Decision Support System for Selection of the Most Suitable Biomedical Material

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***Abstract*—Selection of the most suitable material for a given biomedical application is very complex, important and responsible task. A decision support system based on the use of method of multi-criteria decision making (MCDM) methods, named MCDM Solver, was developed in order to facilitate the selection process of biomedical materials and increase selection confidence and objectivity. In this paper, a MCDM problem which referes to the selection of the most suitable material for the compensation of the missing parts of the long bones was solved by using the developed MCDM Solver.**

I. Introduction

Biomedical materials are commonly characterized as materials used to build artificial organs, rehabilitation devices, or implants to replace natural body tissues [1]. Developing new and improved biomedical implants is seen as a complex design problem-solving activity and, in conjunction with demanding manufacturing constraints, utilizing the most appropriate materials (and materials combinations) presents many unique challenges [2]. Selecting an appropriate material for a given biomedical application is important from more points of view – medical, technological, and economic. Today, there is a large number of biomedical materials and manufacturing processes, each having its own properties, applications, advantages and limitations. Therefore, many difficult decisions need to be made while selecting a material for a specific biomedical implant. Decision makers have to consider a number of issues related to materials' mechanical, biological, chemical, physical technological and economic properties which to the greatest extent affect the quality and application of a biomedical product in a particular domain. Existence of correlations and contradictions among these properties makes the selection procedure more challenging and time consuming for decision makers. In order to select the most suitable biomedical material, the decision maker should have a complete understanding of the functional requirements of the product and a detailed knowledge of the considered criteria for a specific biomedical application. The unsuitable choice of a biomedical material may lead to a premature failure of the product, a need for repeated surgery, a cell death, chronic inflammation or other impairment of tissue functions as well as an extension of healing period and overall increasing of the costs [3]. Therefore, the designers in collaboration with medical specialists must identify and select the most suitable material for an implant device with the minimum possible cost and specific performance considerations.

The objectives and criteria in the material selection process are often in conflicts which involves certain trade-offs amongst decisive factors, such as desired properties, operating environment, production process, cost, market value, availability of supplying sources and product performance [4]. Only with a systematic and structured mathematical approach the best alternative for a specific engineering product can be selected.

The material selection problems with multiple non-commensurable and conflicting criteria can be efficiently solved using multi-criteria decision making (MCDM) methods. The MCDM methods have the capabilities to generate decision rules while considering relative significance of considered criteria upon which the complete ranking of alternatives is determined [5].

Various approaches have already been proposed by the past researchers to solve the material selection problem. Within the common used it can be listed Ashby approach [6], TOPSIS [7], ELECTREE [8], VIKOR [9], COPRAS [10], ANP [11], UTA method [12].

This paper presents the application of the developed software prototype i.e. decision support system (DSS) for the selection the most suitable biomedical material for bone implants which compensate the missing part of a long bone. Within the DSS, named MCDM Solver, a list with potential materials and their properties is created. Three MCDM methods are available for ranking the list of alternative materials, i.e. TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), VIKOR (Više kriterijumska optimizacija – kompromisno rešenje) and WASPAS (Weighted Aggregated Sum Product Assessment). Based on the methods, the most appropriate material was selected and comparison of the ranking results was carried out.

II. Application of the MCDM Methods for Materials Selection

Generally, every MCDM problem starts with the decision/evaluation matrix [13],

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \cdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$$

Where, *m* is the number of candidate alternatives (potential materials), *n* is the number of evaluation criteria (material properties) and x_{ij} is the performance of *i* th alternative with respect to *j* th criterion. Depending on the desired material property, a material performance can be assessed as quantitative number value or qualitative description based on the knowledge and experience of the decision maker, material designers and material users. Determination of the decision matrix is the first step of the material selection process. For example, if the first and second criteria are corrosion resistance and tensile strength, respectively, initial evaluation matrix for three alternative materials is as follow:

$$X = \begin{bmatrix} 7 & 630 \\ 10 & 550 \\ 9 & 655 \end{bmatrix}$$

Where, 7-10-9 and 630-550-655 are relative evaluation of the corrosion resistance and tensile strength of analyzed three materials, respectively. The next one is normalization of the performances in order to obtain dimensionless numbers ranged from 0 to 1. Normalization is followed by mathematical computing which can provide the base for ranking of the alternatives.

