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APPLYING OF AHP METHODOLOGY AND WEIGHTED PROPERTIES METHOD TO THE SELECTION OF OPTIMUM ALTERNATIVE OF STOCK MATERIAL

Abstract:
In this paper, AHP (analytical hierarchy process) methodology and weighted properties method have been compared and applied to the selection of optimum alternative of stock material and manufacturing process. Three alternatives for the manufacturing of work piece are evaluated: rod, plate and tube. Six criteria were defined: stock material costs, stock material preparation costs, manufacturing costs, as well as material availability and purchase possibility, machinability and total material utilization. The criteria weights can be more precisely defined by the AHP methodology using the Saaty scale than using the digital logic method. However, subjectivity is playing a great role in both of methods. Subjectivity is included to the comparison of alternatives by the original AHP methodology, also. Contrary, by using weighted properties method there is no subjectivity concerned of alternatives comparisons because of dealing with transformed values of criteria. From the viewpoint of costs, the best alternative, calculated by both of methods is steel tube machining.

Keywords:
AHP methodology, weighted-properties method, criteria weights

INTRODUCTION

In this paper, three alternatives of stock materials for the same product are chosen and evaluated. Which one is optimal for the defined objective? This problem can be solved quantitative or qualitative. Qualitative approach is quite subjective, because it is based on assumptions and experience from the previous period. It is applied when the number of criteria and alternatives is small. Quantitative approach can be applied when the number of criteria, requirements and alternatives is quite large. Many quantitative methods exist, like operational research methods, decision making methods, as well as quantitative methods of materials selection which can be used to solve this problem.

Analytical hierarchy process methodology (further AHP methodology) is developed by Thomas Saaty [1, 2]. This method is widely applied in almost every field of human activity, for example economy [3], traffic [4], agriculture [5], information technologies [6], inventory control [7], materials selection [8] and many others.

Several quantitative methods of materials selection can be used [9-12]. The most important quantitative initial screening methods are as follows [9]: cost per unit property method, Ashby's material selection charts and Dargie's method. Pahl-Beitz method and weighted properties method represent the quantitative methods which can be applied to select the optimum solution between several combinations of materials and matching manufacturing processes. Sometimes in practice there is a reason for the substitution of one material with another, so the Pugh quantitative method and cost-benefit analysis [9] can be applied to compare properties and costs of used materials and new proposed materials.

In this paper, AHP methodology and weighted properties method are applied to the selection of the best alternative of stock material and manufacturing process concerning the following six criteria: stock material costs, stock material preparation costs, manufacturing costs, as well as material availability and purchase possibility, machinability and total material utilization.

DESCRIPTION OF THE USED METHODS

Analytical hierarchy process

AHP methodology is based on the decomposition of the defined decision problem to the hierarchy structure. The hierarchy structure is a tree-like structure which consists of the main goal at the top of the hierarchy (the first level), followed by the criteria and sub-criteria (also sub-sub-criteria) and finally by the alternatives at the bottom of the hierarchy (the last level), Fig. 1.

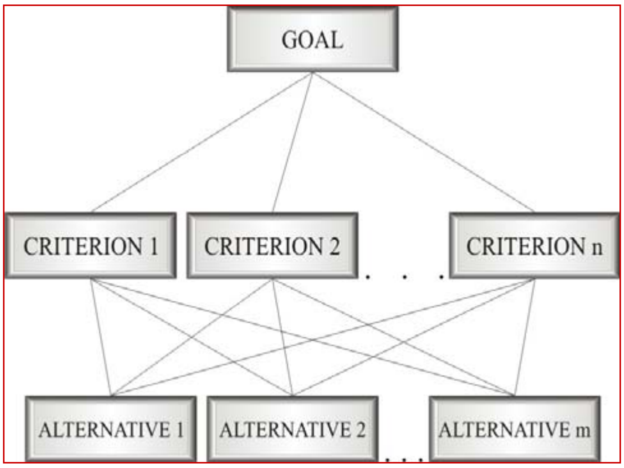

Fig. 1 AHP model with" n" criteria and "m" alternatives

The goal presents the optimum solution of the decision problem. It can be the selection of the best alternative among many feasible alternatives. Also, the ranking of all alternatives can be performed, by obtaining the priorities. Criteria (sometimes called objectives or attributes) are the quantitative or qualitative data (judgements) for evaluating the alternatives. If we compare the terminology of weighted properties method and AHP methodology, the term properties is equivalent to the term criteria. The weights of the criteria present the relative importance of each criterion compared to the goal. Finally, alternatives present the group of feasible solutions of the decision problem. Alternatives are evaluated against the set of criteria.

