Original Research Article: full paper

(2023), «EUREKA: Physics and Engineering» Number 6

# COMPARISON OF TWO METHODS IN MULTI-CRITERIA DECISION-MAKING: APPLICATION IN TRANSMISSION ROD MATERIAL SELECTION

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**Abstract**

Transmission rod is an indispensable part in diesel and gasoline engines. Its job is to convert rotation into translational motion or vice versa. The transmission rod material selection plays a very important role, affecting its working function and durability. This study was conducted to compare two Multi Criteria Decision Making (*MCDM*) methods in transmission rod material selection. They are *PIV* (Proximity Indexed Value) method, and *FUCA* (Faire Un Choi Adéquat) method. Seven types of steel commonly used in transmission rods were reviewed for ranking, inclusive of: 20 steel, 40 steel, 45 steel, 18Cr2Ni4WA steel, 30CrMoA steel, 45Mn2 steel and 40CrNi steel. Nine parameters were used as criteria to evaluate each steel including minimum yield strength, ultimate tensile strength, minimum elongation ratio, contraction ratio, modulus of elasticity, mean coefficient of thermal expansion, thermal conductivity, specific thermal capacity, and density. The weights of the criteria were calculated using three methods inclusive of *MEAN* weight method, Entropy weight method and *MEREC* weight method (Method based on the Removal Effects of Criteria). Each *MCDM* method was combined with the three weight methods mentioned above to rank the alternatives. The obtained results show that when using both *PIV* and *FUCA* methods to rank the alternatives, the best and worst alternatives are found regardless of the weight of the criteria. The best alternative determined using the *PIV* method is also the best alternative determined using the *FUCA* method. It means that the two *PIV* and *FUCA* methods have been shown to be equally effective. Among the seven transmission rod materials reviewed, 20 steel was identified as the best, and 40CrNi steel was identified as the worst.

**Keywords**: transmission rod material selection, *PIV* method, *FUCA* method, weight method.

**DOI: 10.21303/2461-4262.2023.003046**

## 1. Introduction

Multi-criteria decision-making (*MCDM*) is the act of finding the best alternative among many available alternatives [1, 2]. So far, scientists have proposed more than 100 different *MCDM* methods, and they have been used for multi-criteria decision-making in many different fields [3]. A problem often worrying people who use multi-criteria decision-making methods is rank inversion of alternatives. Rank inversion is a phenomenon in which the rankings of alternatives will change in different situations, such as when changing the method of data normalization, or when changing the method of weighting the criteria [4]. Selecting a method minimizing the rank inversion will reduce anxiety for decision makers [5].

*PIV* is known as an *MCDM* method having the advantage of minimizing rank inversion of the alternatives in different situation [6]. *FUCA* is an *MCDM* method that it is not necessary to normalize the data when using it. This also gives it the advantage of minimizing rank inversion of the alternatives [7, 8]. Perhaps thanks to this advantage, these two methods (*PIV* and *FUCA*) have been applied a lot in recent times.

Many studies have applied and compared *PIV* with various *MCDM* methods in selecting the best alternatives across multiple domains. PIV is considered to be equally effective as three methods *ARAS* (Additive Ratio Assessment), *MOORA* (Multiobjective Optimization On the basis of Ratio Analysis), and *MABAC* (Multi-Attributive Border Approximation area Comparison) in the selection of factory construction sites [9]. In [10], *PIV* was also affirmed to be equally effective as *TOPSIS* (Technique for Order Preference by Similarity to Ideal Solution), *WASPAS* (Weighted Aggregates Sum Product

ASsessment), and *COPRAS* (COmplex PRroportional Assessment) in choosing warehouse construction locations. When used for selecting online learning platforms, *PIV* demonstrated equivalent effectiveness to *AHP* (Analytic Hierarchy Process), *VIKOR* (Vlsekriterijumska optimizacijaI KOmpromisno Resenje), and COPRAS [11]. *PIV*, along with four methods *EDAS* (Evaluation Based on Distance from Average Solution), *MARCOS* (Measurement Alternatives and Ranking according to Compromise Solution), *TOPSIS*, and *MOORA* were confirmed to be equally effective in finding the best solution for metal milling [12]. All seven methods *RAFSI* (Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval), *SAW* (Simple Additive Weighting), *WASPAS*, *TOPSIS*, *VIKOR*, *MOORA*, and *COPRAS* showed comparable efficiency and equivalence to the *PIV* method when applied to select metal cutting methods [13, 14]. Both *PIV* and *WASPAS* demonstrated similar effectiveness in choosing metal grinding methods [15]. In [16], *PIV* was proven to be equally effective as *SAW* and *MAUT* (MultiAttribute Utility Theory) in determining the countries most adversely affected by the Covid-19 pandemic. When used to select materials for the gearbox casing of Formula 1 racing cars, *PIV* showed effectiveness equivalent to *ROV* (Range Of Value), *WPM* (Weighted Product Model), *SAW*, *TOPSIS*, *COCOSO* (COmbined COmpromise SOlution), and *MABAC* [17]. In selecting materials for car roof covers, *PIV* and five methods *WASPAS*, *EDAS*, *TOPSIS*, *ROV*, and *COPRAS* showed similar effectiveness [18]. Both *PIV* and *CURLI* (Collaborative Unbiased Rank List Integration) found the best alternative when used to select cutting oils [19]. In [20], it was asserted that using both PIV and AHP resulted in finding the best type of semiconductor packaging material. *PIV* and all five methods *COCOSO*, *WPM*, *WSM* (Weighted Sum Method), *TOPSIS*, and *MABAC* identified the best alternative when used to select materials for car brake pads [21], and so on.

