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# Employing an analytic hierarchy process to prioritize factors influencing surface roughness of wood and wood-based materials in the sawing process

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**Abstract:** This paper focuses on the prioritization of factors having substantial effects on the surface roughness of wood and wood-based materials in the sawing process. Within the model, four main factors were defined: cutting tool properties, machining parameters, wood structure and properties, and cutting phenomena. Furthermore, each main factor was subdivided into various subfactors. The analytic hierarchy process method was proposed to obtain the priorities of the factors. The results showed that feed speed, tooth shape and geometry, and cutting speed are the most important factors. Based on the obtained results, it can be said that the most important factors can be easily determined by the proposed method. Consequently, this study presents a road map for the wood industry to achieve a high quality surface.

**Key words:** Analytic hierarchy process, multicriteria decision-making, sawing process, surface roughness

## 1. Introduction

Wood materials have been widely used for interior and exterior decoration applications owing to their natural beauty and easy processing (Aydin and Colakoglu, 2005). After solid wood undergoes machining by sawing, planing, sanding, etc., it becomes a final product (Sofuoğlu and Kurtoğlu, 2015). The surface quality of wood subjected to machining is influenced by many factors related to both machining conditions and wood characteristics. The most important factors related to the machining conditions are cutting speed, tooth bite, dullness of knife, cutting angle, cutting direction, and workpiece vibration (Csanády et al., 2015). In addition to these factors, wood properties such as wood species, density, moisture content, and anatomical properties significantly affect the surface quality of wood (Aguilera, 2011). Surface roughness is one of the most important criteria in determining the quality of the final product. Therefore, the evaluation of the factors related to machining conditions and wood characteristics is very important in order to achieve a high quality surface. Otherwise, rough wood surface influences further manufacturing processes such as finishing, joint, or bonding quality (Sulaiman et al., 2009; Söğütlü et al., 2016).

A large number of experimental studies have been conducted to examine the effects of various factors on the surface roughness of wood in a machining process (Burdurlu et al., 2005). These studies have revealed that each factor has a different effect on the surface quality of wood. It is very difficult to say which factor is more significant than others. However, prioritizing them by employing a multicriteria decision-making (MCDM) method is more helpful for researchers. The analytic hierarchy process (AHP), the analytic network process (ANP), and the decision-making trial and evaluation laboratory are some MCDM methods. AHP is a widely used decision-making tool due to its simplicity, ease of use, and great flexibility. It can handle objective and subjective factors and has a high potential for determining the priorities among different factors (Sutadian et al., 2017). Therefore, in this study, the AHP method was used for prioritizing effective factors on the surface roughness of wood and wood-based materials.

In recent years, some studies have used the AHP method to solve different decision problems such as selection of the most appropriate package of solar home systems (Ahammed and Azeem, 2013), prioritization of safety risks in construction projects (Aminbakhsh et al., 2013), selection of a small run-of-river hydropower plant (Fuentes-Bargues and Ferrer-Gisbert, 2015), contractor selection (Hadidi and Khater, 2015), prioritization of manufacturing sectors in Serbia for energy management improvement (Jovanović et al., 2015), selection of strategies for rice stem borer management (Abdollahzadeh et al., 2016), and prioritization of water quality parameters

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(Sutadian et al., 2017). These studies have proved that the AHP method is highly successful in solving decision-making problems. Moreover, the MCDM methods have been successfully employed in the field of wood science, for example in bridge material selection (Smith et al., 1995), determining the best option to supply poplar wood (Azizi, 2008), classifying wood products according to their impact on the environment (Lipušček et al., 2010), construction panel selection (Azizi and Modarres, 2011), evaluation of medium density fiberboard (MDF) products supplied from different countries (Azizi et al., 2012), comparison of different construction types (Kuzman and Grošelj, 2012), prioritization of factors affecting markets of particleboard and MDF (Sarfi et al., 2013), and determination of nanocomposites having optimum properties (Karakuş et al., 2017).

The literature review has demonstrated that the number of studies involving the use of MCDM methods in the field of wood science is very limited. Moreover, it is observed that there are many studies to solve different MCDM problems using the AHP method. However, a MCDM method has not yet been employed to prioritize factors influencing the surface roughness of wood and wood-based materials in the sawing process. Therefore, the main objectives of the current study are to obtain priority values for each factor by using the AHP method and to provide a useful guide to the wood industry seeking to enhance the surface quality of wood and wood-based products.

