International Journal for Quality Research 8(2) 155-168
ISSN 1800-6450

Marija Zahar Djordjevic [1]
Hrvoje Puskaric
Aleksandar Djordjevic

Article info:
Received 22.02.2014
Accepted 03.06.2014

UDC – 664.64.016

EVALUATION AND RANKING OF ARTIFICIAL HIP PROSTHESIS SUPPLIERS BY USING A FUZZY TOPSIS METHODOLOGY

Abstract: *The aim of this study is to propose a fuzzy multi-criteria decision-making approach (MCDM) to evaluate the artificial hip prosthesis suppliers with respect to numerous criteria, simultaneously, taking into account the type of each criteria and its relative importance. The fuzzy of the Technique for Order Preference by Similarity to Ideal Solution (FTOSIS) is applied in order to rank the artificial hip prosthesis suppliers. The rank is obtained using the process of fuzzy number comparison. Software solution based on suggested method is also presented. A real-life example with real data is presented to clarify the proposed method.*

Keywords: *Artificial hip prosthesis supplier selection, fuzzy TOPSIS, fuzzy rank*

1. Introduction

From medical records, it is clear that total hip replacement is acknowledged to be one of the most successful surgical interventions ever developed. The total number of hip replacements has been increasing in the last two decades (Burns and Bourne, 2006). Hip and knee replacement surgeries are two of the most commonly performed and effective operations in the United States (American Academy of Orthopaedic Surgeons Website, 2005) with the most rapidly increasing hospital inpatient costs for all payers (Wilson *et al.*, 2008; Dreinhoefer *et al.*, 2006). Hospital costs for implant procedures are high. The main cost drivers were found to be implants (34 % of total cost on average) and ward costs (20.9 % of total cost on average) (Stargardt, 2008). According to the presented facts, the economic effect of this treatment on society as a whole is significant in terms of savings in medical care, drugs, disability aids and reduction in sickness-related absenteeism (Felts, and Zelin, 1989; Callaghan *et al.*, 2000; Berry, *et al.*, 2002).

Hospital efforts to manage implant costs vary in their effectiveness (Wilson *et al.*, 2008). Many researchers have made efforts to improve effectiveness and reduce costs of the whole hip replacement process (Zuckerman *et al.*, 1994). Some authors (Wilson *et al.*, 2008) claim that hospitals have intention to purchase equipment from just one supplier in order to get significant discounts and other valuable benefits which makes the selection of an appropriate supplier a very important issue. The selection of implants is in many cases a "physician preference item" (PPI). Generally, orthopaedists believe that limiting the number of suppliers is appropriate for both hospitals and physicians because both benefit from the focus on a narrower set of products and technological platforms. In that process some stakeholders have different stand points: the hospital seeks to limit the

[1] Corresponding author: Marija Zahar Djordjevic
email: maja_199@yahoo.com

number of implant suppliers (or standardize on one or two) and orthopaedic surgeons not only remain with their implant vendor for a long time but also can receive financial payments from them (Burns *et al.*, 2009). As a possible solution, a hospital usually selects a small number of implants to offer lower prices in order to secure contracts (Dolan and Robinson, 2010).

Therefore, it is evident that the selection of a strategy for the supply of orthopaedic hospitals with hip implants is an important task, which substantially influences the efficiency and costs of the whole hospital supply chain. The reduction of the number of suppliers and selection of the best supplier is characterized as a highly complex multi-criteria group decision-making problem.

The evaluation and ranking of suppliers is based on knowledge of a management team, which typically involves many individuals and groups with different types of expertise, bringing their unique perspectives to the table (Keselman *et al.*, 2004). According to Walczak (2011), "supplier selection is a group effort lead by a physician from the orthopaedic medical staff and supported by representatives from three administrative areas: the business manager of the operating room, the director of materials management, and the administrator for the orthopaedic service line". This mutual work and effort of surgeons, hospital administrators and finance officers can provide a good foundation for supplier selection as well as reducing expenditures without affecting the quality of treatment (Malki *et al*, 2003).

The number and type of criteria according to which the rank of suppliers is obtained are determined by the management team. Multiple criteria need to be carefully examined. In general, criteria can be of different types whose objectives are conflicting, thus selection of appropriate suppliers is far from a trivial task. According to Swarts and Kop (2005), selection could be based on about 50 % qualitative criteria, including demonstrated supply performance, local reps, training, warehousing etc, and 50 % quantitative criteria, such as clinical evidence (40 %) and laboratory quality assurance testing (10 %). Alternatively, Lavernia and Lyon (1998) recommend the following parameters: device costs, supply costs, professional fees. The problem becomes significantly more complex if we take into account the realistic assumption that the considered criteria have different relative importance.