Recently, numerous studies have been conducted to compare the *FUCA* method with various *MCDM* methods across diverse fields. Some research on assessing the financial utilization of companies has indicated that *FUCA* is equally effective as two methods *MOORA* and *MABAC* [22], as well as comparable to the *WAS* (Weighted Sum Approach) [23] and equivalent to the *PROMETHEE* (Preference Ranking Organization Method for Enrichment Evaluation) method [3, 24]. Both *FUCA* and *TOPSIS* methods have demonstrated similar effectiveness when used for selecting chemical production processes [25]. Three methods, including *FUCA*, *MARCOS*, and *PSI* (Preference Selection Index), have shown equivalent efficacy in the selection of electric bicycles [26]. *FUCA* and *TOPSIS* have exhibited similar effectiveness in choosing mechanical machining methods [27]. When applied to select grinding machines, drilling machines, and milling machines, the *FUCA* method and *CURLI* have also shown comparable efficiency [28], and so on.

Thus, it can be stated that the two methods, *PIV* and *FUCA*, have been widely used for multi-criteria decision-making in various fields. These methods have also been evaluated to be equally effective as many other *MCDM* methods. However, no study has been conducted to compare these two methods. An open question is whether the ranking results of alternatives using these two methods are similar. The authors of this article will seek to answer this question.

As mentioned earlier, the phenomenon of ranking reversal can occur when the weights of criteria change. Therefore, to compare two *MCDM* methods, it is necessary to examine cases where criteria weights are determined using different methods. Hence, in this article, all three different weighting methods have been employed: the Mean weighting method, the Entropy weighting method [29], and the *MEREC* (Method based on the Removal Effects of Criteria) weighting method [30]. All three methods are objective, meaning that the weights of criteria are independent of the decision-maker's subjective viewpoint. Using these three objective weighting methods for selection enables choosing the best type of steel with the highest objectivity. These are all methods that have been widely used recently [31, 32]. The selection of materials for manufacturing transmission rods is chosen as the problem for comparing the *PIV* and *FUCA* methods.

## 2. Materials and methods

### 2. 1. Two multi-criteria decision-making methods

Let's suppose that *m* alternatives should be ranked, each of which includes *j* criteria, let $y_{ij}$ be the value of criterion *j* at alternative *i*, with $i = 1 \div m$, $j = 1 \div n$. The order of ranking the alternatives by the *PIV* method is as follows [6].

The normalization of criteria is conducted by applying (1):

$$n_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}}. \tag{1}$$

Let $V_{ij}$ be the product of the normalized value and the weight of the criteria. $V_{ij}$ is calculated in accordance with (2):

$$V_{ij} = w_j \cdot n_{ij}. \tag{2}$$

Let's calculate the quantities $u_i$ in accordance with two formulas (3) and (4). In which, the formula (3) applies to as-large-as-possible criteria, and the formula (4) applies to as-small-as-possible criteria:

$$u_i = v_{\max} - v_i, \tag{3}$$

$$u_i = v_i - v_{\min}. \tag{4}$$

$d_i$ scores of the alternatives are calculated in accordance with the (5):

$$d_i = \sum_{j=1}^{n} u_i. \tag{5}$$

Let's rank the alternatives in ascending order of their scores.

Let's use the *FUCA* method to rank the alternatives in the following order [7, 8].

Let's rank the alternatives for each criterion ($r_{ij}$). If the alternative $i$ with the criterion $j$ is the best, then $r_{ij} = 1$. Otherwise, if the alternative $i$ with the criterion $j$ is the worst, then $r_{ij} = m$.

$v_i$ score of each alternative is calculated in accordance with the (6):

$$v_i = \sum_{j=1}^{n} r_{ij} \cdot w_j. \tag{6}$$

The ranks of the alternatives are ranked in ascending order of the value of $v_i$.

**2. 2. Methods of determining the weights for the criteria having been used**

Three weight methods for the criteria having been used: Mean weight method, Entropy weight method and *MEREC* weight method.

The Mean weight method is the one where the weighted values of the criteria are equal, i.e. equal to $1/n$.

The weighting of the criteria by the Entropy method is conducted by applying three formulas (7)–(9) [29]:

$$n_{ij} = \frac{y_{ij}}{m + \sum_{i=1}^{m} y_{ij}^2}, \tag{7}$$

$$e_j = \sum_{i=1}^{n} \left[ n_{ij} \cdot \ln(n_{ij}) \right] - \left( 1 - \sum_{i=1}^{n} n_{ij} \right) \times \ln \left( 1 - \sum_{i=1}^{n} n_{ij} \right), \tag{8}$$

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)}. \tag{9}$$

The *MEREC* weight method was used to calculate the weights of the criteria in the following order [30].

