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

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U radu je predstavljen izbor glodala sa izmenljivim pločicama za obradu legure aluminijuma pimenom 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 BOV 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 proizvođačkih 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 \( V_r \). Pomoćno kretanje je pravolinjsko 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 \( f_s \) aksijalnim pomeranjem za jedan obrtaj alata

Izbor reznog alata za obradu konkretnog materijala 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 oblučivanje 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 PRIMENTOM METODE CRITIC

Realni problemi višekriterijumskog odlučivanja najčešće nemaju kriterijume istog značaja, pa pri rešavanju problema donosilac odluke mora odrediti stepen značaja svakog kriterijuma. Stupen 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 donosilaca odluke i zasnovane su na određenim problemima određivanja težinskih koeficijenata [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 dobijenih od donosilaca odluke. U subjektivne metode za određivanje težinskih koeficijenata spadaju [1, 4]:
- Metoda srednjih vrednosti,
- Metoda aproksimacije,
- Metoda proporcije,
- Metoda nepotpunih vrednosti,
- Metoda aditivne normalizacije,
- Metoda modificovane 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 devijacije,
- Metoda entropije.

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

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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 meta) različitih proizvođača reznih alata Seco, Iscar i TeaguTec), dok su kriterijumi: broj zuba glodala, brzina rezanja, korak i cena. Čilj je izabrati glodal sa izmenljivim pločicama koje ima maksimalni broj zuba, brzinu rezanja i korak, a minimalnu cenu.

**Tabela 1: Alternative i kriterijumi**

| Alternative | Kriterijumi | C1 | C2 | C3 | C4 |
|-------------|-------------|----|----|----|----|
| Glodala sa izmenljivim pločicama | Broj zuba | Brzina rezanja | Korak po zubu | Cena |
| A1 | max | 2 | 580 | 0.19 | 195 |
| A2 | min | 2 | 640 | 0.25 | 220 |
| A3 | max | 3 | 620 | 0.2 | 160 |
| A4 | min | 3 | 670 | 0.12 | 215 |

Gde su
\[ r_{ij} = \frac{x_{ij} - x_{ij}^{\text{min}}}{x_{ij}^{\text{max}} - x_{ij}^{\text{min}}} \] (1)

Gde je \( n \) broj kriterijuma, \( \bar{x}_j \) aritmetička sredina elementa normalizovane matrice. Standardno odstupanje \( \sigma \) predstavlja odstupanje alternativa u zavisnosti od kriterijuma, tabela 3 [2].

**Tabela 3: Standardno odstupanje**

| Kriterijumi | C1 | C2 | C3 | C4 |
|-------------|----|----|----|----|
| Standardno odstupanje | 0.5773 | 0.4194 | 0.4118 | 0.4538 |

3. korak: Definisanih matrice \( n \times n \) sa elementima \( R_{jk} \) koji predstavljaju koeficijente linearske korelacije \( r_{jk} \) i \( n \) predstavlja broj alternativa, primenom jednačine (3) [1]:

\[ R_{jk} = \frac{n \sum r_{jk} r_{jk} - \sum r_{jk} \sum r_{jk}}{\sqrt{n \sum r_{jk}^2 - \sum r_{jk}^2} \cdot \sqrt{n \sum r_{jk}^2 - \sum r_{jk}^2}} \] (3)

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

**Tabela 4: Koečijenti linearske korelacije**

| Kriterijumi | C1 | C2 | C3 | C4 |
|-------------|----|----|----|----|
| Kriterijumi | 1 | 0.5353 | -0.6469 | -0.4239 |
| A2 | 0.5353 | 1 | -0.3793 | 0.4620 |
| C3 | -0.6469 | -0.3793 | 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]:

\[ \sum_{k=1}^{n} (1 - R_{jk}) \] (4)

**Tabela 5: Mere konflikta kriterijuma**

| Kriterijumi | C1 | C2 | C3 | C4 |
|-------------|----|----|----|----|
| Kriterijumi | 1 | 0 | 1.6469 | 1.4239 |
| C2 | 0.4646 | 0 | 1.3793 | 0.5379 |
5. korak: Određivanje količine informacija u odnosu na svaki kriterijum primenom jednačine (5) data je tabelom 6 [4]:

\[ C_j = \sigma_j \sum_{i=1}^{m} (1 - r_{ij}) \]  

\( (5) \)

Tabela 5: Količina informacija u odnosu na svaki kriterijum

| Količina informacija | Kriterijumi C1 | C2 | C3 | C4 |
|----------------------|----------------|----|----|----|
| Cj                   | 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]:

\[ w_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \]  

\( (6) \)

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 za izmenljivim pločicama za obradu aluminija od četiri alternative, tj. glodala različitih proizvođača (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 definisane se matrice odlučivanja X (7) [1, 9, 10]:

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

\( (7) \)

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:

\[ X = \begin{bmatrix} 2 & 580 & 0.19 & 195 \\ 2 & 640 & 0.25 & 220 \\ 3 & 620 & 0.2 & 160 \\ 3 & 670 & 0.12 & 215 \end{bmatrix} \]  

\( (8) \)