## 2. Materials and methods

### 2.1. Analytic hierarchy process method

The AHP method was proposed by Saaty (1977) as a decision-making tool. This method is composed of four main steps: first, creation of a hierarchy of the elements by breaking down the problem into subproblems; second, comparative judgment of the elements; third, consistency check; fourth, synthesis of the priorities (Nikou and Mezei, 2013).

In the first step, a decision problem is portrayed as a hierarchy. The AHP method breaks down a MCDM problem into a hierarchy of decision elements. While the main goal is expressed at the highest level, the main criteria and subcriteria that contribute to the goal are listed at lower levels. The alternatives are situated at the last level and evaluated with respect to criteria (Aragonés-Beltrán et al., 2014).

The second step is the comparison of criteria and alternatives. In the AHP method, pairwise comparisons are based on a standardized nine-point scale (see Table 1). The aim is to determine the relative priorities (importance) of the elements within each level (Albayrak and Erensal, 2004).

**Table 1.** Saaty's comparison scale.

| Preference factor | Degree of preference | Explanation |
|---|---|---|
| 1 | Equally | Two factors contribute equally to the objective |
| 3 | Moderately | Experience and judgment moderately favor one factor over another |
| 5 | Strongly | Experience and judgment strongly favor one factor over another |
| 7 | Very strongly | One factor is very strongly favored over another and its dominance is demonstrated in practice |
| 9 | Extremely | The evidence favoring one factor over another appears irrefutable |
| 2, 4, 6, 8 | Intermediate | Used as a compromise between two judgments |

Each element ( $a_{ij}$ ) in a pairwise comparison matrix represents the degree preference of the *i*th criterion over the *j*th criterion. The individual preference of decision-maker $k$ can be represented as $a_{ijk}$. Once the overall decision-maker judgments are computed by using the geometric mean formula given in Eq. (1), they are transferred to the pairwise comparison matrix *D*, which is given in Eq. (2) (Aminbakhsh et al., 2013).

$$a_{ij} = \sqrt[n]{a_{ij1} \times a_{ij2} \times \ldots \times a_{ijn}} \tag{1}$$

$$D = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{2}$$

The properties of the comparison matrix *D* are as follows (Aminbakhsh et al., 2013):

$$a_{ij} > 0;\ a_{ij} = 1/a_{ji};\ \forall\ i \text{ where } j = 1,2,\ldots,n. \tag{3}$$

Each criterion is quantified by finding the value of the maximized eigenvalue, consistency index (CI), and consistency ratio (CR). The CR index is used in order to maintain consistency in the decision-making of the responder. This index is computed as follows (Lee et al., 2012):

$$\text{CR} = \frac{\text{CI}}{\text{RC}} \tag{4}$$

The CI value can be computed using Eq. (5). The random consistency (RC) index value in Eq. (4) can be obtained from Table 2.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

Here, $\lambda_{max}$ is the maximum eigenvalue of the matrix and $n$ is the matrix size ($n \times n$).

If the CR value is equal to or less than 0.10, the comparisons are acceptable. Otherwise, the pairwise comparison results are not acceptable and should be revised. This procedure is repeated until each comparison satisfies the consistency criterion (Abdollahzadeh et al., 2016).

In the last step of the method, the mathematical process begins to normalize and determine the weights for each evaluation matrix. This process requires dividing the elements of each column by the sum of the elements of the same column. Then the weights are calculated as the row average of the normalized matrix (Ahammed and Azeem, 2013).

**Table 2.** RC index (Ho, 2011).

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RC | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

**2.2. Analytic hierarchy process analysis**

In the present study, some factors influencing the surface roughness of wood and wood-based materials in the sawing process were analyzed using the AHP method. Figure 1 shows the steps of this study based on the AHP method. In the first step, the goal was determined. After a comprehensive literature review, factors related to the surface roughness were defined. A decision-making team including many experts from the Department of Forest Industrial Engineering and Woodworking Industrial Engineering was constructed to make pairwise comparisons of factors. The experts in the team have many national and international scientific publications on the surface roughness of wood and wood-based materials. Each expert provided judgments on the basis of personal knowledge and expertise.