A. TOPSIS method

The TOPSIS method is proposed by Chen and Hwang [1]. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). Therefore, this method is suitable for risk avoidance designer(s), because the designer(s) might like to have a decision which not only makes as much profit as possible but also avoids as much risk as possible [9]. The TOPSIS method has been used predominantly in materials selection due to its superior characteristics [15]. Pseudo algorithm of the TOPSIS method is shown in Figure 1.

B. VIKOR method

The VIKOR method was introduced as one applicable technique to implement within MCDM [16]. This method was developed for multi-criteria optimization of complex systems, which enjoys a wide acceptance [9]. It focuses on ranking and selecting from the alternatives with conflicting and different units criteria. In the VIKOR method, the compromise ranking is performed by comparing the measure of closeness to the ideal alternative, and compromise means an agreement established by mutual concessions. Pseudo algorithm of the VIKOR method is shown in Figure 2.

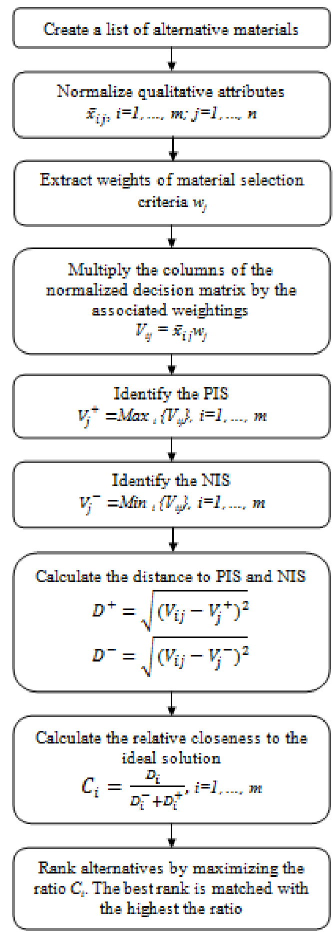

Figure 1. TOPSIS pseudo algorithm

C. WASPAS method

In order to increase ranking accuracy and reliability, a new methodology for optimization of weighted aggregated function was proposed. This method was named as the Weighted Aggregated Sum Product Assessment (WASPAS) and introduced firstly by Zavadskas et al. [17].

From the mathematical point of view, the WASPAS method presents a linear combination of weighted sum method (WSM) and weighted product method (WPM).

The application of the method at first requires linear normalization of the decision matrix, which is followed by weighting of the criteria. A general pseudo algorithm of the WASPAS method is shown in Figure 3.

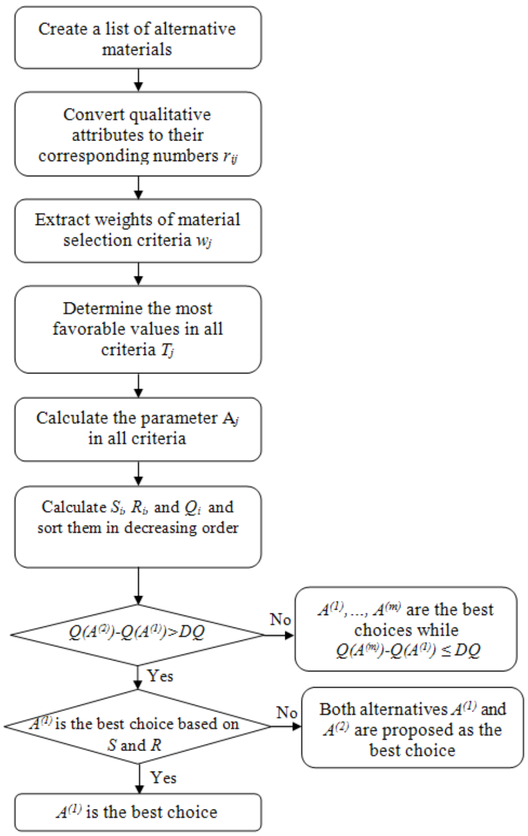

Figure 2. VIKOR pseudo algorithm

III. MDCM Solver prototype for solving biomedical material selection

Decision making which involves a large number of variables (criteria, alternatives) requires advanced and comprehensive knowledge in the applied field. A lot of time is consumed in every selection process due to tedious calculations involved in evaluating each alternative with respect to the selection criteria. To eliminate these tedious calculations and ease out the material selection decision making process, a software prototype named MCDM Solver is developed. This desktop application is developed in Microsoft Visual Studio 2008 environment, using C# as a programming language.

