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Subject review

An Integrated Framework for Non-Traditional Machining Process Technology Selection in Healthcare Applications

Elif DELİCE*, Hakan TOZAN, Melis Almula KARADAYI, Marta HARNICAROVA, Başak TURAN

Abstract: In spite of continuous progress in technical advancement, the conventional machining process became unsatisfactory in the healthcare field due to its disadvantages. This inadequacy lead researchers to consider using the application of nontraditional machining that can machine extremely hard and brittle materials into complicated shapes such as medical devices and implants in healthcare. In this study, the three most popular nontraditional machining process technologies: Laser Beam Machining, Water Jet Machining, and Electrocautery are evaluated to determine the most appropriate technology using the Health Technology Assessment based Multi-criteria Decision-Making framework. HTA is organized evaluation of effects and properties of health technology that enables the application of systematic skills to solve a health problem. HTA's main goal is to raise awareness of new health technologies among decision makers. For these reasons, the HTA core model that enables the production of HTA-related information was utilized.The comparison of selected technologies was carried out via integrating the HTA core model, Best Worst, and Evaluation Based on Distance from Average Solution methods. Finally, a comparison was made to find the most suitable technology to create the necessary infrastructure. As a result, evaluation scores were computed as 0,673; 0,538 and 0,500 for WJM, LBM, and EC, respectively.

Keywords: best worst method; EDAS; health technology selection; multi-criteria decision making; non-traditional machining

1 INTRODUCTION TO NON-TRADITIONAL MACHINING PROCESS

Nowadays, all manufacturing companies run against the global market. This situation leads them to produce new materials, to search for new products and production methods [1]. Applications that provide generating complex shapes with the required tolerance and surface roughness for advanced engineering materials are limited in traditional machining methods. Thus, non-traditional machining processes take the place of traditional machining processes in most areas [2]. In conventional processing methods, the material is removed in the form of sawdust on the workpiece with the help of a cutting tool. On the contrary, Non-traditional Machining Processes (NTMs) make use of the more recent methods of mechanical, electrical, thermal, and chemical energy, or all, to gradually remove material from the workpiece by erosion [3]. Unlike traditional processing methods, tools used in NTM do not need to be harder than the working material and any contact is found between material and tool. Hence, this study aims to evaluate the most popular non-traditional machining process technologies: Laser Beam Machining (LBM), Water Jet Machining (WJM), and Electrocautery (EC) to determine the most appropriate technology for tissue cutting operations using the Health Technology Assessment (HTA) based Multi-criteria Decision Making (MCDM) framework [4].

The conventional machining process became unsatisfactory in healthcare due to its disadvantages. This inadequacy lead researchers to consider the application of NTM. Researches proved that diverse NTM applications are appropriate in manufacturing medical devices and implants for different fields such as therapy and surgery. Furthermore, recent developments confirmed the various applications of WJM, LBM, and EC in the area of machining medical equipment.

To the best of our knowledge, with the detailed review of the literature, there is no study to compare the technologies used in tissue cutting based on the HTA framework by integrating several MCDM methods. This study is expected to be a guide to all stakeholders in this field.

This paper is constituted as follows. Section 1.1 summarizes the literature review on WJM, LBM, EC, Multicriteria Decision Making, and Health Technology Assessment. Section 2 presents the proposed HTA-based MCDM methodology. Results of the proposed framework are given in Section 3. Finally, conclusions and discussion for future research are presented in the last section.

1.1 Literature Review

With the modern technology growth and the need for new advanced technologies in surgeries, researches on WJM, LBM, and EC in cutting soft tissue have been examined with more detailed factors to see if it contributes to improving the quality of the operations. Experiments over years proved the availability of these technologies in cutting soft tissue.

1.1.1 Literature Review on Water Jet Machining (WJM)

Due to the many advantages of waterjet technology, for instance absence of thermal damage caused by temperature, absence of a structural change of material, sharp and clean-cut, controlled fluid pressure, absence of deformation and reduction of blood loss, usage of water jet technology applications in healthcare drew the attention of researchers [5]. Waterjet technology considers all technological modifications such as continuous waterjet, abrasive waterjet and pulsating waterjet.

There are different studies in the literature about WJM, which is one of the popular non-traditional machining processes that will be examined in this study. This section provides a summary of these studies [6].

Hloch et al. [7] searched the issue of identification of factors about the surface topography of bone tissue and the surfaces evaluated by using the surface profile parameters to identify desired surface quality. With their results, this research can set up a basis for future abrasive waterjet cutting applications in orthopedic surgeries. den Dunnen &

Tuijthof [8] aimed to see the effectiveness of different water jet nozzle diameters on drilling bone tissue and showed there was no correlation between the size of the nozzle diameter and efficiency of water jet drilling. The water jet cutting technique is applied by Kraaij et al. [9] to remove interface tissue between bone and the orthopedic implants in loose hip prostheses. den Dunnen et al. [5] showed that using Colliding Water Jet (CWJ) in bone tissue provides safer application by studying to improve the control over drilling depth by comparing CWJ with Single Water Jet (SWJ) considering drilling depth and jet time. Hloch et al. [6] focused on Pulsating Liquid Jet (PLJ) that consists of saline solution for bone cement removal application and determines the minimal liquid pressure that is necessary for the removal procedure.