Within the model, four main factors were defined as cutting tool properties ($F_1$), machining parameters ($F_2$), wood structure and properties ($F_3$), and cutting phenomena ($F_4$). Each main factor was subdivided into various subfactors. The subfactors of cutting tool properties were determined as setting amount ($F_{11}$), tooth shape and geometry ($F_{12}$), band saw blade using time ($F_{13}$), tooth spacing ($F_{14}$), number of teeth ($F_{15}$), and type of cutting tool material ($F_{16}$). The subfactors of machining parameters were identified *as* cutting angle ($F_{21}$), feed speed ($F_{22}$), cutting direction ($F_{23}$), and cutting speed ($F_{24}$). The subfactors of wood structure and properties were defined as moisture content ($F_{31}$), density ($F_{32}$), hardness ($F_{33}$), sapwood and heartwood ($F_{34}$), material defect ($F_{35}$), ring width ($F_{36}$), and material thickness ($F_{37}$). Lastly, the subfactors of cutting phenomena were determined as cutting force variation ($F_{41}$), vibrations ($F_{42}$), and wood shavings formation ($F_{43}$).

To prioritize the factors, a three-level hierarchical model was devised. The hierarchical structure of the decision model of this paper with the main factors and subfactors is portrayed in Figure 2. As seen in Figure 2, the decision problem is composed of three levels. The goal of the problem is placed at the first level of the hierarchical structure, while the main factors are listed at the second level. The last level of the hierarchical structure of the decision problem belongs to the subfactors.

When the decision problem is decomposed and the hierarchical structure is constructed, the prioritization procedure commences to determine the relative importance of the factors within each level. The AHP method first necessitates the pairwise comparisons of the main factors and subfactors to obtain their weights. Therefore, the experts were asked to compare four main factors and twenty subfactors in the scope of the present study. First the experts compared the main factors with respect to the goal of the decision problem; then the experts compared the subfactors with respect to the main factors. In other words, the main factors were compared with each other, and scores were determined based on Saaty's nine-point scale given in Table 1. The same procedure was applied to the other matrices, and the priority weights of each subfactor were computed.

After forming the pairwise comparison matrices, the consistency of each matrix was checked using Eq. (4). As a result of the calculations, it was observed that the CR value of each matrix was under 0.10. It is clear that the consistency of the pairwise judgments in all matrices is acceptable. In the next step, the overall results for each matrix were acquired by computing the geometric means of the scores given by the team members.

After all the evaluation matrices were found consistent, weights were computed. The pairwise comparison matrices can be seen from Tables 3–7.

The priorities of the main factors and subfactors were determined based on the calculation procedure of the method. The final results are summarized in Table 8. As a result of the AHP analysis, feed speed from the machining parameters group was found to be the most important factor influencing the surface roughness of wood and

**Table 3.** Evaluation of the main factors with respect to the goal.

| Main factor | $F_1$ | $F_2$ | $F_3$ | $F_4$ | Weight |
|---|---|---|---|---|---|
| $F_1$ | 1.000 | 0.794 | 1.587 | 2.154 | 0.303 |
| $F_2$ | | 1.000 | 2.289 | 1.710 | 0.354 |
| $F_3$ | | | 1.000 | 1.260 | 0.181 |
| $F_4$ | | | | 1.000 | 0.162 |

**Table 4.** Evaluation of the subfactors with respect to cutting tool properties.

| Subfactor | $F_{11}$ | $F_{12}$ | $F_{13}$ | $F_{14}$ | $F_{15}$ | $F_{16}$ | Weight |
|---|---|---|---|---|---|---|---|
| $F_{11}$ | 1.000 | 0.693 | 2.080 | 0.909 | 0.550 | 1.817 | 0.164 |
| $F_{12}$ | | 1.000 | 2.466 | 2.289 | 1.587 | 2.466 | 0.274 |
| $F_{13}$ | | | 1.000 | 1.000 | 0.693 | 1.000 | 0.112 |
| $F_{14}$ | | | | 1.000 | 0.693 | 2.520 | 0.151 |
| $F_{15}$ | | | | | 1.000 | 2.714 | 0.211 |
| $F_{16}$ | | | | | | 1.000 | 0.088 |

