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# COMBINED PIPRECIA METHOD AND MODIFIED FUCA METHOD FOR SELECTION OF LATHE

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*The choice of technological equipment in general or lathe in particular has a great influence on the efficiency of the machining processes. Lathes are often evaluated by many criteria, both quantitative and qualitative. Sometimes the criteria employed by the methods are opposite to each other. Hence the choice of lathe is usually made through the evaluation of multiple criteria, which is known as "Multi-Criteria Decision Making – MCDM". In the research was used PIPRECIA method to determine the weights of the criteria. Modifications to FUCA method were then implemented. The combination of PIPRECIA method and the modified FUCA method were applied to the lathe selection in two cases. In both cases the best and worst alternatives were determined in the same way as when using the CURLI method. This confirms the correct implementation of the FUCA method modification, and the combination of PIPRECIA and the modified FUCA method turns out to be a right approach in the selection of lathes. Details that need to be considered in future research were also mentioned in this study.*

*Keywords: MCDM, PIPRECIA, modified FUCA method, CURLI, lathe selection*

## LIST OF ACRONYMS

MCDM: Multi-Criteria Decision Making

FUCA: Faire Un Choix Adéquat (in French) - Make an Adequate Choice

PIPRECIA: PIvot Pairwise RElative Criteria Importance Assessment

TOPSIS: Technique for Order Preference by Similarity to Ideal Solution

M-TOPSIS: Modified synthetic evaluation method based on the concept of original TOPSIS

CNC: Computer Numerical Control

AHP: Analytic Hierarchy Process

VIKOR: VIsekriterijumska optimizacija i KOmpromisno Resenje (in Serbian)

LDVIKOR: Later Defuzzification VIKOR

WASPAS: Weighted Aggregates Sum Product Assessment

EDAS: Evaluation based on Distance from Average Solution

CODAS: COmbinative Distance-based Assessment

GRA: Grey Relational Analysis

COPRAS: COmplex PRroportional ASsessment

MOORA: Multi-Objective Optimization on the basis of Ratio Analysis

MULTIMOORA: MULTI- MOORA

BWM: Best Worst Method

ELECTRE: ELimination and Choice Translating Reality

MABAC: Multi-Attributive Border Approximation area Comparison

SAW: Simple Additive Weighting

LINMAP: LINear programming technique for Multidimensional Analysis of Preference

DELPHI: The name for a study of the use of expert opinion that been intermittently conducted at the (research and development) RAND Corporation. The technique employed is called DELPHI method.

CURLI: Collaborative Unbiased Rank List Integration

FDEMATEL: Fuzzy DEcision-MAking Trial and Evaluation Laboratory

PROMETHEE: The Preference Ranking Organization METHod for Enrichment Evaluation

ANP: Analytical Network Process

PEG: Pareto-Edgeworth Grierson

PSI: Preference Selection Index

R: Ranking of the attributes and alternatives

PIV: Proximity Indexed Value

## 1 INTRODUCTION

Lathes are considered the most common type of machine in the field of mechanical processing. The number of lathes usually accounts for about 25-50% of the total number of machine tools in machining workshops [1, 2]. The choice of lathe has great influence on the economic and technical efficiency of machining processes [3, 4]. Choosing a lathe is a complex decision making involving many criteria [5]. This work is known as multi-criteria decision making and has been applied in several studies [6-8].

The *TOPSIS* method was used to select one out of twenty-one CNC lathes [5]. In this study, seven quantitative criteria were used to describe each machine including: cost, spindle speed, feed capacity, fast X-axis travel speed, fast Z-axis travel speed, the maximum machining diameter, and the maximum machining length. The weights of the criteria were determined by the *AHP* method.

Six multi-criteria decision-making methods including *VIKOR*, *WASPAS*, *EDAS*, *CODAS*, *TOPSIS* and *M-TOPSIS* were used simultaneously to select one of the five CNC lathes. Each lathe is described by six quantitative parameters including power, factor of operation, cost, spindle speed, maximum machining diameter and machine space (ground area required for installation machine). The weights of the criteria were also determined by the *AHP* method. The results show that all six *MCDM* methods, when used, consistently gave the same results [9].

The authors in the paper [10] also used the *TOPSIS* method to select one out of eight CNC lathes. Seven quantitative criteria were used to describe each machine: cost, spindle speed, distance between two center points, fast X-axis travel speed, fast Z- axis travel speed, maximum machining diameter, maximum machining length. The AHP method was once again used to determine the parameters for the criteria.