1.1.2 Literature Review on Laser Beam Machining (LBM)

LBM is one of the commonly used methods for tissue cutting and generating medical devices. Some wavelengths of laser beams provide both cutting and congelation of tissues efficiently. Also, Laser cutting ensures extremely thin, precise, and clean cutting. LBM is applied to understand the changes induced in the bone in terms of temperature rise and thermal damage and to study bone healing under functional loading [11].

Allegrini et al. [12] showed that on the laser-treated implant surfaces, new bone tissue is formed more rapidly and distinctly. Ranjan & Mishra [13] conducted a study about the potential of LBM in the processing of Hydroxyapatite. Rahmani-Monfard et al. [14] aimed to form a newly developed, predefined three-dimensional polymethyl methacrylate (PMMA) scaffold produced by CO_2 laser drilling technique. In Boyde [10], the laser ablation method was evaluated in terms of problems arising from the bone. Šugár et al. [15] developed osseointegration of the titanium implants.

1.1.3 Literature Review on Electrocautery (EC)

EC is a method that is used for cutting tissue in surgeries. EC cut opens through the alternative current which causes the blood to clot without damaging adjacent tissues. It is preferred to dissect muscle layers and fascia as well as to stop the bleeding. EC generates incision more quickly [16]. Although EC reduces the incision time and blood loss, it can sometimes lead to the formation of infected wounds, poor cosmetic results, and thermal damage to the tissue due to overheating [18].

In Bo et al. [18], the efficacy and safety of combined electrocautery needle blade against balloon dilatation alone in the treatment of tracheal stenosis was evaluated. Ragulin et al. [19] aim to evaluate the effectiveness of pulmonary metastases after surgery with various techniques according to results and complications of surgery. The number of complications in surgery using laser is less than in surgery with EC. In conclusion, results were more advantageous for Neodymium-doped Yttrium Aluminum garnet (ND: Yag) Laser surgery. Agrawal et al. [20] studied the blood loss in a patient with cancer who has selective neck dissection using these devices. In the end, preoperative blood loss was importantly lower in the patient team using the Harmonic Scalpel device compared to the patient team using the EC device. Derriks et al. [21] studied the use of EC during arthroscopy which can warm the intra-articular fluid and then damage the intra-articular and extra-articular tissue. It has been observed that higher temperatures can damage the surrounding internal and external joint tissues. Due to the lack of randomized controlled trials to compare harmonic scalpel with EC in recent studies, D. Li et al. [22] analyzed the differences between ultrasonic dissection and standard EC. Outcomes of the study such as reduction in operating time, intraoperative blood loss, hospital stay, salivary fistula, and transient facia during harmonic scalpel prove the superiority of harmonic scalpel over EC. Almansour et al. [23] provided a biomechanical analysis of the fatigue life potential effect of the EC device on spinal implants. As a research result, titanium rods failed in the area where EC was applied, and fatigue life was reduced. Doctors should be careful around spinal implants, especially during revision.

1.1.4 Literature Review on Multi-criteria Decision Making (MCDM) method and Health Technology Assessment (HTA)

In the health sector, regulators decide which technology, medical device, drug, or treatment procedure to apply and should be financed using public resources. The cost and effectiveness of technology are important two factors in healthcare. Other factors are prevalence, safety, ethical and social implications. Firstly, the willingness to pay (WTP) of the decision-makers (DM) should be determined because there is a tradeoff between money and health. There have been different approaches to determine WTP but outcomes still showed significant differences. Hence, Jakubczyk [24] aims to show how to integrate the fuzzy approach from the theoretical point of view into the decision-making process. The main result of this study is that it provides a conceptual framework that allows the use of this fuzzy approach to compare different alternatives to health technologies. Ivlev et al. [25] examined MRI systems and tried to improve methodological support for the selection of the technological device used in the field of health in case of uncertainty and to form a theoretical decision support model. As a result, an algorithm was developed by the researchers and tested in the selection of MRI systems in health care facilities in the Czech Republic. Mobinizadeh et al. [26] defined a pilot MCDM model for determining health technology assessment in Iran. The TOPSIS model was formed and three health technologies in Iran were evaluated as an experiment.

Marsh et al. [27] examined the applications of multicriteria decision analysis (MCDA) to support HTA and described three concerns to the use of MCDA starting with the use of additive models, a lack of connection between criteria scales and weights, and the use of MCDA in economic evaluation. Karatas et al. [28] presented the synthesis of MCDM methods that enable selection and sequencing for HTA more reliably and innovatively. An integrated decision support model named "DEMATSEL" has been introduced with the widely used fuzzy AHP, fuzzy TOPSIS, fuzzy VIKOR, and Goal Programming methods in the studies. A case study regarding the selection of bariatric surgery was carried out in Turkey.

Frazão et al. [29] investigated the MCDM techniques used in health care through the existing works, evaluated the problematic aspects, and aimed to turn the results into a structure in this research. In the conclusion, it was observed that the AHP method and fuzzy methods were preferred and MCDM methods had a wide usage area in the health field. Improta et al. [30] developed a new health technology with using HTA to detect thyroglobulin in different patients diagnosed with thyroid cancer using the MCDM of AHP and also, Likert scale that is a scale that provides the measurement of the opinions received from experts and shows the measure of satisfaction, as well as to plan appropriate resource use, educational activities and to meet the technology needs. Mardani et al. [31] searched fuzzy decision-making and traditional decision-making methods systematically, they aimed to observe the health environmental problems by using MCDM, in this way investigating the MCDM's efficiency. As a result, researchers observed that MCDM methods in the medicine and health sector are mostly used to measure quality applications and also help to evaluate and solve problems.

