for selection alternatives, Table 1. The objective is the selection of indexable milling cutter for machining Al 6082-T6 base on the four alternatives, indexable milling cutter from different manufacturer. The criteria for selection are number of teeth, cutting speed, feed per tooth and the price.

Step 2: Base on the of the value of the criteria and alternative defined decision matrix X (7). Each row refers to one alternative, and each column to one criterion [1, 9, 10]:

$$X = [x_{ij}] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (7)$$

Where are: x_{ij} -performance of the i -th alternative in relation to the j -th criteria, m -a number of alternatives and n -a number of criteria.

Matrix of decision (8) for selection of indexable milling cutter base on the Table 1:

$$X = [x_{ij}] = \begin{bmatrix} 2 & 580 & 0.19 & 195 \\ 2 & 640 & 0.25 & 220 \\ 3 & 620 & 0.2 & 160 \\ 3 & 670 & 0.12 & 215 \end{bmatrix} \quad (8)$$

Step 3: Determination of normalized decision matrix with elements for maximum criteria is determined by using the equation (9), while the elements for minimum criterion is determined by using equation (10) [1, 9]:

$$r_{ij} = \frac{x_{ij} - x_{ij}^{\min}}{x_{ij}^{\max} - x_{ij}^{\min}} \quad (9)$$

$$r_{ij} = \frac{x_{ij}^{\max} - x_{ij}}{x_{ij}^{\max} - x_{ij}^{\min}} \quad (10)$$

Normalized decision matrix by using equations (9) and (10) for a selection indexable milling cutter is shown in mills with indexable insert is shown in Table 8.

Table 8: Normalized decision matrix

Alternative	Criteria			
	C1	C2	C3	C4
A1	0	0	0.5384	0.4166
A2	0	0.6666	1	0
A3	1	0.4444	0.6153	1
A4	1	1	0	0.0833

Step 4: Determination of the value utility function of all alternatives in relation to the maximum and minimum criteria.

For maximum criteria the utility function is determined using equation (11), while for minimum criterion the utility function is determined using equation (12) [1, 4]:

$$u_i^+ = \sum_{j=1}^n r_{ij} \cdot w_j \quad (11)$$

$$u_i^- = \sum_{j=1}^n r_{ij} \cdot w_j \quad (12)$$

Where: w_j -weight coefficients which were determined using the method CRITIC. Utility function by using equations (10) and (11) is shown in Table 9.

Table 9: Utility function

Alternative	u_i^+	u_i^-
A1	0.2217	0.1891
A2	0.6914	0
A3	1.0172	0.4538
A4	0.9967	0.0378

Step 5: Determination of the mean value utility function alternative to using the equation (13) [10]:

$$u_i = \frac{u_i^+ + u_i^-}{2} \quad (13)$$

The mean value of the utility function alternative is used to observe the difference between the performance of alternative. Based on the mean value of the utility function alternative ranking of alternatives is performed, the greatest value of u_i is the best alternative. The mean value of the utility function and ranking of alternatives is shown in Table 10.

Table 10: Ranking alternatives

Alternative	u_i	Rang
A1	0.2054	4
A2	0.3457	3
A3	0.7355	1
A4	0.5173	2

By applying ROV methods for decision making for a selection of indexable milling cutter for machining Al 6082-T4, based on the mane number of utility functions of alternative, in the first place is an alternative A3, indexable milling cutter o TE90AX-316-16-06 with inserts AXCT 060 204r AL-K10 manufacturers TeaguTec.

4. CONCLUSION

The selection of cutting tools for machining concrete materials is a complex task. There are a large number of multi-criteria decision making methods or simpler way of selection of the best alternative. Multi criteria decision making methods are using a set of mathematical tools. For the selection of indexable milling cutter for machining Al 6082-T4 is using ROV method of multi-criteria decision making and CRITIC method for determining the weight coefficients. The first choice is the indexable milling cutter TE90AX-316-16-06 with insert AXCT 060 204r AL-K10 (TeaguTec), then the milling cutter R217.69-1616.0-06-3N with insert XOEX060204FR E03-H15 (Seco), HM90 E90A-D16-2 -C1-6 with insert ADCR 1003DFE-P IC28 (Iscar), and at the end of a selection is the milling cutter R217.69-1416.0-10-2A with insert XOEX10T308FR E05-H15 (Seco).

ACKNOWLEDGEMENT

The paper is a part of the research done within the project TR35034. The authors would like to thank to the Ministry of Education and Science, Republic of Serbia.

REFERENCES

- [1] M. Madić, B. Nedić, M. Radovanović, “Poslovno i inženjersko odlučivanje primenom metoda višekriterijumskog odlučivanja”, Univerzitet u Kragujevcu, Fakultet Inženjerskih nauka, (2015)
- [2] A. Ishizaka, O Nemerz, “Multi-Criteria Decision Analzsis Methods and Software”, John Wilez and Sons, (2013)
- [3] E. Jacquet, Y. Siskos, “Preference disaggregation: 20 years of MCDM experience”, Eurepean Journal of the Operational Research, Vol. 21 (3), pp. 233-245, (2011)
- [4] M. Milić, G. Župac, “Objektivni pristup određivanju težina kriterijuma”, Vojnotehnički glasnik, Vol. 60 (1), pp. 39-56, (2012)
- [5] D. Diakoulaki, G. Mavrotas, L. Papayannakis, “Determining objective weights in multiple criteria problems: The critic method”, Vol. 22 (7), pp. 763-770, (1995).
- [6] J. Stanković, T. Stevanović, “Utvrđivanje relevantnih kriterijuma za višekriterijumsko rangiranje banaka”, SYM OP IS, Vol. 16 (19), Zlatibor (Srbija), pp. 213-2016, (2007)
- [7] A. Jahan, K. L. Edwards, “Multicriteria decision analysis for supporting the selection of engineering materials in product design”, Elsevier, (2014) ,
- [8] D. S. Yakowitz, L. J. Lane, F. Szidarovszky, “Multi-attribute decision making: dominance with respect to an importance order of attributes”, Applied Mathematics and Computation, Vol. 54 (10), pp. 167-181, (1993)
- [9] M. Madić, M. Radovanović, M. Manić, “Application of the ROV method for the selection of cutting fluids”, Decision Science Letters, Vol. 5, pp. 245-254, (2016)
- [10] S. Hajkowicz, A. Higgins, “A Comparison of Multiple Criteria Analysis Techniques for Water Resource Management”, European Journal of Operational Research, vol. 184 (2), pp. 255–265, (2008)