The authors of research [11] used *GRA*, *COPRAS*, and *MULTIMOORA* simultaneously to make multi-criteria decisions when choosing CNC lathes. In this study they presented seven different variants of CNC lathes. Each lathe was described by thirteen quantitative criteria: table load, main travel, table size, machine weight, spindle rate, spindle powe, maximum tool weight, feed rate, tool magazine capacity, cutting feed rate, procurement price, operation cost, and maintanance cost. The weights of the criteria were determined using the *BWM* method. The results showed that the two methods *COPRAS* and *MULTIMOORA* gave the same best solution while the GRA method identified another best solution.

Four methods *TOPSIS*, *MOORA*, *COPRAS* and *ELECTRE I* were used simultaneously to rank four types of CNC lathes [12]. Seven quantitative criterias were used to evaluate lathes: maximum machining diameter, spindle speed, number of tools, number of axes, machine weight, floor layout, and horse power. The AHP method was also used to determine the weights for the criteria. This study has shown that when using the above four decision making methods (*TOPSIS*, *MOORA*, *COPRAS*, and *ELECTRE I*) always returned the same best alternative.

As can be seen, multi-criteria decision making for lathe selection has been successfully implemented by a number of scientists with the use of different decision-making methods. However, in all of the above studies, the criteria for evaluating lathes are quantitative criteria. This can be considered as a shortcoming when considering the criteria of the lathe. It can be said that because the choice of lathe should not only consider quantitative criteria (such as cost, spindle speed, maximum size of workpiece that can be turned, and so on), but it is also necessary to consider other qualitative criteria (e.g machine shape, safety issues, complexity of operation, shipping after purchase, machine care service of the supplier). This limitation has also been overcome in some published documents.

In research [13], the authors selected one of five types of lathes. Four criteria were used to evaluate the options: cost related specifications, technical specifications, operational specifications, and quality related specifications. These four criteria are further divided into fifteen sub-criteria, in which there are qualitative criteria and also quantitative criteria. The modified *DELPHI* method and the *AHP* method were combined to determine the weights for the criteria. Besides, the *PROMETHEE* method was used to rank the alternatives.

To select one of the four CNC lathes, the authors in research [14] combined the *FDEMATEL* method and the Entropy method to determine the weights for the criteria. Six criteria were selected to evaluate the machine including maximum spindle speed, failure rate, utilization, max spindle torque, linkage accuracy, and cost. Finally, the *LDVIKOR* method was used by them to rank the alternatives.

The *ANP* method was used to determine the weights for the criteria when selecting CNC lathes [15]. Three types of machines were offered for choice, each described by eight criteria: productivity, flexibility, space (machine dimensions), adaptability, precision, reliability, safety and environment, and maintenance and service. The authors in this study modified the *TOPSIS* method to rank alternatives.

The *AHP* method was also used to determine the weights for the criteria when selecting one of the four machining centers. Eight criteria were used to evaluate machining centers: cost, operative flexibility, installation ease, maintainability and service ability, productivity, compatibility, safety and user friendliness. The multi-criteria decision-making method used in this study is the *TOPSIS* method [16].

In all of the above studies, it was found that the weights of the criteria were determined by the *AHP* method (or the modified *AHP* method). But when using the AHP method, we must also recognize the following limitations. Firstly, weights are assigned to each option or each criterion (both qualitative and quantitative), so the ranking results of the alternatives are heavily influenced by the subjective thoughts of the decision maker [17]. Secondly, the consistency of the comparison matrix will be affected by the subjective thinking of the decision makers. When the consistency of the matrix is not guaranteed, the decision-making results will not be accurate [18]. According to psychology, the consistency among decision makers will be difficult to ensure when the number of alternatives is not within the range of 7±2 and the reliability of the results decreases as the number of criteria/options increases [19]. From this it can be seen that although *AHP* has been successfully used in determining weights for the criteria of lathes. But it would be better to find another method to replace *AHP* so that we can avoid the disadvantages of the *AHP* method.

*PIPRECIA* is a method for determining the weights for criteria when the criteria are both quantitative and qualitative [20]. The steps are also much simpler than those of the *AHP* method. The weights of the criteria do not depend on the subjective thinking of the decision maker, but only on the comparison of importance between the criteria. Detailed steps to follow in this method will be presented in part 2 of this paper. This method has been used to determine the weight of the criteria in many areas: evaluation of a website showcasing the hotels in Eastern and Southern Serbia [21]; green supplier selection [22]; assessing the quality of e-learning materials [23]; choose the form of investment in hotel construction [24]; selecting personnel for management positions for a textile factory [25]; choose the company's development strategy [26]; selection of website design methods [27]; and so on. To date, there have not been any studies applying this method to determine the weights for the criteria in the decision of choosing a lathe. This gap is the reason for this study to apply the *PIPRECIA* method.