Let's calculate the normalized values in accordance with the two formulas (10) and (11). For as-large-as-possible criteria, the formula (10) will be applied. Conversely, for as-small-as-possible criteria, the formula (11) will be applied:

$$n_{ij} = \frac{\min y_{ij}}{y_{ij}}, \tag{10}$$

$$n_{ij} = \frac{y_{ij}}{\max y_{ij}}. \tag{11}$$

$S_i$ values are calculated in accordance with the (12):

$$S_i = Ln\left[1+\left(\frac{1}{n}\sum_{j}^{n}\left|\ln\left(n_{ij}\right)\right|\right)\right]. \tag{12}$$

$S'_{ij}$ values are calculated in accordance with the (13):

$$S'_{ij} = Ln\left[1+\left(\frac{1}{n}\sum_{k,k\neq j}^{n}\left|\ln\left(n_{ij}\right)\right|\right)\right]. \tag{13}$$

$E_j$ values are calculated in accordance with the (14):

$$E_j = \sum_{i}^{m}\left|S'_{ij} - S_i\right|. \tag{14}$$

The weight $w_j$ of the criteria is calculated in accordance with the (15):

$$w_j = \frac{E_j}{\sum_{i}^{n} E_j}. \tag{15}$$

**3. Results and discussion**

Seven types of steel are commonly used to make the transmission rods including 20 steel, 40 steel, 45 steel, 18Cr2Ni4WA steel, 30CrMoA steel, 45Mn2 steel, and 40 CrNi steel [33]. Minimum yield strength, ultimate tensile strength, minimum elongation ratio, contraction ratio, modulus of elasticity, mean coefficient of thermal expansion, thermal conductivity, specific thermal capacity, and density are the nine parameters that can be obtained by the handbook searcher when searching the information on these seven types of steel. Any steel with values of these nine parameters all having large values is considered a good steel. The values of parameters of seven types of steel have been summarized in **Table 1**.

In accordance with the data in **Table 1**, it shows that *C*1 has the highest value corresponding to 45Mn2 steel, *C*2 has the best value corresponding to 18Cr2Ni4WA steel, the best *C*3 is for 40CrNi steel, *C*4 and *C*5 have the best value for 20 Steel, the best *C*6 is for 45Mn2 steel, two types of steel, 45Mn2 and 40CrNi, have the same *C*7 as the best, the best *C*8 is for 20 steel, and the best *C*9 is for 40 steel. Thus, it is clearly that there is no such type of steel having all nine criteria as the best. The selection of a steel considered *«the best»* must consider all nine criteria simultaneously. The two *PIV* and *FUCA* methods will be used to perform this task. However, before applying these two methods to rank types of steel, it is necessary to determine the weights for the nine criteria.

In accordance with the mean weight method, each criterion will have a weight equal to 1/9 = 0.1111. The determination of the weights for the criteria by the other two methods was conducted by applying the formulas from (7) to (15). The weighted values of the criteria, when calculated by the three methods, are shown in **Table 2**.

**Table 1**
Transmission rod materials [33]

| Parameter | Minimum yield strength | Ultimate tensile strength | Minimum elongation ratio | Contraction ratio | Modulus of elasticity | Mean coefficient of thermal expansion | Thermal conductivity | Specific thermal capacity | Density |
|---|---|---|---|---|---|---|---|---|---|
| **Unit** | **N/mm$^2$** | **N/mm$^2$** | **%** | **%** | **GPa** | **$10^{-6}$/°C** | **W/M°C** | **J/kg/°C** | **kg/dm$^3$** |
| **Type** | **Criteria** | | | | | | | | |
| | ***C1*** | ***C2*** | ***C3*** | ***C4*** | ***C5*** | ***C6*** | ***C7*** | ***C8*** | ***C9*** |
| 20 steel | 245 | 410 | 25 | 55 | 987 | 33 | 23.3 | 0.43 | 322 |
| 40 steel | 335 | 570 | 19 | 45 | 661 | 13 | 41.2 | 0.22 | 413 |
| 45 steel | 355 | 600 | 16 | 40 | 298 | 41 | 31.2 | 0.22 | 121 |
| 18Cr2Ni4WA steel | 621 | 957 | 13 | 34 | 284 | 34 | 14.2 | 0.11 | 332 |
| 30CrMoA steel | 589 | 553 | 12 | 31 | 798 | 24 | 21.2 | 0.42 | 142 |
| 45Mn2 steel | 810 | 631 | 14 | 43 | 132 | 44 | 43.2 | 0.11 | 222 |
| 40CrNi steel | 242 | 495 | 32 | 32 | 391 | 12 | 43.2 | 0.24 | 113 |

**Table 2**
Weights of criteria

| Weight method | Criteria | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***C1*** | ***C2*** | ***C3*** | ***C4*** | ***C5*** | ***C6*** | ***C7*** | ***C8*** | ***C9*** |
| Mean | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 |
| Entropy | 0.1491 | 0.1512 | 0.0809 | 0.0934 | 0.1557 | 0.0909 | 0.0910 | 0.0522 | 0.1358 |
| Merec | 0.0999 | 0.0656 | 0.0704 | 0.0410 | 0.2122 | 0.1412 | 0.1318 | 0.1256 | 0.1123 |

The weighted values of the criteria in **Table 2** will be used to rank the alternatives by the two *PIV* and *FUCA* methods, respectively. First, the weights of the criteria calculated by the Mean weight method will be used in conjunction with the *PIV* method.