Therefore, the basic requirement is to have a reliable method and software tool that could be employed in medical supply chains in order to achieve a decrease of expenditures in supply. The main goal of this paper is to propose a method for the evaluation of suppliers using multiple criteria with different relative importance which is used as the base for the development of a software solution. This problem was addressed by an extension of the fuzzy TOPSIS method, similar (Tadić *et al.*, 2011). Practical results in medical institution environments should be used for the definition of the optimal supply strategy that enables the supply of high quality implants for the treatment of patients as well as reduction of costs.

The contributions of this paper are the following. It proposes an extension of the fuzzy TOPSIS methods with some elements, such as the method of average value, in order to facilitate combining both qualitative and quantitative criteria, as well as their relative importance in affecting the supplier selection process in a rational and systematic way. Specifically, a fuzzy positive ideal solution and fuzzy negative ideal solution for uncertain criteria, are determined according to the normalized matrix by using the fuzzy number comparison procedure (Dubois and Prade, 1979). It is possible to determine a measure of belief so that the rank of possible suppliers is stable. Contributions also include the software that was developed based on the suggested approach, and an illustrative example of application of the extended method for selecting the implants suppliers.

The paper is organized in the following way. Section 2 presents a literature review of a fuzzy multi-criteria approach for the ranking of suppliers. Section 3 describes an extension of the fuzzy TOPSIS method for ranking and selecting of implants suppliers, including fuzzy sets based approach to modelling of uncertainty in criteria weights and criteria values. Section 4 presents the supplier selection procedure which is based on the proposed approach. In section 5, the new software, which is based on the developed model, is presented. Section 6 provides a real-life example used to verify the developed procedure. Conclusions are presented in section 7.

2. Literature review

The considered problem is a group decision-making problem under multiple criteria. There are different sources and types of uncertainty along the hospital supply chain: random events, uncertainty in judgments, lack of certainty, etc. The values of some criteria are difficult or impossible to quantify (Swarts and Kop, 2005). The fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. The fuzzy set theory can provide a valuable tool which copes with three major problematic areas of supplier selection: imprecision, randomness and ambiguity. As far as imprecision is concerned, it provides a powerful tool to weigh selection criteria importance. As far as ambiguity is concerned, it copes better than other methods with the treatment of linguistic variables. Fuzzy logic enables us to emulate the human reasoning process and make a decision based on vague or imprecise data (Kaur and Chakrabortyb, 2007).

In many papers, which can be found in literature, the ranking problem of different items with respect to multi criteria and their weights is determined by a two-stage method. In the first stage, the weights of treated criteria are determined by applying either fuzzy set theory, etc. In the second stage, some other multi-criteria methods are used in order to determine the best item with respect to all treated criteria, simultaneously, as well as their relative importance (Ho *et al*., 2009).

The problem of determining criteria weights is stated as fuzzy group decision making problem. Some authors suggest directly assessment of the criteria relative importance. Fuzzy rating of the relative importance of criteria are performed by decision makers. They used pre-defined linguistic expressions which are modelled by triangular fuzzy numbers (TFNs) (Mahdavi *et al.*, 2008; Kelemensis and Askounis, 2010; Zahar Djordjevic and Puskaric, 2013) and trapezoidal fuzzy numbers (TrFNs) (Chen *et al*, 2006; Sadi-Nezhad and Damghani, 2010; Zheng *et al*., 2012). Many authors suppose (Tadić *et al.*, 2011; Das, 2010) that evaluation of the relative importance of criteria should be based on the AHP framework. The new aggregation methods which should be good ranged of fuzzy rating of each decision maker are developed in (Cheng *et al*. 2011; Tadić *et al.*, 2011). In the rest referenced papers, fuzzy average value to integrate the fuzzy rating of the weights criteria for all decision makers is used.
In all considered papers, fuzzy criteria values are normalized by different normalization procedures taking into account criteria types. The linear scale transformation (Shih *et al*, 2007) is used in (Chen *et al*, 2006; Mahdavi *et al*, 2008; Kelemenis and Askounis 2010). In (Sadi-Nezhad and Damghani, 2010) a columnar normalization procedure is used. The uncertain criteria values in (Tadić *et al.*, 2011) are defined within the interval [0-1], so that there is no need for a normalization procedure.

The fuzzy-positive ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) are defined according to the weighted normalized decision matrix. Authors use different procedures for determining FPIS and FNIS. Kaya and Kahraman (2011) used a most likely used technique which is propsed in (Isiklar and Büyüközkan, 2006). FPIS and FNIS for each criterion is obtained by using veto thereholds approach in (Kelemensis and Askounis, 2010). Determining of FPIS and FNIS under each criterion is based on using the method for comparison fuzzy numbers (Bass and Kwakeernak, 1977; Dubois and Prade, 1979), similar in (Tadić *et al.*, 2011). The new approaches for determining FPIS and FNIS, with respect to criterion type are proposed in (Chen *et al.*, 2006; Sadi-Nezhad and Damghani, 2010).