3. korak: Određivanje normalizovane matrice odlučivanja pri čemu se elementi za maksimalne kriterijume određuju primenom jednačine (9), dok se elementi za minimalne kriterijume određuju preimenom jednačine (10) [1, 9]:

\[ r_{ij} = \frac{x_{ij} - x_{ij}^{min}}{x_{ij}^{max} - x_{ij}^{min}} \]  

\( (9) \)

\[ r_{ij} = \frac{x_{ij}^{max} - x_{ij}^{min}}{x_{ij}^{max} - x_{ij}^{min}} \]  

\( (10) \)

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              | 0.5384 | 0.4166 | 0 |
| 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]:

\[ u_i^+ = \sum_{j=1}^{n} r_{ij} \cdot w_j \]  

\( (11) \)

\[ u_i^- = \sum_{j=1}^{n} r_{ij} \cdot w_j \]  

\( (12) \)

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]:

\[ u_i = \frac{u_i^+ + u_i^-}{2} \]  

\( (13) \)

Srednja vrednost funkcije korisnosti alternativa 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    |
Применом ROV методе višekriterijumskog odlučivanja za izbor glodala sa izmenljivim pločicama za obradu legure aluminijuma pokazuje da na osnovu srednje vrednosti funkcije korisnosti alternativa, 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 korisćena je metoda ROV višekriterijumskog odlučivanja. Za određivanje težinskih koeficijenata, tj stepena značaja svakog kriterijuma korisćena je metoda CRITIC. Na osnovu četiri kriterijuma (broj zuba, brzina rezanja, korak i cena) pomoću ROV metode dobijen je redosled rangiranih alternativa 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).

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

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

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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-criteria decision making 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 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.

| Alternatives | Criteria |
|--------------|----------|
| Indexable milling cutter | Number of teeth | Cutting speed | Feed per tooth | Price |
| | \(n\) | \(V_c\) [m/min] | \(f_z\) [mm/tooth] | [\(€\)] |
| 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 |

Table 1: Alternatives and criteria

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]:

\[
r_{ij} = \frac{x_{ij} - x_{ij}^{\min}}{x_{ij}^{\max} - x_{ij}^{\min}}
\]

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

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 \(x_{ij}^{\max}\) and how much far to the anti-ideal values.

| Alternative | 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 |

Table 2: Normalized decision matrix

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

\[
\sigma_j = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (r_{ij} - \overline{r_{ij}})^2}
\]

Where are: \(n\) is a number of elements and \(\overline{r_{ij}}\) is an arithmetic mean. Standard deviation \(\sigma_j\) is a degree of deviation an alternative to giving criterion, Table 3. [2].

Table 3: Standard deviation of criteria

| Criteria | C1 | C2 | C3 | C4 |
|----------|----|----|----|----|
| \(\sigma_j\) | 0.5773 | 0.4194 | 0.4118 | 0.4538 |

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

\[
R_{jk} = \frac{n \sum r_j r_k - \sum r_j \sum r_k}{\sqrt{n \sum r_j^2 - (\sum r_j)^2} \sqrt{n \sum r_k^2 - (\sum r_k)^2}}
\]

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

| Criteria | C1 | C2 | C3 | C4 |
|----------|----|----|----|----|
| C1       | 1  | 0.5353 | -0.6469 | -0.4239 |
| C2       | 0.5353 | 1 | -0.3793 | 0.4620 |
| C3       | -0.6469 | -0.3793 | 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]:

\[
\sum_{k=1}^{n} (1 - R_{jk})
\]

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]:

Table 6: Rates of conflict criteria

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\[ C_j = \sigma_j \sum_{j=1}^{m} (1 - r_{ij}) \]  

(5)

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

| Criteria | C1  | C2  | C3  | C4  |
|----------|-----|-----|-----|-----|
| Quantity of the information | 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]:

\[ w_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \]

(6)

**Table 7: Objective weight coefficients**

| Criteria | C1  | C2  | C3  | C4  |
|----------|-----|-----|-----|-----|
| Weights coefficients \( w_j \) | 0.3350 | 0.1639 | 0.2760 | 0.2249 |

3. ROV METHOD

ROV (Range Of Value) method was developed by Yakowitz et all 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]:

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

(7)

Where: \( x_{ij} \)-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:

\[
X = \begin{bmatrix}
  2 & 580 & 0.19 & 195 \\
  2 & 640 & 0.25 & 220 \\
  3 & 620 & 0.2 & 160 \\
  3 & 670 & 0.12 & 215
\end{bmatrix}
\]

(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]:

\[
r_{ij}^{max} = \frac{x_{ij}^{max} - x_{ij}^{min}}{x_{ij}^{max} - x_{ij}^{min}}
\]

(9)

\[
r_{ij}^{min} = \frac{x_{ij}^{max} - x_{ij}^{min}}{x_{ij}^{max} - x_{ij}^{min}}
\]

(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.

**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]:

\[
u_{ij}^{+} = \sum_{j=1}^{n} r_{ij} \cdot w_{j}
\]

(11)

\[
u_{ij}^{-} = \sum_{j=1}^{n} r_{ij} \cdot w_{j}
\]

(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.

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

\[
u_{i} = \frac{u_{i}^{+} + u_{i}^{-}}{2}
\]

(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          | 0.3437    | 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 main 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.

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