2 METHODOLOGY

In this section, the proposed HTA-based MCDM methodology framework is explained in detail under fou rsections: (2.1) MCDM Method applications in healthcare, (2.2) HTA, (2.3) BWM, and (2.4) EDAS.

2.1 Multi-criteria Decision Making (MCDM) Method Applications in Healthcare

Decision-making needs the comparison of different alternatives by distributing the preferences into different properties and evaluating and determining the relative according to their importance. MCDM is a tool that meets the requirements of DM by analyzing complex problems in real-time due to its unique ability to evaluate different alternatives according to various criteria and to find optimal choices among the alternatives. Although its purpose that creating a better-informed decision-making process is common, various MCDM methods are different from each other due to the nature of their model, the information they use, and the way their model is used.

Decision-making in healthcare is a process that includes complicated steps such as the inclusion of diverse aspects, participation of different stakeholders, or evaluating alternatives concerning evidence-based. Also, the growth of health technologies creates difficulties for health authorities to make a rational decision among opportunities. With the help of HTA promoting an input to the decision making to involve technology in healthcare, only some of the problems about decision making can be analyzed and solved. To have more success, MCDM application in healthcare is considered as an assistant to HTA because it provides a clear, more structured, and sophisticated decision-making process.

2.2 Health Technology Assessment (HTA) and HTA Core Model

The common definition of HTA by the World Health Organization (WHO) is that it is a systematic evaluation of properties, effects, and/or impacts of health technology. Further, that it is a multidisciplinary process to evaluate the social, economic, organizational, and ethical issues of a health intervention or health technology [32]. HTA is a multidisciplinary process that summarizes information about safety, clinical effectiveness, cost, social, legal, and ethical aspects in a systematic, transparent, objective, and effective way in the use of health technology.

The HTA Core Model is the methodological framework that is developed by the European Network for Health Technology Assessment (EUnetHTA) to jointly produce and define the new structure of HTA information content. HTA Core Model is an HTA model used in the evaluation of various types of health technologies such as medical and surgical interventions, drugs, and screening technologies. The basis of HTA is to systematically compile research results on the effectiveness, reliability, and cost of health technology and to present these results in a report. The aim is to increase the applicability of HTA in other similar national and international HTA activities and to provide real cooperation between HTA institutions by providing a common framework for HTA production. HTA core model also deals with health technology primarily in nine dimensions. Each dimension is then divided into one or more subjects. However, a subject can sometimes be discussed in more than one dimension. There are general questions in each subject. The nine dimensions of HTA are Health Problem and Current Use of Technology, Definition and Technical Characteristics of Technology, Clinical Effectiveness, Safety, Costs, and Economic Assessment, Organizational Aspects, Ethical Aspects, Social Aspects, Legal Aspects.

Technical and Technological: Chosen technology is examined in this dimension of the HTA Core model in terms of the current state of this technology, what processes are important for the use of this device, the description, and benefit of the technology, whether there are any assets specifically required for the use of this device.

Safety: Criteria of safety dimension consider the importance of patient's, staff member's safety and also interest of the environmental level of the device.

Clinical Characteristics: Criteria of clinical characteristics provide detailed information about the patient's body functions, quality of life, ability to work, the effect on return to previous living conditions, the overall benefits and harms, the expected beneficial effect of the intervention on overall mortality, the expected beneficial effect on disease-specific mortality, the expected beneficial effect of the disease on progression or how it affects its relapse with the use of technology, whether its use is worth the effort and time spent, and whether the patient is willing to reuse technology.

Cost: For the usage of the device there are many types of costs and cost dimension criteria include these types of costs that differ for each device.

Organizational Aspects: At this stage, assessments that are related to analysis processes and resource usage in the intra- and inter-organizational and healthcare system level and access to technology in terms of management and cultural diversity are made. These criteria include how technology affects existing business processes, which patient/participant flow is associated with the technology, how the personnel will be contacted in terms of technology education, operation and activity, quality assurance systems and monitoring of technology, how human-centered and centralized management affect the technology, in terms of health care system structure; how patients/participants reach technology, procurement and institutional costs of technology, opportunities, and threats to be provided by technology, cultural acceptance of participants/patients focuses on the perspectives of people from different cultures.

Ethical, Social and Legal: For ethical, social, and legal dimensions there is important diversity for each device usage at the aspects of device impacts on patient, the quality level of operation on patient's recovery period.

Criteria Definitions of Technical and Technological Dimension:

(T1) Complexity: This criterion refers to the different elements of technology and the relationship, interaction between these elements. It also reflects the stage of uncertainty and predictability in the device.

(T2) Technology Setup, Preparation: Planning, editing and briefly organizing the technology to be used before an operation is expressed with this criterion.

(T3) Process Control: Process control of technology is associated with monitoring the operation of the device. This criterion considers process control features such as programmable mode, manual mode, and automatic mode separately.