*FUCA* is a multi-criteria decision making method suitable for cases when the criteria are both qualitative and quantitative [28]. This method has been applied to multi-criteria decision making for a number of problems such as to evaluate the rankings of companies in the period before and after the Covid-19 pandemic. It has shown better efficiency than *MOORA* and *MABAC* [29]; When used to assess the financial performance of companies, it is as effective as the *WSA* method [30]. It has also been confirmed to be superior to *TOPSIS* when used in multi-criteria decision making in the selection of chemical manufacturing processes [31]. In research [32], when used to evaluate the financial performance of companies, *FUCA* was confirmed to be equivalent to the *PROMETHEE* method, and better than *COPRAS*, *TOPSIS*, *SAW*, *CODAS*, and *MOORA*. When used in another study on evaluating the financial performance of companies, *FUCA* was also found to be as effective as the *PROMETHEE* method, and better than the *TOPSIS*, *GRA*, *S-*, *WSA*, *SAW*, *COPRAS*, *MOORA*, and *LINMAP* [33].

In some of the above studies, it has been shown that the *FUCA* method is in ranking the options in various fields, mainly in the economic domain. It has also been claimed to be better or equivalent to other *MCDM* methods. However, the application of this method to the selection of lathes has not been found in any study. That is also the reason why *FUCA* is used in this study. On the other hand, when looking closely at this method, we found a limitation in cases when a certain criterion has the same value in two or more alternatives then the ranking of alternatives against this criterion cannot be done. A detailed analysis of this limitation of the *FUCA* method as well as a proposed solution will be presented in the third part of this paper.

From the above analysis, in this study, the *PIPRECIA* method will be applied to determine the weights for the criteria of the lathe. Modifications to the *FUCA* method will also be implemented to rank alternatives. The following contents of this paper include: (1) Introduction of steps to follow the *PIPRECIA* method; (2) Analyze the limitation of the *FUCA* method and modify it to overcome that limitation; (3) Combination of PIPRECIA method and modified *FUCA* method for lathe selection in two cases. The results in each case were compared with another multi-criteria decision-making method; (4) finally, the conclusions to be drawn and the work to be done in the future.

## *2 PIPRECIA METHOD*

The steps to determine the weight of the criteria according to the *PIPRECIA* method are as follows [20]:

**Step 1**: Select a number of assessors (experts) and define the criteria to be used in the evaluation of alternatives.

**Step 2**: Each assessment participant will determine the relative importance of the criteria $s_j$, starting from the second criterion according to the following formula.

$$s_j = \begin{cases} > 1 \; when \; C_j > C_{j-1} \\ 1 \; when \; C_j = C_{j-1} \\ < 1 \; when \; C_j < C_{j-1} \end{cases} \quad (1)$$

**Step 3**: Determine the coefficient $k_j$ according to the following formula, this is applied to each assessment participant.

$$k_j = \begin{cases} 1 & j = 1 \\ 2 - s_j & j > 1 \end{cases} \quad (2)$$

**Step 4**: Determine the recalculated weight of the criteria according to the following formula, which is also applied to each assessment participant.

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \quad (3)$$

**Step 5**: Determine the relative weight of the criteria according to formula (4). If there are $K$ participants in the assessment ($K \geq 2$), additional step 6 should be performed.

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \quad (4)$$

**Step 6**: Assuming there are $K$ assessment participants, then the weights of the criteria are calculated according to (5) and (6). Where $r$ represents the $r^{th}$ evaluation participant; $n$ is the number of criteria.

$$w_j^* = \left(\prod_{r=1}^{K} w_j^r\right)^{1/K} \quad (5)$$

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

## 3 MODIFICATION OF THE FUCA METHOD

The *FUCA* method performs the ranking of alternatives according to the following steps [28]:

**Step 1**. Rank the alternatives for each criterion ($r_{ij}$). Suppose there are $m$ alternatives, the best value will be ranked 1, otherwise the worst value will be ranked $m$. If there are $n$ criteria, perform $n$ ratings for each criterion.

However, at this step we have noticed a limitation of the *FUCA* method, that is, when a certain criterion in two or more options has the same value, it is unclear how the ranking of the alternatives will take place. To make this statement clearer, let us consider a simple example as follows. Suppose there are 4 options *A1*, *A2*, *A3*, *A4*, and each option is represented by three criteria *C1*, *C2*, *C3*, with the assumption *C1* is the criterion as large as possible; *C2* and *C3* are criteria as small as possible, as shown in Table 1.