**Table 5.** Evaluation of the subfactors with respect to machining parameters.

| Subfactor | $F_{21}$ | $F_{22}$ | $F_{23}$ | $F_{24}$ | Weight |
|---|---|---|---|---|---|
| $F_{21}$ | 1.000 | 0.255 | 0.794 | 0.794 | 0.141 |
| $F_{22}$ | | 1.000 | 2.714 | 2.080 | 0.478 |
| $F_{23}$ | | | 1.000 | 0.693 | 0.166 |
| $F_{24}$ | | | | 1.000 | 0.215 |

**Table 6.** Evaluation of the subfactors with respect to wood structure and properties.

| Subfactor | $F_{31}$ | $F_{32}$ | $F_{33}$ | $F_{34}$ | $F_{35}$ | $F_{36}$ | $F_{37}$ | Weight |
|---|---|---|---|---|---|---|---|---|
| $F_{31}$ | 1.000 | 1.260 | 1.326 | 4.579 | 0.693 | 2.289 | 5.593 | 0.212 |
| $F_{32}$ | | 1.000 | 2.714 | 3.634 | 0.693 | 1.587 | 3.271 | 0.192 |
| $F_{33}$ | | | 1.000 | 2.466 | 0.523 | 1.145 | 3.107 | 0.122 |
| $F_{34}$ | | | | 1.000 | 0.168 | 0.550 | 2.080 | 0.055 |
| $F_{35}$ | | | | | 1.000 | 2.884 | 5.944 | 0.273 |
| $F_{36}$ | | | | | | 1.000 | 3.557 | 0.107 |
| $F_{37}$ | | | | | | | 1.000 | 0.039 |

**Table 7.** Evaluation of the subfactors with respect to cutting phenomena.

| Subfactor | $F_{41}$ | $F_{42}$ | $F_{43}$ | Weight |
|---|---|---|---|---|
| $F_{41}$ | 1.000 | 1.101 | 0.941 | 0.333 |
| $F_{42}$ | | 1.000 | 0.585 | 0.266 |
| $F_{43}$ | | | 1.000 | 0.401 |

wood-based materials. With the overall priority value of 0.169, this factor should be considered as the most significant of the factors. Other considerable factors are ranked as follows: tooth shape and geometry (0.083), cutting speed (0.076), wood shavings formation (0.065), and number of teeth (0.064). The lowest priority values belong to material thickness (weight is 0.007), followed by sapwood and heartwood (weight is 0.010) and ring width (weight is 0.019).

## 3. Results and discussion

In order to determine the weights of the factors, the AHP method was used. The data required for the analysis were gathered from experts who have experience with the research topic. A total of twenty factors were analyzed through experts' opinions. The findings obtained for each factor are summarized in Table 8. The prioritization of the factors has been done taking into account the weights.

The ranking of the main factors in descending order with respective weights are machining parameters (0.354) > cutting tool properties (0.303) > wood structure and properties (0.181) > cutting phenomena (0.162). The results of this study demonstrate that machining parameters and cutting tool properties are the most important factors compared to the other main factors.

In the cutting tool properties group, tooth shape and geometry (0.274) and number of teeth (0.211) were found as the first two important factors in this study. The lowest priority value belongs to the type of cutting tool material (weight is 0.088). The results of the subfactors of machining parameters indicate that feed speed (0.478) has the highest value, followed by cutting speed (0.215). From Table 8, it is clear that feed speed is the main factor that significantly influences the surface roughness of wood and wood-based materials with the overall priority value of 0.169. The ranking results reported in Table 6 show that material defect has the maximum weight (0.273). Moisture content with the priority value of 0.212 is positioned at the second rank. Material thickness (0.039) is the least important subfactor within wood structure and properties. In the cutting phenomena group, the most important degree is allocated to wood shavings formation (weight is 0.401).