The formula (1) was used to calculate the normalized values, the results are shown in **Table 3**.

**Table 3**
Normalized values

| Type | ***C1*** | ***C2*** | ***C3*** | ***C4*** | ***C5*** | ***C6*** | ***C7*** | ***C8*** | ***C9*** |
|---|---|---|---|---|---|---|---|---|---|
| 20 steel | 0.1854 | 0.2487 | 0.4746 | 0.5098 | 0.6388 | 0.4016 | 0.2673 | 0.5852 | 0.4641 |
| 40 steel | 0.2536 | 0.3458 | 0.3607 | 0.4171 | 0.4278 | 0.1582 | 0.4727 | 0.2994 | 0.5953 |
| 45 steel | 0.2687 | 0.3639 | 0.3037 | 0.3708 | 0.1929 | 0.4990 | 0.3580 | 0.2994 | 0.1744 |
| 18Cr2Ni4WA steel | 0.4700 | 0.5805 | 0.2468 | 0.3151 | 0.1838 | 0.4138 | 0.1629 | 0.1497 | 0.4785 |
| 30CrMoA steel | 0.4458 | 0.3354 | 0.2278 | 0.2873 | 0.5164 | 0.2921 | 0.2432 | 0.5716 | 0.2047 |
| 45Mn2 steel | 0.6131 | 0.3828 | 0.2658 | 0.3986 | 0.0854 | 0.5355 | 0.4956 | 0.1497 | 0.3200 |
| 40CrNi steel | 0.1832 | 0.3003 | 0.6075 | 0.2966 | 0.2530 | 0.1460 | 0.4956 | 0.3266 | 0.1629 |

The products ($V_{ij}$) of the normalized value and the weights of the criteria were calculated in accordance with the formula (2), resulting in **Table 4**.

The two formulas (3) and (4) were used to calculate the $u_i$ values, the results are shown in **Table 5**.

The scores ($d_i$) of the alternatives are calculated in accordance with the formula (5). In **Table 6**, $d_i$ scores and rankings of alternatives are summarized. The ranking of alternatives when the weights of the criteria were determined by the Entropy method and the *MEREC* method was also conducted in a similar way. The $d_i$ scores and the rankings of alternatives in these two cases are also summarized in **Table 6**.

**Table 4**
Products of normalized values and weights of criteria

| Type | *C*1 | *C*2 | *C*3 | *C*4 | *C*5 | *C*6 | *C*7 | *C*8 | *C*9 |
|---|---|---|---|---|---|---|---|---|---|
| 20 steel | 0.0206 | 0.0276 | 0.0527 | 0.0566 | 0.0710 | 0.0446 | 0.0297 | 0.0650 | 0.0516 |
| 40 steel | 0.0282 | 0.0384 | 0.0401 | 0.0463 | 0.0475 | 0.0176 | 0.0525 | 0.0333 | 0.0661 |
| 45 steel | 0.0299 | 0.0404 | 0.0337 | 0.0412 | 0.0214 | 0.0554 | 0.0398 | 0.0333 | 0.0194 |
| 18Cr2Ni4WA steel | 0.0522 | 0.0645 | 0.0274 | 0.0350 | 0.0204 | 0.0460 | 0.0181 | 0.0166 | 0.0532 |
| 30CrMoA steel | 0.0495 | 0.0373 | 0.0253 | 0.0319 | 0.0574 | 0.0325 | 0.0270 | 0.0635 | 0.0227 |
| 45Mn2 steel | 0.0681 | 0.0425 | 0.0295 | 0.0443 | 0.0095 | 0.0595 | 0.0551 | 0.0166 | 0.0356 |
| 40CrNi steel | 0.0204 | 0.0334 | 0.0675 | 0.0330 | 0.0281 | 0.0162 | 0.0551 | 0.0363 | 0.0181 |