Table 1: Example of a certain criterion having equal value in two or more options

| Alternatives | C1 | C2 | C3 |
|---|---|---|---|
| A1 | 4 | 8 | 5 |
| A2 | 6 | 6 | 5 |
| A3 | 1 | 8 | 4 |
| A4 | 8 | 5 | 5 |

For criterion *C1* (the bigger the better), when ranking the options, we can easily get the results in descending order as follows: *A4* > *A2* > *A1* > *A3*. However, for *C2* and *C3*, the job is not so simple. As follows:

For *C2* (the smaller the better), we find that at *C2* at *A4* is the smallest, so *A4* ranks 1; *A2* ranks 2. However, *C2* at *A1* and *A3* are equal. Therefore, it is not possible to determine whether *A1* ranks 3, *A3* ranks 4, or vice versa.

Similarly, for criterion *C3* (the smaller the better): since *C3* at *A3* is the smallest, *A3* is ranked 1. But *C3* at *A1*, *A2* and *A4* are equal, so what rank do these alternatives belong to? *2nd*, *3rd* and *4th* place is impossible.

Stemming from this limitation of the *FUCA* method, the modification of the *FUCA* method is made as follows:

For the criterion *C2*, consider two options *A1* and *A3*, we rank these two options at the same rank of 3.5 (average of 3 and 4);

For criterion *C3*, all three alternatives *A1*, *A2*, *A4* are ranked 3 (the average of 2, 3, and 4). From there, we have the ranking results of the options for each criterion as shown in Table 2.

Table 2: Ranking of options for each criterion for the data in the Table 1

| Alternatives | $r_{ij}$ | | |
|---|---|---|---|
| | C1 | C2 | C3 |
| A1 | 2 | 3.5 | 3 |
| A2 | 3 | 2 | 3 |
| A3 | 1 | 3.5 | 1 |
| A4 | 4 | 1 | 3 |

The modification of the *FUCA* method presented above offers certain promises for its application where a certain criterion is equally valid in two or more alternatives. After ranking the alternatives for each criterion, the ranking of the alternatives is carried out in the next steps.

**Step 2.** Calculate the score of each option according to the formula.

$$v_i = \sum_{j=1}^{n} r_{ij}.w_j \quad (7)$$

Where $w_j$ is the weight of the jth criterion.

**Step 3.** Rank the alternatives by the value of $v_i$. The best solution is the one with the smallest $v_i$ and vice versa.

## 4 EXAMPLES

### 4.1 Example 1 - selection of CNC lathe

HUYNDAI WIA Machine Tools is a machine tool company of HUYNDAI WIA GLOBAL. It provides modern CNC machines in the world. The CNC lathes of this company have high accuracy, stable operation and are very popular in Vietnam market. For the purpose of choosing to buy a suitable CNC lathe from HYUNDAI WIA Machine Tools, we need to consider choosing one of four models KIT4500, E160A, E160C, and SE2000PA. According to the parameters used to describe the characteristics of the machine displayed on the company's website, we have the data as shown in Table 3 [34]. Generally, all four of these machines can handle the work. This table is not a comprehensive list of information about lathes available on the company's website. Parameters that have the same value for all machines (Driving Method - Belt, Software - H/W FANUC i and so on) were not included in Table 3, as they did not affect decision-making. Only parameters that are different in between at least one of the four machines are included in this table. The price of the machine is also considered a very important parameter in machine selection. At the time of the research, the prices of the mentioned machines were not available. Thus, it can be said that the selection of lathes in this case only considers the technical factors and their technological capabilities without considering the cost issue.

Table 3: Some parameters of CNC lathes [34]

| Criteria | Description | Unit | CNC lathe | | | |
|---|---|---|---|---|---|---|
| | | | KIT4500 | E160A | E160C | SE2000PA |
| *C1* | Max Turning Diameter | mm | 165 | 280 | 280 | 350 |
| *C2* | Max Turning Length | mm | 300 | 300 | 280 | 280 |
| *C3* | Chuck Size | inch | 6″ | 6″ | 8″ | 6″ |
| *C4* | Spindle RPM | revolution/min | 6,000 | 6,000 | 4,000 | 6,000 |
| *C5* | Spindle Output | kW | 15 | 11 | 11 | 15 |
| *C6* | Spindle Torque | N.m | 95.5 | 70 | 126 | 92.5 |
| *C7* | Travel (X) | mm | 450 | 165 | 165 | 210 |
| *C8* | Travel (Z) | mm | 300 | 330 | 330 | 330 |
| *C9* | Rapid Travel (X) | m/min | 30 | 30 | 30 | 24 |
| *C10* | Rapid Travel (Z) | m/min | 36 | 30 | 30 | 24 |
| *C11* | Slide Type | - | LM | LM | LM | BOX |
| *C12* | No. of Tools | EA | 6 | 12 | 10 | 12 |