In (Sadi-Nezhad and Damghani, 2010) the procedure for determining the FPIS and FNIS is based on the method developed by (Chakraborty and Chakraborty, 2007). Distance between two fuzzy numbers are calculated by using the vertex method developed in (Chen and Tzeng, 2004) in (Chen *et al.*, 2006; Kaya and Kahraman, 2011), and described by precise numbers. In (Kelemenis and Askounis 2010) FPIS and FNIS are determined through the comparison of each alternative with the veto threshold defined for each criterion. Many authors suggested using equation in (Sadeghpour-Gildeh and Gien, 2001) for determining of the distances from FPIS and FNIS, such as: Mahdavi *et al.* (2008); Tadić *et al.* (2011). In this paper, distance from FPIS and FNIS are obtained by using method which is proposed in (Sadeghpour-Gildeh and Gien, 2001).

In above mentioned papers, the closeness coefficient is calculated as conventional TOPSIS. According to the closeness coefficient, rank order of all alternatives can be determined.

Comparing papers which propose a model for ranking suppliers under uncertainties, certain differences could be noted, which is further described.

In this paper, an effort is given to observe simultaneously both crisp and uncertain criteria in the problem of supplier ranking (by analogy Tadić *et al.*, 2011).

As it is mentioned, FPIS, and FNIS are determined according to the weighted normalized fuzzy decision matrix by using different methods. In the proposed model, PIS, and NIS for crisp criteria are determined by using procedure defined in conventional TOPSIS. In this paper, determining of FPIS, and FNIS for each uncertain criterion is based on applying technique is proposed in (Sadeghpour-Gildeh and Gien, 2001) and it is used in (Mahdavi *et al*., 2008; Tadić *et al.*, 2011). In this paper, the distance from PIS and NIS are determined with respect to expressions from conventional TOPSIS.

In this way, the closeness coefficient for each supplier is described by fuzzy number. According fuzzy algebra rules, values of closeness coefficients do not TFNs but it is possible to express approximated values of fuzzy operations as TrFNs (Kwang, 2005).

3. Modelling of uncertainties

It is closer to human reasoning if decision makers express their opinions and evaluations by using linguistic expressions rather than numeric values. In this paper, the fuzzy rating of each decision maker is expressed by predefined linguistic expressions, which are modelled by TFNs.

3.1 The relative importance of criteria

All of the criteria for evaluating suppliers are usually not of the same relative importance. They do not depend on the suppliers and can be taken as unchangeable during the considered period of time. Inevitably, they involve subjective judgments and individual preferences of a management team. Accordingly, this is a group decision problem, which includes the elicitation of criteria weights from decision makers.

The relative importance of identfied criteria are different and are based on decision makers' subjective evaluation. The criteria weights are described by linguistic expressions which are modelled by triangular fuzzy numbers

$$\tilde{w}_k^e = \left(x; l_k^e, m_k^e, u_k^e \right), k = 1,\dots,K; e = 1,\dots,E$$

where K is the overall number of the considered criteria and E the total number of decision makers. The aggregate fuzzy rating of criterion k, k=1,...,K, denoted by $\tilde{w}_k = (x; l_k, m_k, u_k)$, is determined by the average method. Values in the domain of these TFNs are defined on common measurement scale.

In this paper, we use eight linguistic expressions for describing the fuzzy rating of criteria, which are defined by TFNs in the following way:

- *very low importance:* $\tilde{R}_1 = (x;1,1,1.5)$
- *low importance:* $\tilde{R}_2 = (x;1.5,2,2.5)$
- *fairly moderate importance:* $\tilde{R}_3 = (x;2,3,4)$
- *moderate importance:* $\tilde{R}_4 = (x;3,4,5)$
- *highly moderate importance:* $\tilde{R}_5 = (x;4,5,6)$
- *high importance:* $\tilde{R}_6 = (x;5,6,7)$
- *very high importance* - $\tilde{R}_7 = (x;7,8,9)$
- *extreme importance* $\tilde{R}_8 = (x;8.8,9,9)$

The estimation mean is calculated by using method of average value:

$$\tilde{w}_k = \frac{1}{E} \sum_{e=1}^{E} \tilde{w}_k^e, k = 1,\dots, K$$

3.2 Uncertain criteria values

There are numerous criteria for supplier evaluation that cannot be precisely determined, such as the period of payment, reliability of delivery, research and development, communication with supplier, the offered training, etc. All uncertain values are based on evidence data.

