

**BAŐKENT ÜNİVERSİTESİ**  
**FEN BİLİMLERİ ENSTİTÜSÜ**

**DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR**  
**PURCHASING OF DENTAL IMPLANTS**

**Funda G. ÖZDİLER ÇOPUR**

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**DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR  
PURCHASING OF DENTAL IMPLANTS**

**DENTAL İMPLANTLARIN SATINALINMASINDA  
KULLANILACAK KARAR DESTEK SİSTEMİ  
GELİŞTİRİLMESİ**

**Funda G. ÖZDİLER ÇOPUR**

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Öğrencinin Adı, Soyadı : Funda Güler ÖZDİLER ÇOPUR

Öğrencinin Numarası :21410173

Anabilim Dalı :Biyomedikal Mühendisliği Ana Bilim Dalı

Programı :Biyomedikal Mühendisliği Yüksek Lisans

Danışmanın Adı, Soyadı :Prof.Dr. Dilek ÇÖKELİLER SERDAROĞLU

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## **ABSTRACT**

### **DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR PURCHASING OF DENTAL IMPLANTS**

Funda Güler ÖZDİLER ÇOPUR

University of Baskent Institute of Science

Department of Biomedical Engineering

Most attractive treatment option for the replacement of missing teeth is Dental implants. Dental implantation is a very troublesome process since there are a lot of factors affect the success of implantation. While some factors may depend on patient related parameters, others may depend on surgeon and dental implant design. One of the significant parameters is the quality of dental implants. Therefore, it is very important to choose the one which has the best quality and optimum price as well. There are a few dental implant brands placed on Turkish market, but it is very struggling for hospitals to find a standardized way to select appropriate suppliers or brand according to the specific needs and requirements of dentists.

In this thesis, a procurement tool has been designed by using Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), MCDA method, to facilitate decision making for procurers and prove that lowest priced brand might not be the best option to purchase.

**KEYWORDS:** Decision making tools, TOPSIS, dental implant selection, most economically advantageous tender, health policy

**Advisor:** Prof. Dr. Dilek Çökeliler Serdaroğlu

**Co-Advisor:** Assoc. Prof. Dr. Yusuf Tansel IC



## ÖZ

### **DENTAL İMPLANTLARIN SATINALINMASINDA KULLANILACAK KARAR DESTEK SİSTEMİ GELİŞTİRİLMESİ**

Funda Güler ÖZDİLER ÇOPUR

Başkent Üniversitesi Fen Bilimleri Enstitüsü

Biyomedikal Mühendisliği Ana Bilim Dalı

Kaybedilen dişleri yerine koymak için en doğru tedavi seçeneği Dental implantlardır. Dental implant tedavisi oldukça zahmetli bir işlemdir. Çünkü implantasyonun başarısını etkileyen birçok faktör vardır. Bazı faktörler hastayla ilgili parametrelere bağlı olsa da, bazıları ise cerrah ve dental implant tasarımına bağlıdır. Buradaki en önemli parametrelerden biri diş implantının kalitesidir. Bu nedenle, en iyi kalitede ve en uygun fiyata sahip olan dental implantı seçmek çok önemlidir. Türkiye pazarına arz edilen çok fazla sayıda dental implant markası vardır, ancak hastaneler tarafından, dişhekimlerinin ihtiyaçlarına ve gereksinimlerine göre uygun tedarikçi veya marka seçimi için sistematik bir yol belirlemek oldukça zordur.

Bu tezde, tedarikçiler için karar vermeyi kolaylaştırmak ve en düşük fiyatlı markanın her zaman en iyi seçenek olamayacağını kanıtlamak için ÇKKV yöntemlerinden İdeal Çözüme Yakınlık ile Sıralama Tercihi Tekniği (TOPSIS) kullanılarak bir satın alma aracı tasarlanmıştır.

**ANAHTAR SÖZCÜKLER:** Karar destek araçları, TOPSIS, dental implant seçimi, en ekonomik ve avantajlı ihale, sağlık politikası

**Danışman:** Prof. Dr. Dilek Çökeliler Serdaroğlu

**Eş danışman:** Assoc. Prof. Dr. Yusuf Tansel İÇ

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## ABBREVIATIONS

MCDA	Multiple Criteria Decision Analysis
YLD	Years Lived with Disability
MATLAB	Matrix Laboratory
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
DM	Decision Maker
PIS	Positive Ideal Solution
NIS	Negative Ideal Solution
GUI	Graphical User Interface
AHP	Analytical Hierarchy Process
NICE	National Institute for Health and Care Excellence
CADTH	Canadian Agency for Drugs and Technologies
IQWiG	German Institute for Quality and Efficiency
HTA	Health Technology Assessment
dPRO	Dental Patient Reported Outcome
OHIP	Oral Health Impact Factor
CE	Conformité Européenne
FDA	USA Food and Drug Administration
EU	European Union
PMA	Premarket Approval
HDE	Humanitarian Device Exemption
SLA	Sand Blasted Acid Etch
SAW	Simple Additive Weighting
PROMETEE	Preference Ranking Organization Methods for Enrichment Evaluations
OHRQoL	Oral Health Related Quality of Life
GL	Gingival Level





## 1. INTRODUCTION

Multiple Criteria Decision Analysis (MCDA) is a decision methodology, incorporates identifying the criteria relevant to the decision and determining their relative importance, or 'weights'. MCDA is utilized for addressing complex problems with high uncertainty, conflicting objectives, and heterogeneous interests.[1] MCDA tools have been developed to support decision makers in order to perform more rational, transparent and efficient decisions.