When the results given in Table 8 are examined, it is seen that feed speed (0.169), tooth shape and geometry (0.083),

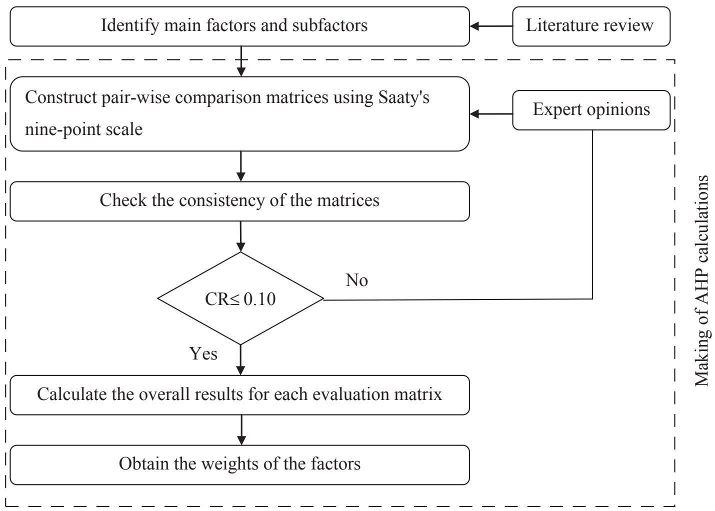


**Figure 1.** Steps of this study based on the AHP method.

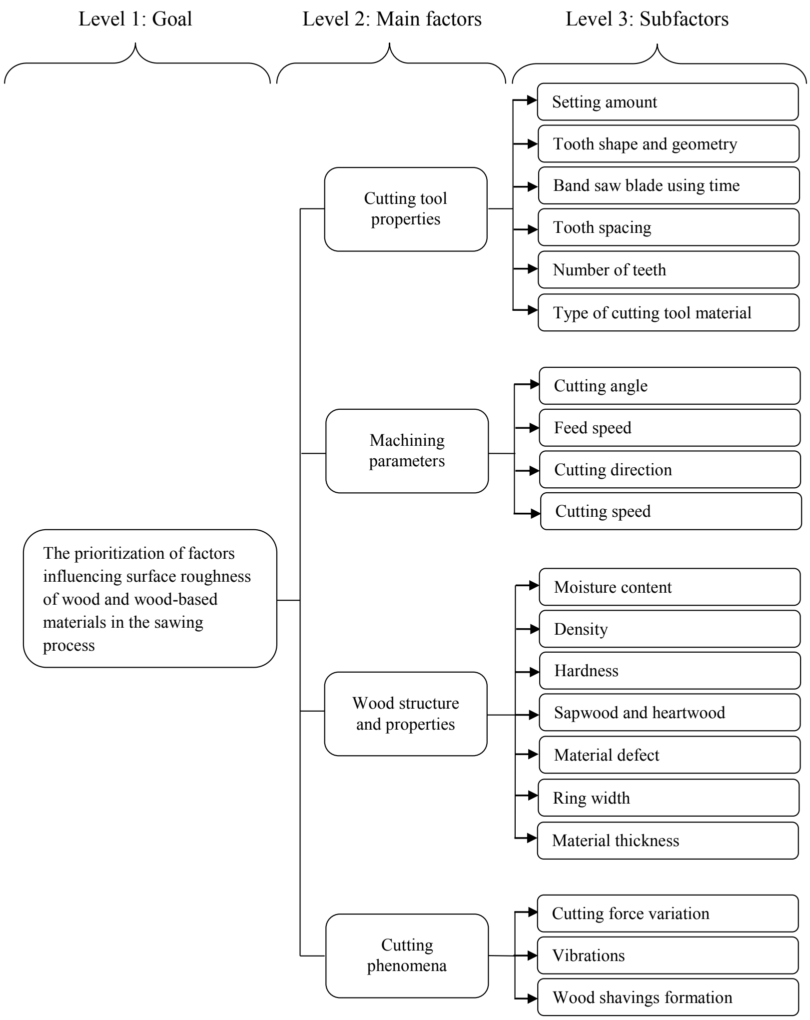


**Figure 2.** The hierarchical structure of the decision problem.

**Table 8.** Summary of the weights.

| Main factor | Local importance | Subfactor | Local importance | Local ranking | Global importance | Global ranking |
|---|---|---|---|---|---|---|
| Cutting tool properties ($F_1$) | 0.303 | Setting amount ($F_{11}$) | 0.164 | 3 | 0.050[a] | 8 |
| | | Tooth shape and geometry ($F_{12}$) | 0.274 | 1 | 0.083 | 2 |
| | | Band saw blade using time ($F_{13}$) | 0.112 | 5 | 0.034 | 14 |
| | | Tooth spacing ($F_{14}$) | 0.151 | 4 | 0.046 | 10 |
| | | Number of teeth ($F_{15}$) | 0.211 | 2 | 0.064 | 5 |
| | | Type of cutting tool material ($F_{16}$) | 0.088 | 6 | 0.027 | 15 |
| Machining parameters ($F_2$) | 0.354 | Cutting angle ($F_{21}$) | 0.141 | 4 | 0.050 | 8 |
| | | Feed speed ($F_{22}$) | 0.478 | 1 | 0.169 | 1 |
| | | Cutting direction ($F_{23}$) | 0.166 | 3 | 0.059 | 6 |
| | | Cutting speed ($F_{24}$) | 0.215 | 2 | 0.076 | 3 |
| Wood structure and properties ($F_3$) | 0.181 | Moisture content ($F_{31}$) | 0.212 | 2 | 0.038 | 12 |
| | | Density ($F_{32}$) | 0.192 | 3 | 0.035 | 13 |
| | | Hardness ($F_{33}$) | 0.122 | 4 | 0.022 | 16 |
| | | Sapwood and heartwood ($F_{34}$) | 0.055 | 6 | 0.010 | 18 |
| | | Material defect ($F_{35}$) | 0.273 | 1 | 0.049 | 9 |
| | | Ring width ($F_{36}$) | 0.107 | 5 | 0.019 | 17 |
| | | Material thickness ($F_{37}$) | 0.039 | 7 | 0.007 | 19 |
| Cutting phenomena ($F_4$) | 0.162 | Cutting force variation ($F_{41}$) | 0.333 | 2 | 0.054 | 7 |
| | | Vibrations ($F_{42}$) | 0.266 | 3 | 0.043 | 11 |
| | | Wood shavings formation ($F_{43}$) | 0.401 | 1 | 0.065 | 4 |

[a]This output is calculated as follows: 0.303 × 0.164  0.050.

and cutting speed (0.076) are the most important factors. Many researchers reported the effect of feed speed on the surface roughness of wood and wood-based materials, and the results showed that feed speed is an important factor in achieving a smooth surface (Hernández and Cool, 2008; Iskra and Hernández, 2009; Prakash and Palanikumar, 2011; Tiryaki et al., 2014). Several researchers stated that tooth shape and geometry is directly responsible for the surface quality of the final product (Budakçı et al., 2011; Kminiak et al., 2015). On the other hand, previous studies reported that cutting speed has an important effect on surface roughness (Kvietková