(T4) Cutting Ability (in very small and fine tissues): Cutting ability describes the device's capability to cut on tissue. This refers to the talent of the technology to initiate or terminate the operation at whichever point of tissue on very small and fine tissues.

(T5) Clean Cut: It expresses the technology that is used in operation how smooth and clean-cut the tissue. It also answers the question of how healthy a cut is made with each technology's unique characteristics, such as blood clotting.

(T6) Reliability: The reliability criterion describes measuring and defines the operating system of the technology. With this measurement and identification, it is stated that the confidence measure in the operation of these devices is used in cutting tissue, that is, whether the device fulfills its duty or not.

Criteria Definitions of Safety Dimension:

(S1) Infection Risk: The rate of infection that a patient can get during an operation.

(S2) Radiation Risk: The rate of radiation that patient can get during operation.

(S3) Occupational Health & Safety: Ensuring that medical staff member works under proper conditions.

Criteria Definitions of Clinical Dimension:

(Cl1) Complications: The complication is the addition of a new disease or problem when there is a disease. The additional problem disease is due to the disease itself, drug treatment, or surgery. Due to the developing complication, the disease becomes even more complex. Complications of a disease may lead to a new disease. This criterion gives a ratio of complications that derive from used technology.

(Cl2) Coagulation of Blood: Coagulation, in physiology, is the process by which a blood clot is formed. The ratio of Coagulation of Blood for these three technologies shows which technology allows a higher rate of blood clotting.

(Cl3) Thermal Damages: Intraoperative thermal tissue damage is an important parameter affecting postoperative tissue healing, infection, pain, and hospitalization. It is important to determine the thermal methods of used technologies for surgical dissections, which will prevent excessive temperature rise in the tissue and cause minimal temperature spread to the surrounding tissues. Thus, the level of thermal damages of these three technologies should be specified.

(Cl4) Cosmetical Results: Cosmetic results are the appearance of the surgical area after the wound has healed. The degree of cosmetic results of the technology used in tissue cutting is an important criterion for the evaluation of the technology and the patient.

(Cl5) Technology Related Side Effects: The level of undesired symptoms caused by used technology in operation.

(Cl6) Technology Related Restraint, Limitations: This criterion inquires whether the technology/device used in tissue cutting creates a condition that prevents surgery.

(Cl7) Ease of the Technology Usage in Difficulties Due to Tissue Layout: This criterion responds to the question of whether the device or technology used in tissue cutting has a flexible application procedure that may vary depending on the location of the tissue to be cut. What are the working levels of these three technologies in tissue locations that are difficult and dangerous to cut?

Criteria Definitions of Cost Dimension:

(C1) Investment Cost: The cost for purchasing the device.

(C2) Maintenance Cost: Cost for maintenance of the device.

Criteria Definitions of Organizational Aspects:

(O1) Staff Education: The level of education of the personnel using the technology to be used in tissue cutting is an important factor in the successful outcome of the surgery. Therefore, this criterion allows evaluating the question of the level of training of the personnel who will use the technology.

(O2) Operating Room Conditions Eligibility (Physical Space Needed): This criterion answers questions such as: What level of physical space do the technologies require for the operation, and are there specific requirements for the technology involved in the location of the operation?

Criteria Definitions of Ethical, Social and Legal:

(ESL1) Equal Access to All Patients: Accessibility of operation for every type of patient.

(ESL2) Understanding of Technology's Procedures by the Patient: Confirmation of patient for operation.

According to the meetings with experts, HTA Core Model is constructed (see Fig. 1) Based on the final model, the survey was prepared and transferred into Google Forms then sent to the decision-makers to gather required data.

2.3 Best Worst Method (BWM)

BWM is one of the latest MCDM methods. This method is used to achieve the weighting of the main and sub-criteria in the problem. It is a way that compares the criterion that is selected as the best with the other determining criteria and the criterion that is selected as the worst with all other determining criteria. As stated in studies comparing BWM and AHP in the literature BWM has advantageous aspects which make it preferred; in this method, less pairwise comparisons are made, the weight values obtained as a result of the operations are more reliable, and when comparing, only the integers are included in the pairwise evaluations [33].