In this paper, the fuzzy rating of uncertain criteria values are described by linguistic expressions which can be represented as triangular fuzzy numbers $\tilde{v}_{sk} = (y; l_{sk}, m_{sk}, u_{sk})$ with the lower and upper bounds l_{sk}, u_{sk} and modal value m_{sk}, respectively. Values in the domain of these TFNs belong to a real set within the interval [1-5]. Specifically, we use five linguistic expressions, which are modelled by triangular fuzzy numbers as follows:

- *very low value:* $(y;1,1,2)$
- *low value:* $(y;1,2,3)$
- *moderate value:* $(y;2,3,4)$
- *high value:* $(y;3,4,5)$
- *very high value:* $(y;4,5,5)$

4. Extended topsis method

The proposed fuzzy model enables us to determine the most suitable artificial hip prosthesis supplier with respect to numerous criteria and their weights. The role of the model is to reduce subjectivity of the decision making process and generate precise evaluations and rankings of alternatives.

4.1. The proposed algorithm for supplier selection

The proposed fuzzy TOPSIS method for ranking suppliers is carried out in the following steps:

Step 1. Calculation of weights vector of the considered criteria by using the method of average value, $\tilde{W} = (\tilde{w}_1,\dots,\tilde{w}_k,\dots,\tilde{w}_K)$.

Step 2. Calculation of normalized values for crisp criteria by applying normalized procedure which is used in the conventional TOPSIS.

Step3. Transformation of all linguistic criteria values, $\tilde{v}_{sk}$ into $\tilde{r}_{sk}$ whose domains

are defined on a common scale [1-9] by applying the linear normalization method (Shih *et al.*, 2007):
For a benefit type criterion:

$$\tilde{r}_{sk} = \left(\frac{l_{sk}}{u_k^*}, \frac{m_{sk}}{u_k^*}, \frac{u_{sk}}{u_k^*} \right) \quad (4.1)$$

where:

$$u_k^* = \max_{s=1,..,S} u_{sk}, \; k = K^{'} + 1,..., K$$

For a cost-type criterion $k, k = K^{'} + 1,..., K$:

$$\tilde{r}_{sk} = \left(\frac{l_k^-}{u_{sk}}, \frac{l_k^-}{m_{sk}}, \frac{l_k^-}{l_{sk}} \right)$$

(4.2)

where:

$$l_k^- = \min_{s=1,..,S} l_{sk}$$

Step 4. Determining of the positive-ideal, v_k^+, and negative-ideal, v_k^-, solutions for all crisp criteria are the same as in the conventional TOPSIS.

Step 5. The fuzzy positive ideal solution, $\tilde{v}_k^+$ and fuzzy negative ideal solution $\tilde{v}_k^-$, respectively, under uncertain criteria. are calculated according to the procedure based on the method for comparing fuzzy numbers (Dubois and Prade, 1979, Bass and Kwakernaak, 1977).

Step 6. Calculate separation measures.

$$\tilde{d}_s^+ = \sum_{k=1}^{K^{'}} \tilde{w}_k \cdot \left| v_k^+ - v_{sk}^n + \right| \sum_{k=K^{'}+1}^{K} \tilde{w}_k \cdot d\left(\tilde{r}_{sk}, \tilde{v}_k^+\right)$$

$$\tilde{d}_s^- = \sum_{k=1}^{K^{'}} \tilde{w}_k \cdot \left| v_k^- - v_{sk}^n + \right| \sum_{k=K^{'}+1}^{K} \tilde{w}_k \cdot d\left(\tilde{r}_{sk}, \tilde{v}_k^-\right)$$

where $d(.,.)$ is the distance measurement between two triangular fuzzy numbers (Sadeghpour-Gildeh and Gien, 2001).

Step 7. A closeness coefficient is defined to determine the ranking order of all possible suppliers once $\tilde{d}_s^+$ and $\tilde{d}_s^-$ of each supplier s, s=1,..,S has been calculated. The closeness coefficient represents the distances to the fuzzy positive-ideal solution, $\tilde{d}_s^+$, and the fuzzy negative-ideal solution $\tilde{d}_s^-$, simultaneously by taking the relative closeness to the fuzzy positive-ideal solution. Calculate a fuzzy closeness coefficient for supplier:

$$\tilde{c}_s = \frac{\tilde{d}_s^-}{\tilde{d}_s^- + \tilde{d}_s^+} \quad (4.3)$$

Concerning that the fuzzy positive-ideal solution and fuzzy negative ideal-solution are described by fuzzy numbers whose supports are defined on a real set which belongs to [0-1], based on the rules of fuzzy algebra it follows that the support of fuzzy numbers which describe values of a closeness coefficient for all treated suppliers belong to interval [0-1].

Step 8. According to the descending order of the level of trust we set the rank of suppliers. Consequently, we can determine the ranking order of all suppliers and select the best one from the set of feasible suppliers with respect to all considered criteria as well as their relative importance. The proposed model gives an opportunity to determine the measure of belief that fuzzy numbers with a lower rank position are greater than fuzzy numbers which are ranked higher. Results gained in such a way enable decision makers to determine the best strategy for supplying artificial hips to the clinic.