AHP methodology has three basic steps:

- *Decomposition of the defined decision problem to the hierarchic structure - building an AHP model with the overall goal, the evaluation criteria (sub-criteria) and alternatives.*
- *Pair wise comparisons of the criteria and alternatives based on the Saatys scale of numbers from 1 to 9, Table 1. The value 1 means equal importance of two criteria (alternatives), while the value 9 stands for extreme importance of one criterion (alternative) to another. Pair wise comparisons of the criteria are performed with respect to the goal or criteria at higher level. The weights of the criteria present the ratio of how much more important is one criterion than another, with respect to the goal or criterion at higher level. Pair wise comparisons of the alternatives are performed against each criterion and present the ratio of how much more important is one alternative than another, taking into account each criterion. The local priorities of alternatives are derived. Testing the consistency of subjective judgements is also performed.*
- *Synthesising the results by the calculation of the total priorities of alternatives. The total priority of each alternative is calculated by the multiplication of the local priority of alternative by the weight of corresponding criterion and then summing all the products for each criterion. Sensitivity analysis can be also performed and it gives the response of*

the alternative priorities to the change of the input data.

Tab. 1 Saaty's scale for pair wise comparisons.

Scale	Description of the importance
1	equal
3	moderate
5	strong
7	very strong
9	extreme
2, 4, 6, 8	intermediate values

Weighted Properties Method

This method is very useful when there are a lot of important criteria (properties) to compare and evaluate. Scaled value of the criteria (S_V) is multiplied by the weighting factor (B_i) (see the expression 1). The sum of multiplied scaled properties and weighting factors represents the performance index (V_r), see the Eq. (1). The combination of stock material and matching manufacturing process with the highest performance index is the optimum solution.

$$V_r = \sum_{i=1}^{k} B_i \cdot S_{Vi} \rightarrow \max. \qquad (1)$$

where:

V_r - performance index
B_i - weighting factor
S_{Vi} - scaled property value
k - number of properties

Weighting factor B_i represents the relative importance of the requirement according to the defined objective. This factor is determined by using the experience or the digital-logic method. Digital-logic method is based on the comparison of properties, where more important property has mark 1, and less important property has mark 0. After that, for every property the number of positive decisions is determined. Weighting factor for the property is the ratio of the number of positive decisions and the total number of decisions, Eq. (2).

$$\text{The total number of decisions} = \frac{k(k-1)}{2} \qquad (2)$$

where:

k - number of requirements (properties)

Scaled values of the properties are applied because of more reliable comparison of the properties with different units of measurements. Eq. (3) represents the dimensionless scaled property value for the property where a lower value is desirable (for example costs, mass loss, etc.).

$$S_V = \frac{\text{Minimum value in the list}}{\text{Numerical value of the property}} \cdot 100 \qquad (3)$$

Equation (4) represents the dimensionless scaled property value for the property where a higher value is desirable (for example hardness, tensile strength, etc.).

$$S_V = \frac{\text{Numerical value of the property}}{\text{Maximum value in the list}} \cdot 100 \qquad (4)$$

All the properties data are transformed to the 0 - 1 scale. The property with the value 100 (or 1, without multiplying with 100, Eq.. 3 and 4) is the best property.

In AHP methodology, for a very large number of alternatives, making pair wise comparisons of alternatives, with respect to each criterion, can be time consuming and confusing, because the total number of comparisons is very big, too. Therefore, instead of pair wise comparisons, alternatives relative priorities can be obtained by the scaling (normalizing, transforming) the alternative data for each criterion. The data (qualitative or quantitative) can be transformed in such a manner described previously in weighted properties method. The sum of multiplied scaled criteria values and weighting factors across all of the criteria (so called weighted sum) presents the overall score for the alternative item (see and compare the expression 1, weighted properties method). The alternative with the maximum score is on the top, while the alternative with the minimum score is on the bottom of the ranking scale.

Analysis And Evaluation Of Variants

The following part of the paper illustrates the application of AHP methodology and weighted properties method for selecting the optimum combination between three combinations of stock materials to manufacture the connector (see Fig. 2) [13].

Three types of stock materials have been quantitatively analyzed. These are: rod, plate and tube made from material C45 (the material is assigned in accordance with the Euronorm EN

10027, classification by the chemical composition). Six requirements are included and calculated [13]:

- *stock material costs, $TR_{(o)}$ (calculated by multiplying the mass of work piece and the unit material price),*
- *material availability and purchase possibility, $O_{(rn)}$ (rated from 1 – poor to 5 – excellent),*
- *stock material preparation costs, $TR_{(PM)}$ (calculated by taking into account the quality control costs, storage costs and cutting costs),*
- *machinability, $O_{(ob)}$ (calculated according to experiment results by taking into account work piece material, tool material, processing conditions and cutting rate),*
- *manufacturing costs, $TR_{(P)}$ (calculated by considering the turning and milling machining costs, cooperation costs and additional costs)*
- *total material utilization, f (calculated from the stock over dimension losses, cutting losses, machining losses and fallout losses [14]).*