et al., 2015; Rolleri et al., 2016). According to Magoss (2015), surface pressure, feed speed, grit size, and cutting speed are the most important operational parameters. Lu (2008) stated that process parameters such as cutting speed, cutting depth, feed rate, and tool geometry significantly influence the surface quality of machined wood. Consequently, it can be said that the findings of this study are compatible with the existing literature on the surface roughness of wood and wood-based materials.

The results of the questionnaire were analyzed by employing the AHP method. It was shown that the priorities of many factors related to both machining conditions and wood characteristics can be obtained by the proposed method. Based on the findings of the current study, it can be said that the present study provides useful information to improve the surface quality of wood and wood-based products.

In the age of increased competitive markets, the improvement of the surface quality of wood and wood-based products is an important task. It is a fact that determining the priorities of factors having substantial effects on surface roughness will play the key role for success in enhancing the product quality. Therefore, in this paper, the AHP method is proposed to prioritize factors influencing the surface roughness of wood and wood-based materials in sawing.

In light of the aim, four main factors were determined, namely cutting tool properties, machining parameters, wood structure and properties, and cutting phenomena. Each main factor was then subdivided into various subfactors. The data collected from experts in Turkey were used in the model to find the priorities of the factors. The viewpoints of the experts were utilized throughout the entire course of the study. The main factors and subfactors used in this study were assigned weights by using AHP.

As pointed out previously, there is no information on the use of AHP to prioritize factors influencing the surface roughness in wood machining. The findings obtained in this study for the factors are highly important from an industrial viewpoint. The results showed that the wood industry should focus on feed speed, tooth shape and geometry, and cutting speed to produce satisfying surface quality.

In conclusion, the proposed methodology can be easily employed to determine the importance ratings of factors having an important effect on surface roughness. In further research, the findings of the present study can be compared with the results of experimental studies.

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