**Table 5**
$u_i$ values in PIV method

| Type | *C*1 | *C*2 | *C*3 | *C*4 | *C*5 | *C*6 | *C*7 | *C*8 | *C*9 |
|---|---|---|---|---|---|---|---|---|---|
| 20 steel | 0.0475 | 0.0369 | 0.0148 | 0.0000 | 0.0000 | 0.0149 | 0.0254 | 0.0000 | 0.0146 |
| 40 steel | 0.0399 | 0.0261 | 0.0274 | 0.0103 | 0.0234 | 0.0419 | 0.0025 | 0.0318 | 0.0000 |
| 45 steel | 0.0383 | 0.0241 | 0.0337 | 0.0154 | 0.0495 | 0.0041 | 0.0153 | 0.0318 | 0.0468 |
| 18Cr2Ni4WA steel | 0.0159 | 0.0000 | 0.0401 | 0.0216 | 0.0506 | 0.0135 | 0.0370 | 0.0484 | 0.0130 |
| 30CrMoA steel | 0.0186 | 0.0272 | 0.0422 | 0.0247 | 0.0136 | 0.0270 | 0.0280 | 0.0015 | 0.0434 |
| 45Mn2 steel | 0.0000 | 0.0220 | 0.0380 | 0.0124 | 0.0615 | 0.0000 | 0.0000 | 0.0484 | 0.0306 |
| 40CrNi steel | 0.0478 | 0.0311 | 0.0000 | 0.0237 | 0.0429 | 0.0433 | 0.0000 | 0.0287 | 0.0480 |

**Table 6**
Ranking of types of steel for making transmission rods by PIV method

| Type | Weight method | | | | | |
|---|---|---|---|---|---|---|
| | Mean | | Entropy | | *MEREC* | |
| | *di* | Rank | *di* | Rank | *di* | Rank |
| 20 steel | 0.1540 | 1 | 0.1754 | 1 | 0.1385 | 1 |
| 40 steel | 0.2034 | 2 | 0.2018 | 2 | 0.1829 | 2 |
| 45 steel | 0.2589 | 6 | 0.2789 | 6 | 0.2329 | 6 |
| 18Cr2Ni4WA steel | 0.2400 | 5 | 0.2194 | 4 | 0.2158 | 5 |
| 30CrMoA steel | 0.2263 | 4 | 0.2313 | 5 | 0.2035 | 4 |
| 45Mn2 steel | 0.2128 | 3 | 0.2141 | 3 | 0.1913 | 3 |
| 40CrNi steel | 0.2655 | 7 | 0.2940 | 7 | 0.2388 | 7 |

Thus, the ranking of types of steel by the *PIV* method has ended. Some of the comments drawn are as follows:

– the ranks of types of steel are completely identical when using two methods of weight determination as Mean weight method and *MEREC* weight method;

– 5/7 types of steel have the same rank when using the Entropy method to determine the weight compared to the other two methods;

– in all three cases, the types of steel with first grade, second grade, third grade, sixth grade and seventh grade are exactly the same;

– among the seven types of steel reviewed, 20 steel was determined as the best type, whereas 40CrNi steel was determined as the worst type. All the results presented here are based on the notable advantages of the PIV method over other methods advocated by its proposer. This advantage lies in minimizing the phenomenon of ranking reversal for alternatives in different situations [6].

In this context, when weights are calculated using three different methods (Mean, *MEREC*, and Entropy), the rankings for steel types 1st, 2nd, 3th, 6th, and 7th are entirely identical.

The next content in this section is to perform the ranking of types of steel using the *FUCA* method. The ranking of types of steel for each criterion has been carried out, the results are shown in **Table 7**.

**Table 7**
Ranking of types of steel for each criterion

| Type | *C1* | *C2* | *C3* | *C4* | *C5* | *C6* | *C7* | *C8* | *C9* |
|---|---|---|---|---|---|---|---|---|---|
| 20 steel | 6 | 7 | 2 | 1 | 1 | 4 | 5 | 1 | 3 |
| 40 steel | 5 | 4 | 3 | 2 | 3 | 6 | 3 | 4.5 | 1 |
| 45 steel | 4 | 3 | 4 | 4 | 5 | 2 | 4 | 4.5 | 6 |
| 18Cr2Ni4WA steel | 2 | 1 | 6 | 5 | 6 | 3 | 7 | 6.5 | 2 |
| 30CrMoA steel | 3 | 5 | 7 | 7 | 2 | 5 | 6 | 2 | 5 |
| 45Mn2 steel | 1 | 2 | 5 | 3 | 7 | 1 | 1.5 | 6.5 | 4 |
| 40CrNi steel | 7 | 6 | 1 | 6 | 4 | 7 | 1.5 | 3 | 7 |

Applying formula (6) to calculate the score ($v_i$) for each type of steel. This score has also been used to rank the types of steel. In **Table 8**, there are scores and ranks of the types of steel when ranked by the *FUCA* method with three different weight methods.

**Table 8**
Raking of types of steel for making transmission rods by *FUCA* method

| Type | Weight method | | | | | |
|---|---|---|---|---|---|---|
| | Mean | | Entropy | | *MEREC* | |
| | *vi* | Rank | *vi* | Rank | *vi* | Rank |
| 20 steel | 3.3333 | 1 | 3.3350 | 1 | 3.1389 | 1 |
| 40 steel | 3.5000 | 3 | 3.4355 | 2 | 3.6119 | 2 |
| 45 steel | 4.0556 | 4 | 4.1202 | 5 | 4.1517 | 5 |
| 18Cr2Ni4WA steel | 4.2778 | 5 | 3.8555 | 4 | 4.5535 | 6 |
| 30CrMoA steel | 4.6667 | 6 | 4.5178 | 6 | 4.1411 | 4 |
| 45Mn2 steel | 3.4444 | 2 | 3.6418 | 3 | 3.7961 | 3 |
| 40CrNi steel | 4.7222 | 7 | 5.0943 | 7 | 4.6068 | 7 |