According to the data in Table 3, out of 12 criterias, only C11 is a qualitative criterion, where LM represents the rectangular cross-section of the body, and BOX represents the square cross-section of the body. On the other hand, except for C11, all other parameters are set as large as possible. According to the data in Table 3, it is very difficult to choose 1 machine out of 4 machines because there are many contradictory parameters between those four types of machines. The following examples will make this statement clearer. For example, the C1 of the SE2000PA is larger than the C1 of the 165, but the C2 of the SE2000PA is smaller than the C2 of the KIT4500; The C3 of the E160C is the largest, but the C4 of the same machine is the smallest; The C6 of the E160C is the largest but its C5 is smaller than that of the KIT4500 and SE2000PA, ect. In addition to the complexity of the machine evaluation criteria, personal views on each criterion are also different. For example, some people think that C1 is the most important, others think C2 or C3. Because of this, we have conducted a survey for 6 individuals, all of whom are experts in the relevant field. The questionnaire was built as in step 1 and step 2 of the PIPRECIA method (refer to item 2). After receiving the responses from all six experts, the results as shown in Table 4 were constructed.

For each expert, the kj, qj and wj values were also calculated according to the respective formulas (2), (3), and (4). The results have been summarized in Table 5.

Formulas (5), (6) were used to calculate the weights for the criteria, the results are presented in Table 6. According to the data in Table 6, it shows that C2 (Max turning length) is the criterion with the highest weight, followed by C1 (Max turning diameter), while C11 (Slide type) is the criterion with the smallest weight. The criteria are in descending order of weights (C2 > C4 > C1 > C3 > C5 > C8 > C7 > C6 > C9 > C10 > C12 > C11). This is also the order of priority for the criteria.

The modified FUCA method was used to rank the alternatives in the following order:

First, the ranking of alternatives for each criterion is performed.

For criterion C1: We see that C1 of SE2000PA is the largest among the four, so this alternative is ranked 1st, C1 of E160A and E160C is equal, so these two options are ranked 2.5 (average of 2 and 3), C1 of KIT4500 is the smallest, so this alternative is ranked 4.

For C2 criterion: Both options KIT4500 and E160A have the same C2, so these two options are ranked 1.5 (the average of 1 and 2), and the two options E160C and SE2000PA also have the same C2, so the two options are equal. This alternative is rated 3.5 (the average of 3 and 4).

Table 4: $S_j$ values assessed by experts

| Criteria | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 |
|---|---|---|---|---|---|---|
| *C1* | | | | | | |
| *C2* | 1.1 | 1.2 | 1 | 0.9 | 1 | 0.9 |
| *C3* | 0.9 | 0.9 | 1 | 0.9 | 0.9 | 1 |
| *C4* | 1.2 | 0.9 | 1 | 1 | 1.1 | 1.1 |
| *C5* | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 1 |
| *C6* | 0.9 | 0.9 | 1 | 0.9 | 0.9 | 1 |
| *C7* | 1.2 | 0.9 | 1.2 | 1 | 1 | 0.9 |
| *C8* | 1.2 | 0.9 | 1 | 1 | 1 | 0.9 |
| *C9* | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| *C10* | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| *C11* | 0.8 | 0.9 | 1 | 0.8 | 0.9 | 0.8 |
| *C12* | 1.1 | 1.2 | 1 | 1.1 | 1.2 | 1 |