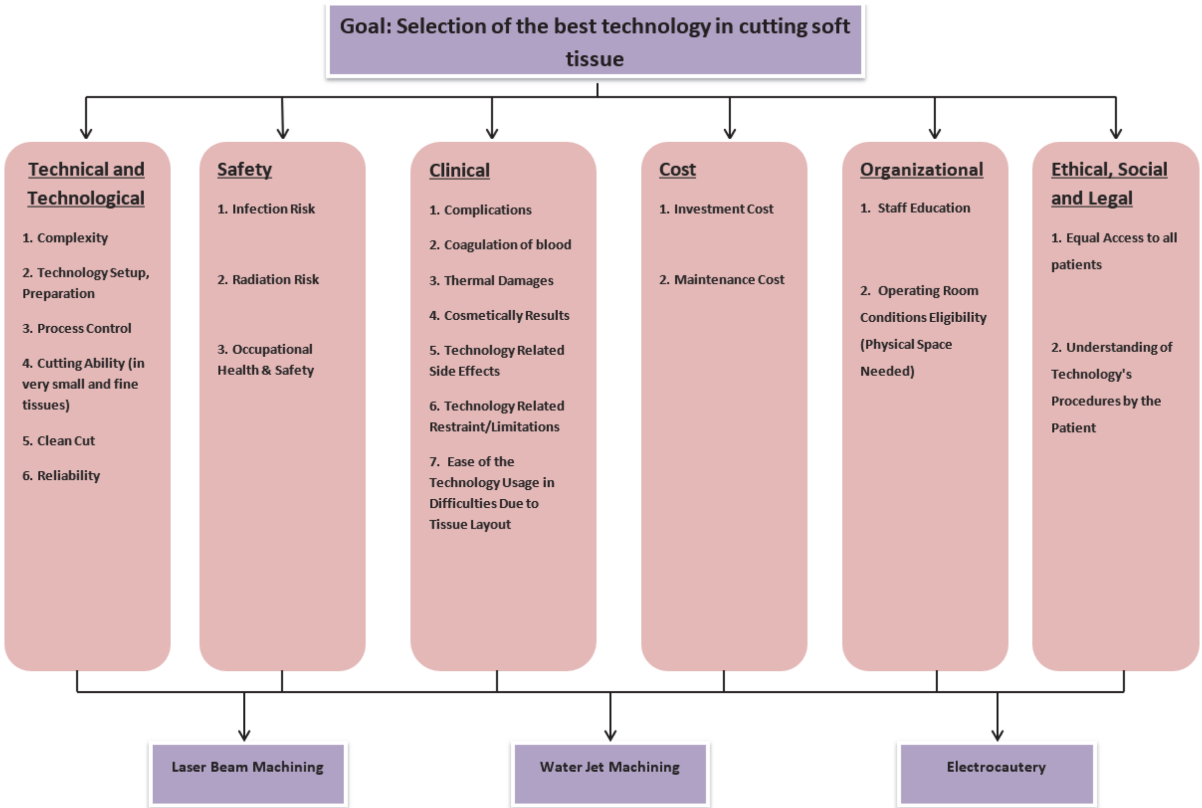

Figure 1 The HTA core model of problem

Step 1: Determine the set of decision criteria such as $\{C_1, C_2, ..., C_n\}$.

Step 2: Determine the best i.e., most important criteria, and the worst i.e., least important criteria.

Step 3: Determine the preference of the best criterion over all the other criteria using a number between 1 and 9. (1: equally important, 3: moderately more important, 5: highly important 7: much more important, 9: extremely important).

The result of this step is to achieve a vector called Best-Others (A_B), which advances from the best to the others. This vector should be:

$$A_B = (a_{B1}, a_{B2}, ..., a_{Bn}) \quad (1)$$

Each a_{Bj} in the A_B vector shows the preference of the best criterion (B) over criterion j. Also $a_{BB} = 1$. This means that the most important criterion will be compared with itself.

Step 4: Determine the preference of all criteria over the worst criterion using a number between 1 and 9.

As a result of this step, the worst vector should be:

$$A_W = (a_{W1}, a_{W2}, ..., a_{Wn}) \quad (2)$$

In this vector, each a_{Wj} indicates the preference of criterion j over the worst criterion (W) and should be $a_{WW} = 1$. This means that the worst criterion will be compared with itself.

Step 5: In the last step, the most appropriate weight for each criterion should be determined $\left(w_1^*, w_2^*, ..., w_n^*\right)$. The objective in this step is to determine the optimal weights of the criteria to ensure the maximum absolute differences.

The problem equation is modelled as the following linear programming problem:

$$min\, \xi_a \quad (3)$$

$$| w_B - a_{Bj} * w_j | \le \xi_a, \text{ for all } j \quad (4)$$

$$| w_j - a_{jW} * w_w | \le \xi_a, \text{ for all } j \quad (5)$$

$$\sum w_j = 1 \quad (6)$$

$$w_j \ge 0, \text{ for all } j \quad (7)$$

The generated linear programming model is solved by any solver to obtain optimal weights for each criterion.

2.4 Evaluation based on Distance from Average Solution (EDAS) Method

EDAS is an efficient and relatively new method which deals with MCDM problems for general situations. In the EDAS method, for each criterion, every alternative has its positive and negative distance that is calculated according to the type of criteria (beneficial or non-beneficial) and the desirability of the alternatives is calculated based on the positive and negative distances from the average solution concerning each criterion. The average solution contains average elements obtained on each criterion. The best alternative is chosen according to the rule of having more positive distances and fewer negative distances from the average solution. The advantage of EDAS based on studies comparing the other much-used methods such as VIKOR, TOPSIS, SAW, and COPRAS is obtaining the best alternative from average solution, eliminates the risk of biasedness of experts towards an alternative, therefore, it provides a better and accurate solution [34, 35].

Step 1: The decision-making matrix $\left(\boldsymbol{X}\right)$ is created. The following equation shows the decision-making matrix. Eq. (8) shows the performance of the n-th alternative in the n-th criterion.

$$\boldsymbol{X} = \left[X_{ij}\right]_{nxm} = \begin{bmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{bmatrix} \tag{8}$$

Step 2: Determine the average solution $\left(AV_j\right)$.

$$AV_j = \frac{\sum_{i=1}^{n} X_{ij}}{n} \tag{9}$$

Step 3: Calculate the positive distance matrix from average $\left(PDA\right)$.