From the ranking results of types of steel by the *FUCA* method, some comments are drawn as follows:

– 3/7 types of steel have the same rank when using two Mean and Entropy methods to calculate the weights for the criteria. 4/7 types of steel have the same rank when using two Entropy and *MEREC* methods calculate the weights for the criteria;

– in all three cases, the best steel and the worst steel are always determined to be the same. Accordingly, the best type is 20 steel, the worst type is 40CrNi steel. To achieve consistent results as mentioned above, the use of the *FUCA* method eliminates the need for data normalization. It is important to emphasize that employing different data normalization methods in conjunction with specific *MCDM* methods will lead to varying rankings of alternatives [7, 8]. In this context, when using the *FUCA* method, data normalization is unnecessary, thus eliminating the influence of data normalization on the ranking of alternatives.

In **Fig. 1**, it is a chart comparing the ranking results of types of steel using two *PIV* and *FUCA* methods.

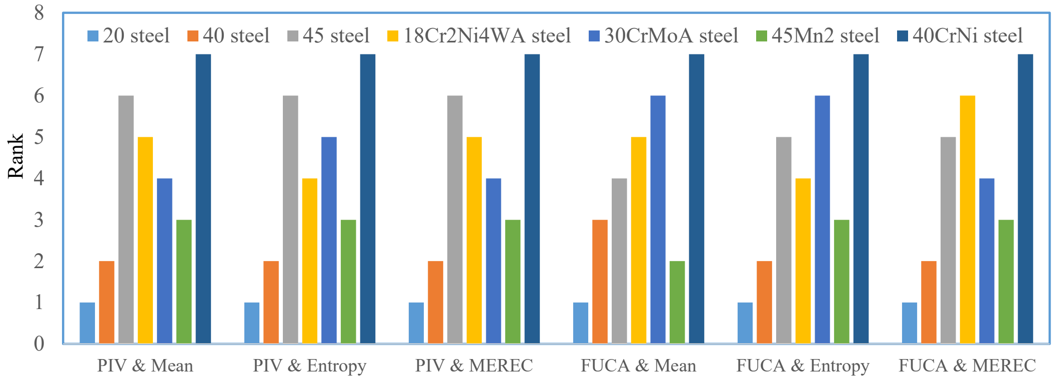


**Fig. 1.** Ranking of types of steel for making transmission rods

Let's find that, in all cases examined, 20 steel is always determined to be the best type of steel, and 40CrNi steel is always determined to be the worst type of steel. In an experimental study comparing various types of steel for the fabrication of transmission rods, alongside a series of tests measuring fatigue strength, flexural strength, corrosion-induced damage, etc., a recommendation was made to use type 20 steel for manufacturing transmission rods [34]. This further underscores that the application of both *PIV* and *FUCA* methods can rapidly identify the best material, significantly reducing time and costs while still determining the optimal steel type, as demonstrated by the experimental research results. This also affirms that the *PIV* and *FUCA* methods are equally effective in multi-criteria decision-making. In addition, the best type of steel found using these two methods is independent of the weights of the criteria. This is achieved by leveraging the prominent advantages of the *PIV* and *FUCA* methods, as previously mentioned [6–8].

## 4. Limitations and development of this research

All three methods used to determine the weights for the criteria in this article, including the Mean method, the Entropy method, and the *MEREC* method, are objective methods. This means that the calculation of weights for the criteria does not take into account the decision-maker's perspective. When it is necessary to seek the opinions of experts on the importance of criteria while still ensuring objectivity, a combined method for weight determination (both subjective and objective) should be used, such as the *MPSI* (Modified Preference Selection Index) method [35].

The criteria used to evaluate each option are all related to the properties of steel (technical criteria of steel). Meanwhile, two cost-related criteria, namely cost and processing cost of steel types, have not been considered in this study. When these two criteria are added to the list of criteria, the selection of the best type of steel will be more comprehensive.

## 5. Conclusions

The best type of steel and the worst type of steel are determined by the *PIV* method regardless of the weights of the criteria. This matter also occurs when applying the *FUCA* method.

The best type of steel determined by the *PIV* method always matches that by the *FUCA* method. This matter also occurs for the worst type of steel.

20 steel is the best type of steel for making transmission rods out of the seven types of steel reviewed.

## Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

## Financing

The study was performed without financial support.

**Data availability**

Manuscript has data included as electronic supplementary material.