Table 5: Some parameters in PIPRECIA

| Criteria | | *C1* | *C2* | *C3* | *C4* | *C5* | *C6* | *C7* | *C8* | *C9* | *C10* | *C11* | *C12* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Expert 1 | $k_j$ | 1.000 | 0.900 | 1.100 | 0.800 | 1.100 | 1.100 | 0.800 | 0.800 | 1.100 | 1.100 | 1.200 | 0.900 |
| | $q_j$ | 1.000 | 1.111 | 1.010 | 1.263 | 1.148 | 1.044 | 1.304 | 1.631 | 1.482 | 1.348 | 1.123 | 1.248 |
| | $w_j$ | 0.068 | 0.076 | 0.069 | 0.086 | 0.078 | 0.071 | 0.089 | 0.111 | 0.101 | 0.092 | 0.076 | 0.085 |
| Expert 2 | $k_j$ | 1.000 | 0.800 | 1.100 | 1.100 | 1.100 | 1.100 | 1.100 | 1.100 | 1.100 | 1.100 | 1.100 | 0.800 |
| | $q_j$ | 1.000 | 1.250 | 1.136 | 1.033 | 0.939 | 0.854 | 0.776 | 0.706 | 0.641 | 0.583 | 0.530 | 0.663 |
| | $w_j$ | 0.099 | 0.124 | 0.112 | 0.102 | 0.093 | 0.084 | 0.077 | 0.070 | 0.063 | 0.058 | 0.052 | 0.066 |
| Expert 3 | $k_j$ | 1.000 | 1.000 | 1.000 | 1.000 | 1.100 | 1.000 | 0.800 | 1.000 | 1.100 | 1.100 | 1.000 | 1.000 |
| | $q_j$ | 1.000 | 1.000 | 1.000 | 1.000 | 0.909 | 0.909 | 1.136 | 1.136 | 1.033 | 0.939 | 0.939 | 0.939 |
| | $w_j$ | 0.084 | 0.084 | 0.084 | 0.084 | 0.076 | 0.076 | 0.095 | 0.095 | 0.087 | 0.079 | 0.079 | 0.079 |
| Expert 4 | $k_j$ | 1.000 | 1.100 | 1.100 | 1.000 | 1.100 | 1.100 | 1.000 | 1.000 | 1.100 | 1.100 | 1.200 | 0.900 |
| | $q_j$ | 1.000 | 0.909 | 0.826 | 0.826 | 0.751 | 0.683 | 0.683 | 0.683 | 0.621 | 0.565 | 0.470 | 0.523 |
| | $w_j$ | 0.117 | 0.106 | 0.097 | 0.097 | 0.088 | 0.080 | 0.080 | 0.080 | 0.073 | 0.066 | 0.055 | 0.061 |
| Expert 5 | $k_j$ | 1.000 | 1.000 | 1.100 | 0.900 | 1.100 | 1.100 | 1.000 | 1.000 | 1.100 | 1.100 | 1.100 | 0.800 |
| | $q_j$ | 1.000 | 1.000 | 0.909 | 1.010 | 0.918 | 0.835 | 0.835 | 0.835 | 0.759 | 0.690 | 0.627 | 0.784 |
| | $w_j$ | 0.098 | 0.098 | 0.089 | 0.099 | 0.090 | 0.082 | 0.082 | 0.082 | 0.074 | 0.068 | 0.062 | 0.077 |
| Expert 6 | $k_j$ | 1.000 | 1.100 | 1.000 | 0.900 | 1.000 | 1.000 | 1.100 | 1.100 | 1.100 | 1.100 | 1.200 | 1.000 |
| | $q_j$ | 1.000 | 0.909 | 0.909 | 1.010 | 1.010 | 1.010 | 0.918 | 0.835 | 0.759 | 0.690 | 0.575 | 0.575 |
| | $w_j$ | 0.098 | 0.089 | 0.089 | 0.099 | 0.099 | 0.099 | 0.090 | 0.082 | 0.074 | 0.068 | 0.056 | 0.056 |

The ranking of alternatives for the remaining criteria is also done in a similar way. Particularly for *C11* as a qualitative criterion, all the respondents have the same opinion that the BOX type is better than the LM model, so for this criterion, the SE2000PA option is ranked *1st*, the remaining options ranked *3rd* (average of 2, 3 and 4). The ranking results of the alternatives for all criteria are summarized in Table 7.

After determining the weights of the criteria (in Table 6) and ranking the options for each criterion (in Table 7), apply formula (7) to calculate the value of $v_i$ for each option. The results are presented in Table 8. The results of the ranking of alternatives according to the value of $v_i$ have also been summarized in this table.

Table 6: Weight of criterias

| Criteria | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weight | 0.0935 | 0.0957 | 0.0898 | 0.0950 | 0.0878 | 0.0824 | 0.0859 | 0.0864 | 0.0785 | 0.0714 | 0.0631 | 0.0705 |

Table 7: Ranking of alternatives for each criterion

| Alternatives | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KIT4500 | 4 | 1.5 | 3 | 2 | 1.5 | 2.5 | 1 | 4 | 2 | 1 | 3 | 3.5 |
| E160A | 2.5 | 1.5 | 3 | 2 | 3.5 | 4 | 3.5 | 2 | 2 | 2.5 | 3 | 1 |
| E160C | 2.5 | 3.5 | 1 | 4 | 3.5 | 1 | 3.5 | 2 | 2 | 2.5 | 3 | 2 |
| SE2000PA | 1 | 3.5 | 3 | 2 | 1.5 | 2.5 | 2 | 2 | 4 | 4 | 1 | 3.5 |

Table 8: $v_i$ values of alternatives and ratings

| Alternatives | $v_i$ | Rank |
|---|---|---|
| KIT4500 | 2.4106 | 1 |
| E160A | 2.5423 | 3 |
| E160C | 2.5675 | 4 |
| SE2000PA | 2.4796 | 2 |