5. Software for selection of implants suppliers

To support supplier selection in the field of medical devices (hip implants), a software solution was developed based on the method presented in the previous sections. The main purpose is to provide a user-friendly software solution for medical doctors for the procedure of hip implant supplier selection. The proposed methodology gives the basis for a web-based supplier evaluation and a selection system for managing tenders and supplier selection. The software solution was developed for Serbian orthopaedic clinics, so all text and comments on the graphical user interface (Figure 1) are in the Serbian language. We placed comments on screen shots to explain the interfaces.

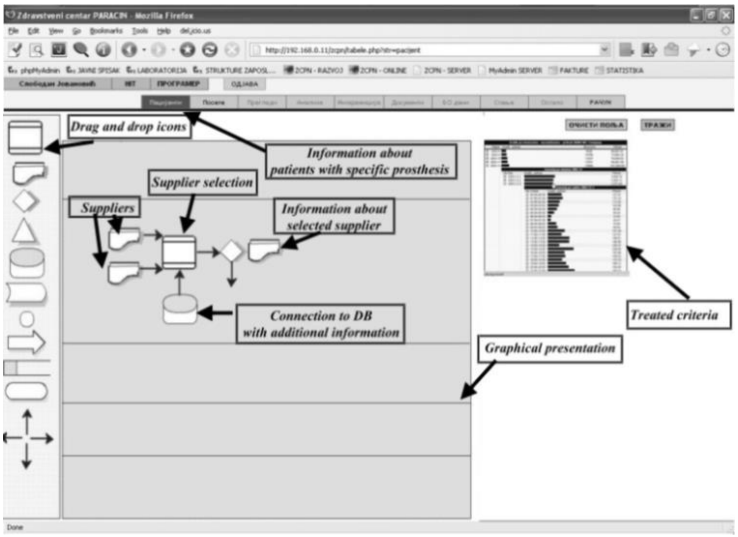

Figure 1. The graphical interface of software

The software consists of three modules:

1) *Module for monitoring and assessment of implants*. The first step in supplier selection is the definition of (or modification of the already existing) requirements for new implants. This is also the first step of the proposed method. The second step is the identification of criteria and sub-criteria used to evaluate the suppliers' potential. Selection criteria are listed and the fuzzy rating of each decision maker can be described by using eight linguistic expressions. Initially, eight criteria are listed, but they could be easily changed and added. Some of the criteria could be stated by value and other by linguistic expressions (three values, five linguistic expressions – see the real-life example in the next section). The procedure of definition of relative importance of criteria is stated for each supplier. This module even covers the definition of criteria for suppliers and their selection from a previously defined data base.
2) *Module for medical implant supplier selection*. Using the presented method, this module calculates ranks for the listed suppliers. The calculation of

uncertain criteria values is based on the Fuzzy TOPSIS model for supplier selection (section 4).

3) *Patients' monitoring module*. In this module the system keeps track of the surgical procedure and complete life cycle of the implant, including possible difficulties during the implantation and exploitation and a possible replacement. This module needs to provide feedback and additional information about the performance of the implant, from surgery to a possible replacement.

Working with the software starts with a definition of the project. Users employ a graphical user interface to define a formal process-oriented diagram for hip implant supplier selection. Users of the system could define or redefine the evaluation criteria. The document symbol represents an object that contains all attributes that define a potential supplier and its product (medical device, implant, artificial hip joint). It is also possible to upload information about a specific supplier (diagrams of the hip implant including different technical information such as material, tolerances, endurance, etc), medical data and necessary data for specific criteria calculation.

It is important to emphasize that the suggested criteria list could be changed or defined in a more detailed way. Each criterion could be subdivided into sub-criteria. The software automatically calculates comparative scoring, weighting, and evaluation, and (according to the presented method) shows the results through graphical charts. All data could be exported in different file formats in order to support the file interchange. Having defined the suppliers and their characteristics, a medical doctor could search the database of similar cases and professional criteria assessments from the orthopaedic clinic centre. The database is also used for storage of all clinical cases with different information that covers the life cycle of implants (implementation during surgical procedure, possible advantages/disadvantages during the procedure, exploitation, possible replacement). Finally, the medical data from specific clinical cases could be used for additional evaluation. Additionally, suppliers could be invited for on-line participation in the procedure, so they could provide answers to different questionnaires, or give different technical, medical, and service information about their products. They could also have on-line access to publicly available information about the assessment of suppliers and the selection procedure. This step increases the transparency of the process. Furthermore, all suppliers could get information about the strengths and weaknesses of their products or processes evaluated by the system, so they could use information from their customers to improve their product and/or quality of services. The software is a .NET application with web services. The web services or web forms access a SQL Server Data Base via a DB Access Application Block. The software for supplier selection is user-friendly with mainly what-you-see-is-what-you-get (WSIWYG) orientation.