If j-th criterion is beneficial, $\left(PDA_{ij}\right)$ is calculated using Eq. (10):

$$PDA_{ij} = \frac{\max\left(0, \left(X_{ij} - AV_j\right)\right)}{AV_j} \tag{10}$$

If j-th criterion is non-beneficial, $\left(PDA_{ij}\right)$ is calculated using Eq. (11):

$$PDA_{ij} = \frac{\max\left(0, \left(AV_j - X_{ij}\right)\right)}{AV_j} \tag{11}$$

Step 4: Calculate the negative distance matrix from average $\left(NDA\right)$.

If j-th criterion is beneficial, $\left(NDA_{ij}\right)$ is calculated using Eq. (12):

$$NDA_{ij} = \frac{\max\left(0, \left(AV_j - X_{ij}\right)\right)}{AV_j} \tag{12}$$

If j-th criterion is non-beneficial, $\left(NDA_{ij}\right)$ is calculated using Eq. (13):

$$NDA_{ij} = \frac{\max\left(0, \left(X_{ij} - AV_j\right)\right)}{AV_j} \tag{13}$$

Step 5: The SP_i and SN_i values are calculated for all alternatives using Eq. (14) and Eq. (15). SP_i indicate the weighted total positive value of the i-th alternative and SN_i indicate the weighted total negative value of the i-th alternative.

$$SP_i = \sum_{j=1}^{m} w_j \cdot PDA_{ij} \tag{14}$$

$$SN_i = \sum_{j=1}^{m} w_j \cdot NDA_{ij} \tag{15}$$

Step 6: The SP_i and SN_i values for all alternatives are normalized using Eq. (16) and Eq. (17).

$$NSP_i = \frac{SP_i}{\max_i SP_i} \tag{16}$$

$$NSN_i = 1 - \frac{SN_i}{\max_i SN_i} \tag{17}$$

Step 7: Finally, the evaluation scores $\left(AS_i\right)$ for each alternative are calculated using Eq. (18). The ranking is obtained based on evaluation scores. The alternative with the largest evaluation score is determined as the best alternative.

$$AS_i = \frac{1}{2}\left(NSP_i + NSN_i\right) \tag{18}$$

3 FINDINGS

In this study, WJM, LBM, and EC devices were compared using BWM and EDAS MCDM methods based on the HTA Core Model. Flowchart of the proposed framework is presented in Fig. 2.

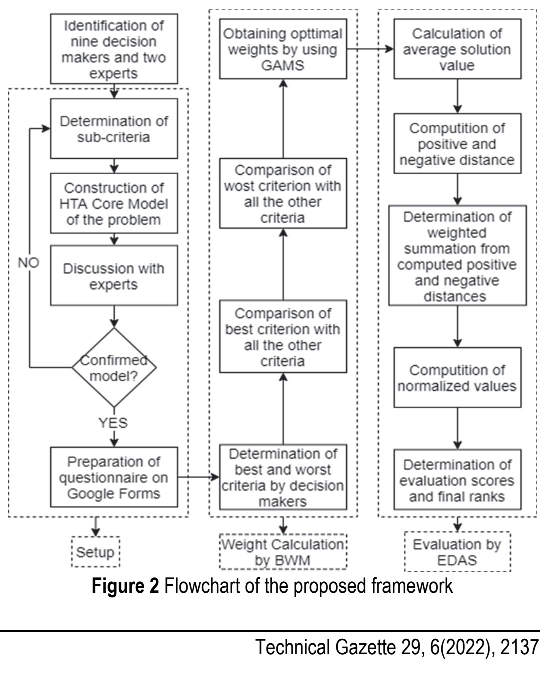

Figure 2 Flowchart of the proposed framework

The results of the applied models, evaluation scores were computed as 0,673; 0,538, and 0,500 for WJM, LBM, and EC, respectively. The most optimal technology in tissue cutting is WJM within the frame of HTA Model dimensions and criteria.

Application steps for BWM and EDAS methodologies can be summarized in detail as follows.

3.1 Application of BWM Methodology

Step 1: The set of evaluation criteria were determined for the related decision problem. For this study, Fig. 1 presents the proposed HTA Core Model that includes six main criteria and twenty-two sub-criteria to determine the most appropriate NTM technology.

Step 2 and Step 3: The best i.e., most important criteria, and the worst i.e., least important criteria were determined by nine experts.

Then, the preference of the best criterion overall the other main criteria was determined using a number between 1 and 9. As a result of this step, a vector called Best-Others (A_B) was gained for the main criteria, which advances from the best to the others.

Furthermore, the same procedure was applied separately for the sub-criteria of each main criterion. The result of this step a vector called Best-Others (A_B) was reached for sub-criteria of each main criterion $A_B = (a_{B1}, a_{B2}, ..., a_{Bn})$.

Step 4: The preference of all main criteria over the worst main criterion was determined using a number between 1 and 9. As a result of this step, a vector called Others-Worst A_W was gained for the main criteria, which advances from others to the worst.

Also, the same procedure was applied separately for the sub-criteria of each main criterion. As a result of this step, the worst vector was reached $A_W = (a_{W1}, a_{W2}, \dots, a_{Wn})$ for the sub-criteria of each main criteria.