The developed MCDM Solver integrates the users' requirements with the technical requirements and can be used to select the most appropriate biomedical material for a given application based on the selected requirements, as considered in the present research work.

Namely, this study is aimed to select the most suitable biomedical material for bone implants which compensate the missing part of a long bone. The main role of the implant is to replace the human bone in term of the function and aesthetic. Therefore, the implant material must have the properties so close to the properties of the missing bone, i.e. excellent biocompatibility, mechanical strength, wear and corrosion resistance. The compressive strength of compact bone is about 140 MPa, and the elastic modulus is about 14 GPa in the longitudinal direction and about 1/3 of that in the radial direction. These values are modest compared to most engineering materials. However, live healthy bone is self-healing and has a great resistance to fatigue loading. The implant is fixed to the surrounding bone structure by screws.

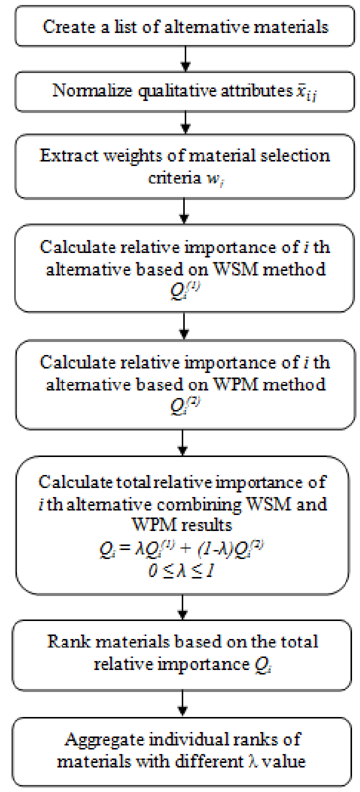

Figure 3. WASPAS pseudo algorithm

In order to select the most suitable bone implant biomaterial, requirements (criteria for selection) such as tissue tolerance, corrosion resistance, mechanical behavior, elastic compatibility, weight and cost have been considered. The initial list of potential biomedical materials with criteria and their performances is defined based on the previous similar studies [15, 18].

Figure 4 shows the screen shot of the developed MCDM Solver where candidate materials, criteria, weights, desired properties of the materials (target values) and available MCDM methods are shown.

IV. Results and discussion

Results of the proposed rankings of the biomedical materials for bone implant are presented in Table I. As could be seen from the table, application of different methods gives different ranking order. The best ranked material according to both TOPSIS and VIKOR methods is material number 6 (Co-Cr wrought alloy), while material number 8 (Ti-6Al-4V) is proposed as the best solution by using the WASPAS method. The WASPAS method proposed material number 6 as the second ranked material. Therefore, by applying an aggregation technique Co–Cr wrought alloy is proposed as the most appropriate biomedical material for the bone implant.

TABLE I. RANKING RESULTS OF THE BONE IMPLANT MATERIAL BASED ON THE TOPSIS, VIKOR AND WASPAS METHODS

No.	Material	TOPSIS	VIKOR	WASPAS
1	SS 316	5	5	7
2	SS 317	7	7	3
3	SS 321	8	8	6
4	SS 347	6	6	5
5	Co-Cr cast alloy 1	3	2	9
6	Co-Cr wrought alloy 2	1	1	2
7	Unalloyed Ti	4	4	4
8	Ti-6Al-4V	2	3	1
9	Composites Epoxy-70% glass	9	9	8
10	Composites Epoxy-63% carbon	11	11	11
11	Composites Epoxy-62% aramid	10	10	10

On the other hand, all three methods consistently yielded unalloyed Ti, composites epoxy-62% aramid and composites epoxy-63% carbon as the 4, 10 and 11 ranked materials, respectively.

It is also noticed that there is no total match between the methods but a very strong correlation between the TOPSIS and VIKOR methods (Spearman's rank correlation coefficient - 99%) is evident. Spearman's rank correlation coefficient also shows 71% between the TOPSIS and WASPAS methods and 64% between the VIKOR and WASPAS methods.