6. A real-life example

The developed procedure is illustrated by an example presenting real data obtained in the Orthopaedic Clinic of Kragujevac Medical Center, Serbia. The total number of hip replacement operations in this centre was 1,060 in 2006, 1,804 in 2007, and 1,731 in 2008 (no more recent data available).

During the mentioned period, the selection of implants was a “physician preference item” (PPI). The decision was made to try to reduce expenses by reducing the number of potential suppliers (to select one or two suppliers) and to try to encourage producers to offer lower prices in order to secure contracts. The task of the decision-making team consisted of two steps. In the first step, the team defined the main evaluation criteria. Also, using the proposed Delphi method, the management team could determine criteria weights. In the second step, they determined the criteria values for each supplier on an already defined list of criteria (Swarts and Kop, 2005; Lavernia and Lyon, 1998). In this case, the team for the evaluation and ranking of potential suppliers consisted of six members: three orthopaedic medical doctors; the business manager of the operating room; the director of materials management, and the administrator for the orthopedic service line. The list of defined evaluation criteria is: unit cost (k=1), monetary unit,delivery time (k=2), in hours, replacement (k=3), in percent, period of payment (k=4), in months, reliability of delivery (k=5), research and development (k=6), communication with supplier (k=7), the offered training: how much the supplier is asking for the training (k=8). Criteria values for each potential supplier are given in Table 1.

Table 1. Criteria values for hip prosthesis supplier evaluation (s_i are suppliers, and k_i criteria)

	k1	k2	k3	k4	k5	k6	k7	k8
s1	90000	24	0	low value	very high value	very low value	moderate value	low value
s2	89950	12	100	moderate value	high value	high value	low value	very low value
s3	89900	48	70	high value	very low value	moderate value	very high value	very high value
s4	90353	48	30	very high value	low value	very high value	very low value	moderate value

By applying the average method, the weights vector is calculated:

$$\tilde{w}_1 = (6.67, 7.67, 8.67) \quad \tilde{w}_2 = (1.67, 2.33, 3) \quad \tilde{w}_3 = (4.67, 5.67, 6.67)$$
$$\tilde{w}_4 = (2.83, 3.83, 4.83) \quad \tilde{w}_5 = (1.83, 2.67, 3.5) \quad \tilde{w}_6 = (1.5, 2, 2.67)$$
$$\tilde{w}_7 = (5.67, 6.83, 8) \quad \tilde{w}_8 = (2.67, 3.83, 4.5)$$

By applying the procedure from Step 2 to Step 5 of the developed algorithm (section 4), the normalized decision matrix is obtained and it is presented in Table 2. By applying the procedure from Step 6 to Step 8 of the developed algorithm, closeness coefficients are calculated and the ranks of the treated suppliers are determined as shown in Table 3.

Based on the obtained results, the Clinical Center of Kragujevac management team should achieve the partnership with the supplier s_2, which is best with respect to the many criteria and their relative importance. Also, based on the obtained closeness coefficient, the measure of belief that a supplier who is in the second place (s_3) is better than s_2 is calculated and is equal to 0.761579.

Table 2. Normalized decision matrix

	k1	k2	k3	k4	k5	k6	k7	k8
s1	0.2498	0.1818	0	(0.2,0.4,0.6)	(0.9,1,1)	(0.2,0.2,0.4)	(0.4,0.6,0.8)	(0.33,0.5,1)
s2	0.2497	0.0904	0.5	(0.4,0.6,0.8)	(0.6,0.8,1)	(0.6,0.8,1)	(0.2,0.4,0.6)	(0.67,1,1)
s3	0.2495	0.3636	0.35	(0.6,0.8,1)	(0.2,0.2,0.3)	(0.2,0.6,0.8)	(0.9,1,1)	(0.2,0.2,0.22)
s4	0.25	0.3636	0.15	(0.9,1,1)	(0.2,0.4,0.6)	(0.9,1,1)	(0.2,0.2,0.3)	(0.25,0.33,0.5)
PIS/FPIS	0.2495	0.094	0.5	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.67,1,1)
NIS/FNIS	0.25	0.3636	0	(0.2,0.4,0.6)	(0.2,0.2,0.3)	(0.2,0.2,0.3)	(0.2,0.2,0.3)	(0.2,0.2,0.22)

Table 3. Closeness coefficients and rank of suppliers

	Cs	RANK	Degree of belief
s1	0,22968 0,37454 0,59423	4	
s2	0,40533 0,69058 1,01566	1	0.761579
s3	0,36475 0,54967 0,85547	2	
s4	0,24465 0,40782 0,67223	3	

The remaining two suppliers are not going to be considered when the management team is defining supply strategies. Results which are obtained by the proposed method are in compliance with the supplier selection practice of the Clinical Centre of Kragujevac.