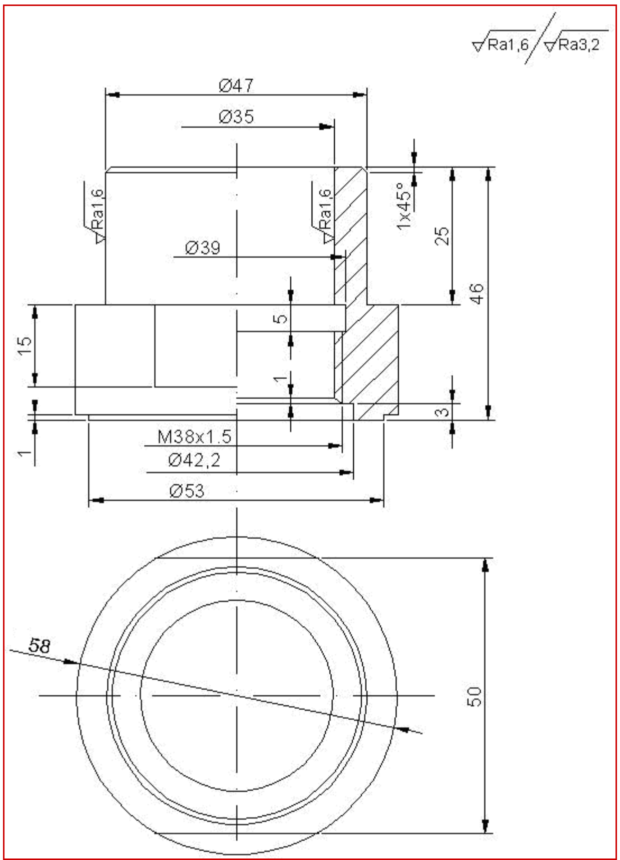

Fig. 2 Technical drawing of the connector

The selection of the optimum combination of stock material and manufacturing process is carried out by the application of the above mentioned methods.

Figure 3 presents the AHP hierarchy model of this problem with the overall goal, six evaluation criteria and three alternatives.

The criteria weights are calculated by the pair wise comparisons of criteria using the Saaty scale (Tab. 1), and their amounts are as follows: 0,197; 0,302; 0,133; 0,064; 0,197 and 0,107. The values of criteria weights are corresponding to the order of criteria in Fig. 3 (from left to right).

Local priorities of alternatives are calculated by the comparison of the alternatives in terms of each criterion using the Saaty scale (Tab. 1).

Using the criteria weights and local alternative priorities, the total priority of each alternative is calculated (0,246 – rod; 0,353 – plate and 0,401 – tube). The third alternative (tube machining) is the optimum solution for obtaining minimal total costs because of the highest total priority.

In the following part of the paper, weighted properties method is applied. Using the calculated values for six defined properties as well as calculated linearly scaled property values according to the Eq. (3) and (4), performance indexes for these three variants are derived, Eq. (1).

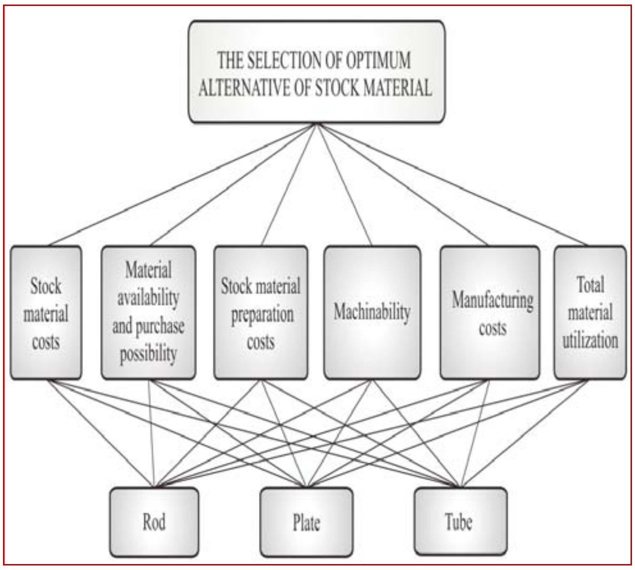

Fig. 3 AHP model

They are as follows: 83,39 – rod, 88,59 – plate and 89,964 – tube. Weighting factors are calculated using the digital logic method and their values are as follows: B_1=0,2, B_2=0,3333, B_3=0,1333, B_4=0, B_5=0,2667 and B_6=0,0667. The *values of criteria weights are corresponding to the order of criteria in Fig. 3 (from left to right). The third variant (tube machining) is the optimum solution for obtaining minimal total costs because of the highest performance index.*

CONCLUSION

On the basis of the above calculated results obtained by the application of AHP methodology and weighted properties method, the following conclusions can be made. In order to obtain minimal total costs, the third variant (tube machining) is the optimum solution because of the highest total priority (AHP method) and the highest performance index (weighted properties method).

It can be concluded that the criteria weights can be more precisely defined by the AHP methodology using the Saaty scale than using the digital logic method. A Saaty scale is larger scale (from 1 to 9) in comparison to digital logic method (only 0 and 1).

However, subjectivity is playing a great role in both of methods of comparison. Subjectivity is included to the comparison of alternatives by the original AHP methodology, also. Contrary, by using weighted properties method there is no subjectivity concerned of alternatives because of dealing with transformed values of criteria. However, the optimum solution obtained by the application of quantitative methods should be subjected to further analysis of an experienced decision maker.

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