**Use of artificial intelligence**

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

**References**

[1] Hoang Tien, D. (2021). Multi-objective optimization of the cylindrical grinding process of SCM440 steel using Preference Selection Index Method. Journal of Machine Engineering. doi: https://doi.org/10.36897/jme/141607

[2] Trung, D. D. (2022). Development of data normalization methods for multi-criteria decision making: applying for MARCOS method. Manufacturing Review, 9, 22. doi: https://doi.org/10.1051/mfreview/2022019

[3] Baydaş, M., Elma, O. E., Pamučar, D. (2022). Exploring the specific capacity of different multi criteria decision making approaches under uncertainty using data from financial markets. Expert Systems with Applications, 197, 116755. doi: https://doi.org/10.1016/j.eswa.2022.116755

[4] Trung, D. D. (2022). Comparison r and curli methods for multi-criteria decision making. Advanced Engineering Letters, 1 (2), 46–56. doi: https://doi.org/10.46793/adeletters.2022.1.2.3

[5] Tran, D. V. (2022). Application of the Collaborative Unbiased Rank List Integration Method to Select the Materials. Applied Engineering Letters : Journal of Engineering and Applied Sciences, 7 (4), 133–142. doi: https://doi.org/10.18485/aeletters.2022.7.4.1

[6] Mufazzal, S., Muzakkir, S. M. (2018). A new multi-criterion decision making (MCDM) method based on proximity indexed value for minimizing rank reversals. Computers & Industrial Engineering, 119, 427–438. doi: https://doi.org/10.1016/j.cie.2018.03.045

[7] Mendoza Luis Fernando, M., Perez Escobedo, J. L., Azzaro-Pantel, C., Pibouleau, L., Domenech, S., Aguilar-Lasserre, A. (2011). Selecting the best portfolio alternative from a hybrid multiobjective GA-MCDM approach for New Product Development in the pharmaceutical industry. 2011 IEEE Symposium on Computational Intelligence in Multicriteria Decision-Making (MDCM). doi: https://doi.org/10.1109/smdcm.2011.5949271

[8] Do, D. T. (2022). Application of FUCA Method for Multi-Criteria Decision Making in Mechanical Machining Processes. Operational Research in Engineering Sciences: Theory and Applications, 5 (3), 131–152. doi: https://doi.org/10.31181/oresta051022061d

[9] Ulutaş, A., Karakuş, C. B. (2021). Location selection for a textile manufacturing facility with GIS based on hybrid MCDM approach. Industria Textila, 72 (02), 126–132. doi: https://doi.org/10.35530/it.072.02.1736

[10] Ulutaş, A., Balo, F., Sua, L., Demir, E., Topal, A., Jakovljević, V. (2021). A new integrated grey mcdm model: case of warehouse location selection. Facta Universitatis, Series: Mechanical Engineering, 19 (3), 515. doi: https://doi.org/10.22190/fume210424060u

[11] Khan, N. Z., Ansari, T. S. A., Siddiquee, A. N., Khan, Z. A. (2019). Selection of E-learning websites using a novel Proximity Indexed Value (PIV) MCDM method. Journal of Computers in Education, 6 (2), 241–256. doi: https://doi.org/10.1007/s40692-019-00135-7

[12] Trung, D. D. (2021). Application of EDAS, MARCOS, TOPSIS, MOORA and PIV Methods for Multi-Criteria Decision Making in Milling Process. Strojnícky Časopis - Journal of Mechanical Engineering, 71 (2), 69–84. doi: https://doi.org/10.2478/scjme-2021-0019

[13] Trung, D. D., Thinh, H. X., Ha, L. D. (2022). Comparison of the RAFSI and PIV method in multi-criteria decision making: application to turning processes. International Journal of Metrology and Quality Engineering, 13, 14. doi: https://doi.org/10.1051/ijmqe/2022014

[14] Duc Trung, D. (2021). A combination method for multi-criteria decision making problem in turning process. Manufacturing Review, 8, 26. doi: https://doi.org/10.1051/mfreview/2021024

[15] Do, T. (2021). The Combination of Taguchi – Entropy – WASPAS – PIV Methods for Multi-Criteria Decision Making when External Cylindrical Grinding of 65G Steel. Journal of Machine Engineering, 21 (4), 90–105. doi: https://doi.org/10.36897/jme/144260

[16] Tuzcu, S. E., Türkoğlu, S. P. (2022). How vulnerable are high-income countries to the covid-19 pandemic? An MCDM approach. Decision Making: Applications in Management and Engineering, 5 (2), 372–395. doi: https://doi.org/10.31181/dmame0318062022t

[17] Wakeel, S., Bingol, S., Bashir, M. N., Ahmad, S. (2020). Selection of sustainable material for the manufacturing of complex automotive products using a new hybrid Goal Programming Model for Best Worst Method-Proximity Indexed Value method.

Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 235 (2), 385–399. doi: https://doi.org/10.1177/1464420720966347

[18] Wakeel, S., Bingol, S., Ding, Z., Ahmad, S., Bashir, M. N., Mohammad Mohsen Emamat, M. S., Hussain, F. (2021). A New Hybrid LGPMBWM-PIV Method for Automotive Material Selection. Informatica, 45 (1). doi: https://doi.org/10.31449/inf.v45i1.3246

[19] Thinh, H. X., Mai, N. T., Giang, N. T., Khiem, V. V. (2023). Applying multi-criteria decision-making methods for cutting oil selection. Eastern-European Journal of Enterprise Technologies, 3 (1 (123)), 52–58. doi: https://doi.org/10.15587/1729-4061.2023.275717

[20] Bingol, S. (2022). Selection of Semiconductor Packaging Materials by Combined Fuzzy AHP-Entropy and Proximity Index Value Method. Mathematical Problems in Engineering, 2022, 1–12. doi: https://doi.org/10.1155/2022/7901861

[21] Jahan, F., Soni, M., Wakeel, S., Ahmad, S., Bingol, S. (2022). Selection of Automotive Brake Material Using Different MCDM Techniques and Their Comparisons. Journal of Engineering Science and Technology Review, 15 (1), 24–33. doi: https://doi.org/10.25103/jestr.151.04

[22] Baydaş, M. (2022). The effect of pandemic conditions on financial success rankings of BIST SME industrial companies: a different evaluation with the help of comparison of special capabilities of MOORA, MABAC and FUCA methods. Business & Management Studies: An International Journal, 10 (1), 245–260. doi: https://doi.org/10.15295/bmij.v10i1.1997

[23] Baydaş, M. (2022). Comparison of the Performances of MCDM Methods under Uncertainty: An Analysis on Bist SME Industry Index. OPUS Toplum Araştırmaları Dergisi, 19 (46), 308–326. doi: https://doi.org/10.26466/opusjsr.1064280

[24] Baydaş, M., Pamučar, D. (2022). Determining Objective Characteristics of MCDM Methods under Uncertainty: An Exploration Study with Financial Data. Mathematics, 10 (7), 1115. doi: https://doi.org/10.3390/math10071115

[25] Ouattara, A., Pibouleau, L., Azzaro-Pantel, C., Domenech, S., Baudet, P., Yao, B. (2012). Economic and environmental strategies for process design. Computers & Chemical Engineering, 36, 174–188. doi: https://doi.org/10.1016/j.compchemeng.2011.09.016

[26] Van Huy, T., Quang Quyet, N., Huu Binh, V., Minh Hoang, T., Thuy Tien, N. T., Thi Nga, D. et al. (2022). Multi-criteria decision-making for electric bicycle selection. Advanced Engineering Letters, 1 (4). doi: https://doi.org/10.46793/adeletters.2022.1.4.2

[27] Hoang, X. T. (2023). Multi-Objective Optimization of Turning Process by Fuca Method. Strojnícky Časopis – Journal of Mechanical Engineering, 73 (1), 55–66. doi: https://doi.org/10.2478/scjme-2023-0005

[28] Son, N. H., Hieu, T. T., Thang, N. M., Tan, H. N., Can, N. T., Thao, P. T., Bao, N. C. (2023). Choosing the best machine tool in mechanical manufacturing. EUREKA: Physics and Engineering, 2, 97–109. doi: https://doi.org/10.21303/2461-4262.2023.002771

[29] Trung, D. D., Thinh, H. X. (2021). A multi-criteria decision-making in turning process using the MAIRCA, EAMR, MARCOS and TOPSIS methods: A comparative study. Advances in Production Engineering & Management, 16 (4), 443–456. doi: https://doi.org/10.14743/apem2021.4.412

[30] Keshavarz-Ghorabaee, M., Amiri, M., Zavadskas, E. K., Turskis, Z., Antucheviciene, J. (2021). Determination of Objective Weights Using a New Method Based on the Removal Effects of Criteria (MEREC). Symmetry, 13 (4), 525. doi: https://doi.org/10.3390/sym13040525

[31] Do, D. T., Nguyen, N.-T. (2022). Applying Cocoso, Mabac, Mairca, Eamr, Topsis and Weight Determination Methods for Multi-Criteria Decision Making in Hole Turning Process. Strojnícky Časopis – Journal of Mechanical Engineering, 72 (2), 15–40. doi: https://doi.org/10.2478/scjme-2022-0014

[32] van, T., Hoang, T., Duc, T., Nguyen, N.-T. (2021). Multi-objective optimization of turning process using a combination of Taguchi and VIKOR methods. Journal of Applied Engineering Science, 19 (4), 868–873. doi: https://doi.org/10.5937/jaes0-29654

[33] Bringas, J. E. (Ed.) (2016). Handbook of Comparative World Steel Standards, 5th Edition. ASTM International. doi: https://doi.org/10.1520/ds67d-eb

[34] Ashby, M. F. (2016). Materials Selection in Mechanical Design. Butterworth-Heinemann, 660.

[35] Gligorić, M., Gligorić, Z., Lutovac, S., Negovanović, M., Langović, Z. (2022). Novel Hybrid MPSI-MARA Decision-Making Model for Support System Selection in an Underground Mine. Systems, 10 (6), 248. doi: https://doi.org/10.3390/systems10060248

*Received date 02.08.2023*
*Accepted date 13.11.2023*
*Published date 30.11.2023*



***How to cite:*** *Thinh, H. X., Mai, N. T. (2023). Comparison of two methods in multi-criteria decision-making: application in transmission rod material selection. EUREKA: Physics and Engineering, 6, 59–68. doi: https://doi.org/10.21303/2461-4262.2023.003046*