7. Conclusion

In this paper, we proposed a new fuzzy TOPSIS method and supporting software for the selection of appropriate artificial hip prosthesis suppliers. This is considered to be an important step in determining optimal supply policies for artificial hip prostheses in orthopaedic clinics. The proposed method can deal with the rating of both quantitative and qualitative criteria and can select a suitable supplier effectively. The relative importances of criteria are described by linguistic expressions which are modelled by fuzzy sets. These values are calculated by using method of average value. All uncertainties and imprecision present in the considered problem are modelled by triangular fuzzy numbers.

As a contribution to real-life practice, the method was implemented in a web-based software solution that provides a flexible, user-friendly environment for medical doctors, suppliers and hospitals. The method and software could be very useful for: (1) producers to improve their processes and products, (2) a medical centre to increase the efficiency of its business operations which is measured by the number of successful hip replacements, which further makes the medical centre more competitive on the orthopaedic services market and keeps low costs in the hospital supply chain, and (3) patients, where it advances the process of recovery, potentially cutting costs to all family and friends, employers and society. The proposed method is flexible: the changes, such as the changes in the number of criteria or their relative importance, or the number of suppliers and the membership functions shape of fuzzy numbers can be easily incorporated into the model, and (3) can be easily extended to the analysis of other management decision problems in different research areas. Also, the software solution provides many additional features, such as storage of developed activities and keeping track of the suppliers' performances.

This paper contributes to both practice and research. The developed model and software present a suitable tool for supplier selection in the field of medical implants considering the number of previously mentioned characteristics for the supply of medical goods. Since different parties are involved in the process of supplier selection (doctors, management, etc), this approach enables the ranking of different suppliers using a linguistic expression in order to provide savings in the purchase of medical implants by reducing the number of suppliers. It is also clear that this model and software could also be used in a wide range of supplier selection tasks in health care systems.

Acknowledgments: Research presented in this paper was supported by Ministry of Science and Technological Development of Republic of Serbia, Grant III-44010, Title: Intelligent Systems for Software Product Development and Business Support based on Models

References:

American Academy of Orthopaedic Surgeons Website, Data from 2003 analyzed from the National Center for Health Statistics, 2005.

Bass, M.S., & Kwakernaak, H. (1977). Rating and Ranking of Multiple-aspect Alternatives using Fuzzy sets. *Automatica*, *3*, 47-58.

Berry, D., Harmsen, S., Cabanela, M., & Morrey, B. (2002). Twenty-five-year survivorship of two thousand consecutive primary Charnley total hip replacements. Factors affecting survivorship of acetabular and femoral components. *Journal of Bone and Joint Surgery*, 84-A, 171-177.

Burns, A.W.R., & Bourne, B.R. (2006). *Economics of revision total hip arthroplasty*, London Health Sciences Centre, University of Western Ontario.

Burns, R.L., Housman, G.M., Booth, E.R., & Koenig, A. (2009). Implant vendors and hospitals: Competing influences over product choice by orthopedic surgeons. *Health Care Manage Rev*, *4*(1), 2-18, 2009.

Callaghan, J.J., Albright, J.C., Goetz, D.D., Olejniczak, J.P., & Johnson, R.C. (2000). Charnley total hip arthroplasty with cement. Minimum twenty-five-year follow-up. *Journal of Bone and Joint Surgery*, *82*, 487-497.

Chakraborty, C., & Chakraborty, D.A. (2007). Theoretical development on a fuzzy distance measure for fuzzy numbers. *Mathematical and Computer Modelling*, *43*, 254-261.

Chen, C.T., Lin, C.T., Huang, S.F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management, *International Journal of Production Economics*, *102*, 289-301.

Chen, M.F., & Tzeng, G.H. (2004). Combining grey relation and TOPSIS concepts for selecting and expatriate host country. *Mathematical and Computer Modelling*, *40*, 1473-1490.

Cheng, Y-L., Lin, Y-H., Tseng, M-L. (2011). Analysis of Hotel Service Quality Perceptions using Fuzzy TOPSIS. *Progress in Business Innovations&Technology Management*, *1*, 90-109.

Das, P. (2010). Selection of business strategies for quality improvement using fuzzy analytical hierarchy process. *International Journal for Quality Research*, *4*(4), 283-289.

Dubois, D., & Prade, H. (1979). *Decision-making under fuzziness, in: Advances in Fuzzy Set Theory and Applications, by (ed.) M.M. Gupta, R.K. Pagade, and P.R Yager*, North-Holland, Amsterdam, 279-302.

Felts, W., & Zelin, E. (1989). The economic impact of the reumatic disease in the United States. *Journal of Rheumatology*, *16*, 867-884.