According to the data in Table 8: KIT4500 is considered the best choice, followed by SE2000PA, ranked *3rd* E160A, and *4th* place belongs to option E160C. Looking back at the data in Table 3, it shows that, for criterion *C2* which is the criterion with the greatest weight, option KIT4500 is equal to option E160A and larger than the other two options (E160C and SE2000PA). For criterion *C4* which is the criterion with the second weight, the three options KIT4500, E160A, and SE2000PA have the same value and greater than that of option E160C, etc. Thus, it can be said that KIT4500 is a good solution. In contrast, E160C is considered the worst option. In this case *C2* is the smallest compared to other options, *C4* of this option is also smaller than the other three options etc. Therefore, the conclusion that E160C is the worst option can also be confirmed to be correct. From that, it can be said that the ranking of the options in this example has been done successfully. However, in order to further strengthen this assumption, it is necessary to compare the results of the ranking when performed by a different decision-making method. Since the criteria used to describe lathes are both qualitative and quantitative, the number of methods that can be used to rank options in this case is also very limited. Fortunately, *CURLI* has been found to be one of the few methods of dealing with this situation. *CURLI* is a method to rank the solutions without normalizing the data and without determining the weights for the criteria. It is considered as a suitable solution for the problem with the criteria in the form of both qualitative and quantitative. Details on how to rank alternatives according to this method can be found in the literature [35-37]. This method has been successful in ranking applicants studying at a medical school [35]. When used to rank alternatives of turning, it has also been shown to have an accuracy comparable to that of the *PEG* method and better than that of the *PSI* method [36]. Recently, the *CURLI* method also determines the best option in robot selection like the R method and the *CODAS* method; select the best option for the turning process as if using the other eight methods (*R*, *SAW*, *WASPAS*, *TOPSIS*, *VIKOR*, *MOORA*, *COPRAS*, and *PIV*); choose the best option when choosing the bridge construction option like the *R* method and the *MABAC* method [37]. These give some confidence when using the *CURLI* method as a tool for comparison with the modified *FUCA* method in this study.

Using the *CURLI* method, it was determined that KIT4500 is the best option, followed by the SE2000PA option, the third-ranked E160A option, and the fourth-ranked E160C option. Thus, in this case, the ranking results of the options are exactly the same when using both the modified *FUCA* and *CURLI* methods. This reinforces the claim that the combined application of the *PIPRECIA* method and the modified *FUCA* method was successful in this example.

### *4.2 Example 2 - Selection of a used lathe*

In this example, the ranking of options of used universal lathes has been performed. Seven types of old lathes were given the rating; five criteria were used to evaluate the options including:

*C1* – Max turning diameter (mm);

*C2* - Max turning length (mm);

*C3* – Cost (USD);

*C4* is a composite criterion, including accuracy, stability, and safety. To determine this criterion of the machines, we proceeded to use those machines to turn ten steel samples per machine, after determining the machining accuracy, accuracy stability, stability of the machine during operation, the level of safety when operating the machine, etc., has confirmed the criteria according to the levels: "*VG = Very Good*", "*G1 = Good 1*", "*G2 = Good 2*", "*AV1 = AVerage 1*", "*AV2 = AVerage 2*", and "*W= Weak*". In which, *VG* is the best, *G1* is better than *G2*; *AV1* is better than *AV2*, and *W* is worst.

*C5* is also an aggregate criterion. It is evaluated by appearance, year of manufacture, etc. From observing the machines, this criterion has been determined for each machine as *G1*, *G2*, *G3*, *G4*, *G5*, *G6*, and *G7*. Where *G1* is considered the best, *G7* is considered the worst.

In the above five criteria, *C1*, *C2*, *C3* are quantitative criteria, and *C4* and *C5* are qualitative criteria. *C1* and *C2* are criteria as large as possible, whereas *C3* is criteria as small as possible. The criteria for each type of machine are presented in Table 9.