Step 5: In the last step, the most appropriate weights for each main criterion and sub-criterion were determined by solving a linear programming model. After that, arithmetic mean was used to find out the common weight of each criterion to incorporate experts' evaluations. The final optimal weights of the main criteria are presented in Fig. 3. Also, the final optimal weights of all sub-criteria are shown in Fig. 4.

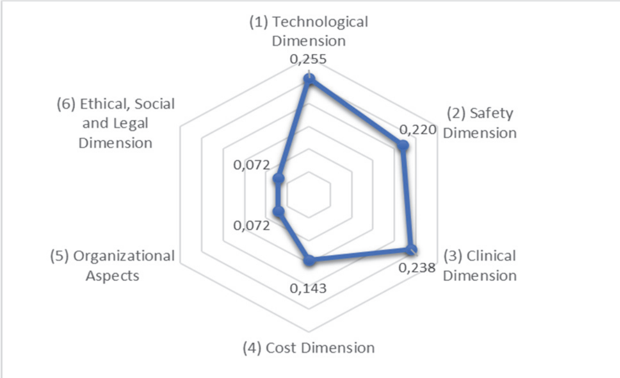

Figure 3 Optimal weights of main criteria

Figure 4 Optimal weights of sub-criteria

3.2 Application of EDAS Methodology

Step1: Firstly, the data obtained verbally from nine experts was translated into triangular fuzzy numbers in Tab. 1. In order to create the final decision-making matrix, the arithmetic mean of the fuzzy values entered by each DM was taken. The reason for using the arithmetic average is that the DMs give the values about the devices close to each other.

Table 1 Linguistic terms and corresponding triangular fuzzy numbers

Linguistic variable	Corresponding Triangular Fuzzy Number
Very Low (VL)	(0, 0, 0, 1, 0, 3)
Low (L)	(0, 1, 0, 3, 0, 5)
Medium (M)	(0, 3, 0, 5, 0, 7)
High (H)	(0, 5, 0, 7, 0, 9)
Very High (VH)	(0, 7, 0, 9, 1, 0)

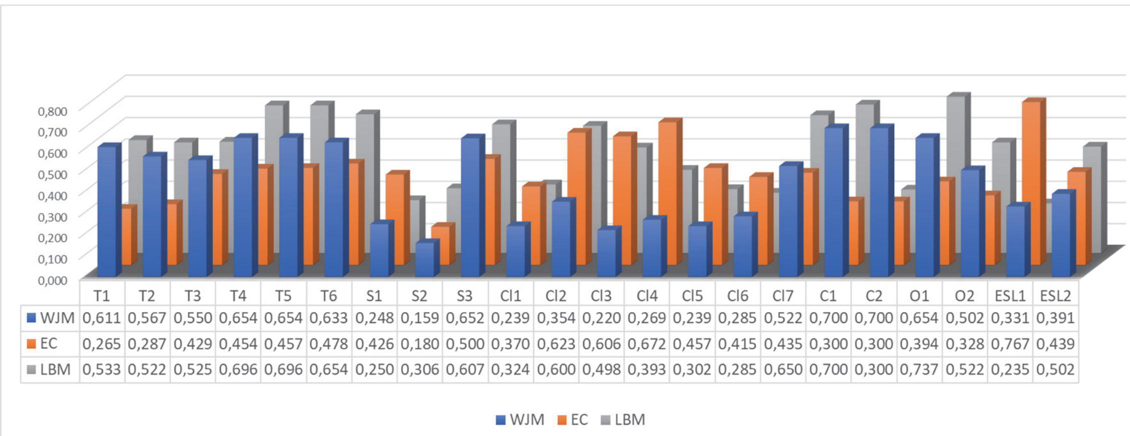

Figure 5 Crisp values calculated by GMIR method for each sub-criterion

Step 2: Fuzzy EDAS could not be used because there were unanswered data in the survey. Thus, defuzzification of triangular fuzzy numbers is accomplished using the Graded Mean Integration Representation (GMIR) method to match the standard version of EDAS. The GMIR $R(a)$ of TFN *a* represents the ranking of a triangular fuzzy number.

Let $a_i = (l_i, m_i, u_i)$, and the GMIR $R(a)$ of TFN a_i can be calculated by:

$$R(a_i) = \frac{l_i + 4m_i + u_i}{6} \tag{19}$$

Crisp data scores which were calculated according to the GMIR method are given in Fig. 5. The average solutions (AV_j) were calculated based on Step 2 and Eq. (9) in the EDAS Method part.

Step 3: Each sub-criterion is categorized as "beneficial" or "non-beneficial". The positive distance matrix from average (*PDA*) was calculated using Eq. (10) and Eq. (11). Calculations of these values were computed in Excel.

Step 4: The negative distance matrix from average (*NDA*) was calculated using Eq. (12) and Eq. (13).

Step 5: The SP_i and SN_i values are calculated for three alternatives using Eq. (14) and Eq. (15), respectively.

Step 6: The SP_i and SN_i values for three alternatives are normalized using Eq. (16) and Eq. (17), respectively (see Tab. 3).

Step 7: Finally, the evaluation scores (AS_i) for three alternatives are calculated using Eq. (18).

Finally, three devices (alternatives) were ranked based on evaluation scores that were shown in Tab. 3. The alternative with the highest evaluation score was selected as the best alternative.