Taking into account pretty different ranking results obtained by the WASPAS method, an additional analysis is carried out. Hence the effect of varying values of the parameter λ on the rankings of the considered material selection is graphically presented in Figure 5. It is clearly visible that the rankings of the best material alternative (material number 8) remains unaffected for different values of the parameter λ.

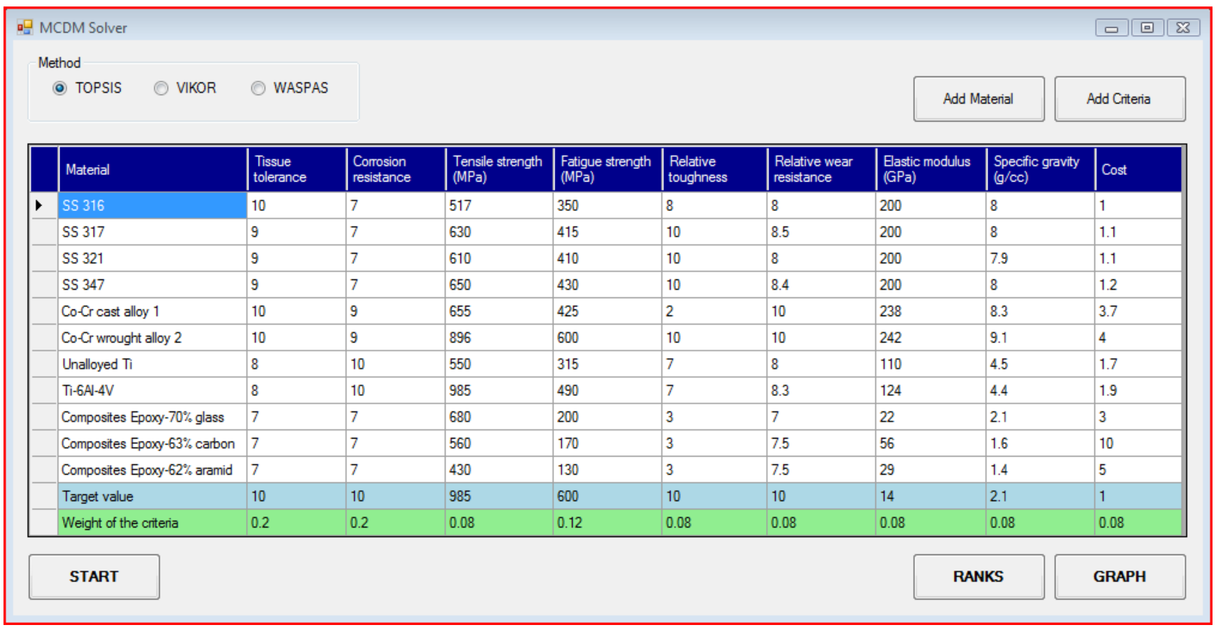

Figure 4. Screen shot of the MCDM Solver - initial step

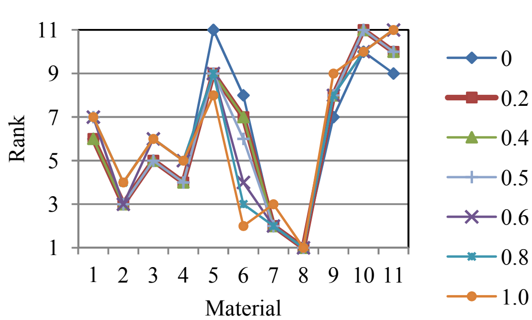

Figure 5. Variations of the materials rank depending on the values of parameter λ

V. CONCLUSION

The selection of a the most suitable material for a given biomedical application is a complex task due to limited knowledge about specific material properties, as well as complexity of the requirements which involve a large number of additional considerations. The use of the MCDM methods is proved to be a powerful tool for making genuine and objective decisions while selecting the most suitable biomedical material.

In this paper, the application of the TOPSIS, VIKOR and WASPAS methods for the selection of the most suitable bone implant material is demonstrated. A software prototype, named MCDM Solver, is developed to automate this material selection decision making process. It is important to highlight that the developed software can be wider applied within the material selection field with the possibility to add new alternatives (materials) and criteria for the evaluation of alternatives.

Although there is no full match of results, the optimum choice of materials is clear. Additionally, it can be noticed very strong correlation between the TOPSIS and the VIKOR method.

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