Table 9: Criteria of old lathes

| Alternatives | *C1 (mm)* | *C2 (mm)* | *C3 (USD)* | *C4 (-)* | *C5 (-)* |
|---|---|---|---|---|---|
| *M1* | 2100 | 400 | 2500 | *AV2* | *G2* |
| *M2* | 1750 | 350 | 1900 | *VG* | *G4* |
| *M3* | 1950 | 312 | 2150 | *G2* | *G1* |
| *M4* | 1800 | 380 | 1700 | *G1* | *G3* |
| *M5* | 1450 | 312 | 1520 | *AV2* | *G6* |
| *M6* | 1700 | 280 | 1900 | *W* | *G7* |
| *M7* | 1600 | 312 | 2300 | *AV1* | *G5* |

Choosing one of the seven types of machines (in Table 9) will be difficult if you just look at this table. For example, comparing M1 and M2, M1's C1 is better than M1's C2, M1's C2 is also better than M2's C2, but M1's C3 is worse than M2's C2, M2's C4 is better than M1's C4, but M2's C5 is worse than M1's C5. A pairwise comparison of the options revealed the same thing. Thus, in order to choose an option that is considered the best, it is necessary to first determine the weights for the criteria. However, each decision maker also has different views on the priority level for each criterion, some people think that C1 should be the first priority criterion, others think that the ranking criteria is the most important first rank should be C2, others say C3 should be the top priority criterion, ect. Thus, in order to determine the weights for the criteria, it is also necessary to distribute questionnaires to experts. Six experts were also asked to complete a questionnaire (similar to the example in section 4.1). The PIPRECIA method was also used to determine the weights for the criteria. The results have determined the weights for criteria C1, C2, C3, C4, and C5 are 0.1719, 0.1653, 0.1574, 0.2624, and 0.2430, respectively. Thus, the weight of the criteria decreases in the order C4 > C5 > C1 > C2 > C3, which means that according to the expert opinion, when choosing an old lathe, the aggregate criterion C4 (including accuracy, safety, stability, etc) is the first priority, while cost (C3) is the final consideration.

The modified FUCA method is also used to rank the alternatives. Doing the same as in section 4.1, the alternatives have been ranked as shown in Table 10. The CURLI method is also used to rank the alternatives, the results are also summarized in this table.

According to the data in Table 10, the ranking results of the alternatives between the two methods FUCA and CURLI are not the same. This is understandable because when using the FUCA method, it is necessary to determine the weights for the criteria, and for the CURLI method, the weighting for the criteria is not necessary. Even so, the best alternative (M2) and the worst alternative (M6) are consistently determined using these two methods. That said, we can confirm that M2 is the best solution to find. In option M2, the criterion with the largest weight (C4) is VG, which is the best level among the alternatives. In contrast, in option M6, criterion C4 is W, which is the worst of the alternatives. That said, the determination of the best alternative (M2) and the worst alternative (M6) was successful in this study. From this it can be concluded that the combination of the PIPRECIA method and the modified FUCA method was also successful in this example.

Table 10: Ranking options for classifying old lathes

| Alternatives | Modified FUCA method | CURLI method |
|---|---|---|
| M1 | 4 | 2 |
| M2 | 1 | 1 |
| M3 | 3 | 4 |
| M4 | 2 | 3 |
| M5 | 6 | 5 |
| M6 | 7 | 7 |
| M7 | 5 | 6 |

Through two implemented examples, the combination of modified PIPRECIA and FUCA methods has been successfully implemented in the selection of used CNC and universal lathes. When using this combination, the best and worst alternatives are always the same as when using the CURLI method. CURLI is a proven method with comparable accuracy to many other decision - making methods. This gives us a solid conclusion that the modification of the FUCA method has been successfully implemented. This success allows to widen the applicability of the FUCA method in cases where a certain criterion is equally valid in two or more alternatives. This is the limitation that the original FUCA method has not mentioned.

## 5 CONCLUSION

The choice of lathe has a great influence on the efficiency of the manufacturing process. Selecting a lathe is a complex job that involves many criteria taken into consideration simultaneously, including both quantitative criteria and qualitative criteria. This study used the PIPRECIA method to determine the weights for the criteria. Modification of the FUCA method was also performed in this study. The modified FUCA method was applied to the lathe rating in two different cases. Some conclusions are drawn as follows:

- Modification of the FUCA method was successfully performed in this study. This extends the scope of this method over its original version.
- For the first time, the combination of the PIPRECIA method and the modified FUCA method was performed in this study. This combination is as effective as the CURLI method in decision making for lathe selection. This combination also promises to be successful when used for multi-criteria decision making in other fields.
- It is expected that the presented combination of methods can be used to make decisions with other production machines (milling machines, planers, machining centers, etc.).
- For new CNC lathes, many criteria have not been mentioned in this study (cost, warranty, form of payment - discount, and so on). Similarly, for used lathes, there are many criteria that have not been considered in this study such as the cost of maintaining the machine before use, the remaining life of the machine, and so on. Even important criteria like power consumption, environmental damage, etc. were also not considered in this study. These are the criteria that need to be added to future studies.
- Determining the number of experts needed to consult in order to ensure that the weighting of the criteria achieves the highest accuracy when using the PIPRECIA method is a work in the future.

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