As a result, in our problem, the most suitable device for tissue cutting operation was found to be the WJM with the highest score. The second highest score belonged to the LBM device. The third and the lowest one was found as EC.

Table 3 Result table for NTM Technology Selection Problem

	SP_i Values	SN_i Values	NSP_i	NSN_i	AS_i	Rank
Water Jet	0,122	0,085	0,819	0,526	0,673	1
Electrocautery	0,148	0,180	1,000	0,000	0,500	3
Laser Beam Machining	0,089	0,094	0,600	0,476	0,538	2
Maximum of SP_i and SN_i	0,148	0,180				

4 DISCUSSION AND CONCLUSION

According to the research done so far, it is an undeniable fact that NTM is an advanced type of machining which is becoming quite important in modern engineering and its applications areas are getting increased. One of these fields where NTM is preferred is healthcare where medical equipment requirements are difficult to meet with standards and it carries significant importance. It is seen that there are continuous developments in different health fields and in different countries with the evaluation of the NTM processes and especially the applications of the 3 processes in the healthcare field.

In this study, an MCDM framework combining BWM and EDAS methods based on HTA Core Model is proposed for evaluating WJM, LBM, and EC devices, which are the most widely used technologies in tissue cutting operations in the healthcare field. Data were gathered from nine experts who are specialized in different fields and have extensive knowledge about these devices. As a result of the proposed HTA based MCDM framework, it is understood that WJM has more advantages in tissue cutting operations compared to the other technologies.

During the study, support was received from operators and specialist physicians working in a private hospital. In the first stage, the criteria based on dimensions of the HTA Core Model were created with the support of the studies in the published literature, they were finalized as a result of face-to-face interviews and discussions with the experts working in this field at the hospital. In the second phase, questionnaires were prepared based on the criteria created, answers were obtained through face-to-face interviews with the operators, weighting was made using the BWM method for the dimensions and criteria with the relevant answers. By using the determined weights, in order to be able to rank the technologies and to determine the most suitable technology in accordance with the purpose of this study, the ranking was made with the help of the EDAS method.

Since some criteria do not correspond to a numerical value, the data were taken from experts as linguistic expressions, using triangular fuzzy numbers to apply the established model, numerical values were assigned to linguistic expressions and included in the model. Another issue is that data could not be obtained as numerical data from the DMs for the cost dimension in the HTA Core Model. Therefore, several biomedical officers gave data in terms of very low, low, medium, high, and very high for three devices.

In conclusion, although electrocautery is the most preferred device in Turkey, with the proposed MCDM-based HTA evaluation framework, it has been understood that the more technologically advanced WJM is more advantageous in tissue cutting operations.

Moreover, in the scope of this study, the variety and importance of the NTM processes are investigated to capture the developments in the field of tissue cutting operationsThere are many NTM processes and their usage areas in industries such as automotive, aerospace, electronics, and medical. With the awareness of the medical sector as one of the most vital sectors around the world and the consideration of the developing technology, it can be concluded that studies on EC, LBM, and especially WJM are not sufficient at the national level so it is recommended that the studies on these technologies and their use in different operations should be increased.

It is noteworthy that most of the studies on electrocautery, LBM and WJM belong to European countries, India and America. The diversity and importance of NTM studies to catch up with the developments in the field of tissue cutting operation are clearly stated in this study. Depending on the need, the diversity of processes has the potential to increase even in a certain area. Hence, this study is expected to be a guide to all stakeholders in this field. Within our knowledge, although there are many studies in the literature referring to NTM technologies, no studies were evaluating these technologies within the framework of HTA and MCDM, especially in the field of health. Therefore, this paper is expected to show the applicability of MCDM and HTA methods in the field of health and to throw light on future studies.

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Contact information:

Elif DELİCE
(Corresponding author)
Istanbul Topkapı University,
School of Economics,
Administrative and Social Sciences,
Department of Management Information Systems,
34087, Istanbul, Turkey
E-mail: elifdelice@topkapi.edu.tr

Hakan TOZAN, Prof. Dr.
Istanbul Medipol University,
School of Engineering and Natural Sciences,
Department of Industrial Engineering,
34810, Istanbul, Turkey
E-mail: htozan@medipol.edu.tr

Melis Almula KARADAYI, Asst.Prof. Dr.
Istanbul Medipol University,
School of Engineering and Natural Sciences,
Department of Industrial Engineering,
34810, Istanbul, Turkey
E-mail: makaradayi@medipol.edu.tr

Marta HARNIČÁROVÁ, PhD, M. Eng.
1) Department of Electrical Engineering,
Automation and Informatics,
Faculty of Engineering,
Slovak University of Agriculture in Nitra,
Tr. A. Hlinku 2, 949 76 Nitra, Slovakia
E-mail: marta.harnicarova@uniag.sk
2) Institute of Technology and Business in České Budějovice,
Faculty of Technology,
Department of Mechanical Engineering,
Okružní 10, 370 01 České Budějovice, Czech Republic
E-mail: harnicarova@mail.vstecb.cz

Başak TURAN
Istanbul Medipol University,
Graduate School of Engineering and Natural Sciences,
34810, Istanbul, Turkey
E-mail: basak.turan2@std.medipol.edu.tr