Ho, W., Xu, X., & Dey, K.P. (2009). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of Operational Research*, *5*, 16-24.

Isiklar, G., Büyüközkan, G. (2006). Using a multi-criteria decision making approach to evaluate mobile phone alternatives. *Computer Standards and Interfaces*, *29*, 265-274.

Kaur, P., & Chakrabortyb, S., (2007). A new approach to vendor selection problem with impact factor as an indirect measure of quality. *Journal of Modern Mathematics and Statistics*, *1*(1-8).

Kaya, T., & Kahraman, C. (2011). Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Systems with Applications*, *38*, 6577-6585.

Kelemenis, A., & Askounis, D. (2010). A new TOPSIS-based multi-criteria approach to personal selection. *Expert System with Applications*, *7*(37), 4999-5008.

Kelemenis, A., & Askounis, D., (2010). A new TOPSIS-based multi-criteria approach to personal selection. *Expert System with Applications*, doi:10.1016/j.eswa.2009.12.013.

Keselman, A., Tang, X., Patel, L.,V., Johnson R.T., & Zhang, J. (2004). Institutional Decision-Making for Medical Device Purchasing: Evaluating Patient Safety. *MEDINFO,* 1357-1361.

Kwang, H.L. (2005). *First course on Fuzzy Theory and Applications.* Springer-Verlag, Berlin-Heidelberg/New York 137-144.

Lavernia, C., Lyon, R. (1998). The Short-Term Implications of Prosthetic Selection in Hemiarthroplasty of the Hip. *The American Journal of Orthopedics*, 414-418.

Mahdavi, I., Mahdavi-Amiri, N., Heidarzade, A., & Nourifar, R. (2008). Designing a model of fuzzy TOPSIS in multiple criteria decision making. *Applied Mathematics and Computation*, 206, 607-617.

Malki, A.A., Dhaif, B., Al-Mousawi, F. (2003). Reducing Hospital Expenditures: Experience with Orthopaedic Implants” *Bahrain Medical Bulletin*, *25*(2), 1-9.

Sadeghpour-Gildeh, B., & Gien, D. (2001). *La Distance-Dpq et le Coeffcient de orrelation entre deux Variables Aleatories floues*. Actes de LFA’2001, 97-102.

Sadi-Nezhad, S., & Damghani, K.K. (2010). Application of a fuzzy TOPSIS method based on modified preference ratio and fuzzy distance measurement in assessment of traffic police centers performance. *Applied Soft Computing*, *10*(4), 1028-1040.

Shih, H.S., Shyur, H.J., & Lee, E.S. (2007). An extension of TOPSIS for group decision making. *Mathematical and Computer Modelling*, *45*(7/8), 801-813.

Stargardt, T., (2008). Health service costs in Europe: cost and reimbursement of primary hip replacement in nine countries. *Health Economics*, *17*, S9-S20.

Swarts, E., & Kop, A. (2005). Supply of Primary Orthopaedic Hip and Knee Implants. *Implant Technology and Biomaterials*, *4*.

Tadic, D., Milanovic, D., Misita, M., & Tadic, B. (2011). A new integrated approach to the problem of ranking and supplier selection under uncertainties. *Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture, London, UK, 225 (B9)*, 1713-1724.

Walczak, R.C. (2011). Cooperative vendor selection saves money, helps improve care. *Healthcare Financial Management*. Retrieved from: http://findarticles.com/p/articles/mi_m3257/is_n12_v47/ai_14858509/

Wilson, A.N., Schneller, S.E., Montgomery, K., & Bozic, J.K. (2008). Hip And Knee Implants: Current Trends And Policy Considerations. *Health Affairs*, *27*(6), 1587-1598.

Zahar Djordjevic, M., & Puskaric, H. (2013). Management of process safety in food chain. *International Journal for Quality Research*, *7*(1), 141-152.

Zheng, G., Zhu, H., Tian, Z., Chen, Y., & Sun, B. (2012). Application of a trapezoidal fuzzy AHP method for wotk safety evaluation and early warning rating of hot and humid environments. *Safety Science*, 50, 228-239.

Zuckerman, J.D., Kummer, F.J., & Frankel, V.H. (1994). The effectiveness of a hospital-based strategy to reduce the cost of total joint implants. *Journal for Bone and Joint Surgery*, *76*, 807-811.

Marija Zahar Djordjevic
University of Kragujevac
Faculty of Engineering,
Center for Quality
Kragujevac
Serbia
maja_199@yahoo.com

Hrvoje Puskaric
University of Kragujevac
Faculty of Engineering,
Center for Quality
Kragujevac
Serbia
xpboje@gmail.com

Aleksandar Djordjevic
University of Kragujevac
Faculty of Engineering,
Center for Quality
Kragujevac
Serbia
cqm@kg.ac.rs