MCDA first appeared in 1960s and has grown significantly since 1976 by Keeney and Raffia's book. Following the years of this book publication, increasing numbers of applications of MCDA has been applied and adopted by both private and public sectors in different areas such as product design, health "technologies" funding (i.e., drugs, devices, procedures, etc.), economic evaluation of disease management programs, healthcare infrastructure location etc. MCDA can be utilized either prospectively or retrospectively.[2][3][4]

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a MCDA approach to rank alternatives from a definite set of alternatives. The essential idea behind TOPSIS is to calculate the options concurrently by measuring their distances to the-positive-ideal solution (PIS) and to the negative-ideal solution (NIS) [5]. NIS is the least preferred solution and PIS might be considered the most preferred by the decision maker (DM) since it maximizes the benefit criteria and minimizes the cost criteria. The options are put in order according to the relative proximity of the other possible substitutes to PIS, which is a measurable attribute that combines these two distance measures. TOPSIS has been utilized in this study because TOPSIS is well-suited as supplier selection and easy to implement in selected software language MATLAB.

"The Global Burden of Disease Study 2016" anticipates that serious tooth loss and edentulism (the absence or complete loss of all natural) is one of the outstanding ten causes of Years Lived with Disability (YLD) in some countries. Dental implants are the most appropriate and permanent treatment for the replacement of missing teeth. The quality of dental implants has the utmost importance to decrease risk factors might be encountered after or during treatment which will bring extra

expenses. Within this respect, hospitals or procurers have the prominent responsibility while purchasing dental implants with the existence of scarce financial resources. It is quite difficult for procurers to make fair decisions and find a systematic way to select appropriate supplier or brand according to the specific needs and requirements of experts and almost all the procurers struggle while buying dental implants which has the best quality and optimum price.

Therefore, an adoptable procurement tool is proposed with aim of determining appropriate implant brands by using the method of MCDA to carry out the most advantageous tender for dental hospitals. Additionally, MATLAB based procurement tool explicitly developed for dental implants makes this study unique. Within this aim and motivation, previously collected experts' opinion and market research data are utilized to structure the database which will be input for the execution of TOPSIS. We further require from hospitals to realize a tender by using MATLAB based procurement tool. Based on the real case study, results are discussed then from the perspective of both private and university hospitals.

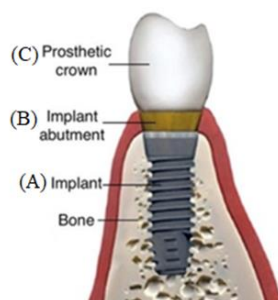


Figure 2.1 Components of Dental Implant [85]

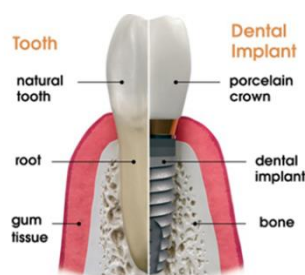


Figure 2.2 Dental Implant Comparison with Natural Teeth [85]

## **2. BACKGROUND**

### **2.1. Dental Implant**

One of the most frequently used treatments for teeth lost due to caries, periodontal diseases or injuries, is dental implants. Dental implant is kind of a tooth root surgically screwed into mandibular or maxillary jawbone(A). Surgically placed artificial tooth root become a bulky base for supporting one or more artificial teeth, called crowns. Prosthetic tooth crown is supported with a connection called abutment (B). On top of the dental implant

Abutment is placed on top of the dental implant root to hold and support crowns. The crowns are produced custom-made and fit the mouth of patient. Figure 2.1 and 2.2.

### **2.2. Implant Design Parameters Determined by Expert Groups**

As of today, approximately 1300 different implantation systems exist in different shape, size, thread design, surface topography, surface chemistry, wettability, and surface modification [7]. In this study, only the criteria which are determined by our expert group have included. Criteria determined by expert group are: 1) Gingival Level, 2) Mini Implant, 3) Performance, 4) Implant Diameter (mm), 5) Implant Loading Time, 6) Implant Length (mm)

#### **2.2.1. Gingival Level Implants**

Gingival Level (GL) dental implant is in conical shape. It has an internal hex connection. The implant is equipped with a micro grooved collar for cortical maintenance and has a polished rim to hold soft tissues. Implants of the GL range have the same platform dimensions, although, it has different diameters and this specification allows for a simplified prosthetic protocol [3].

#### **2.2.2. Mini Implants**

Mini dental implants are known as narrow diameter diameter implants. Mini implants differ from traditional implants with the specialty of being only one solid body. This solid piece screws into the bone with a diameter smaller than 3mm most of the time.

Mini implants are generally designed to be used in two pieces, the anchor is linked with the abutment, and the crown is placed on the abutment. On the top of the device is a ball-shaped protrusion, which helps to hold and support dentures. The main aim of using mini implants is stabilizing lower total denture. Mini dental implants are commonly used in orthodontics with a less-invasive techniques. [8] Mini implants are utilized temporarily for bone anchorage in orthodontic treatment. Osseointegration of mini implants in orthodontic treatment is not important since the mini implant will be removed as soon as treatment is finished.

### **2.2.3. Implant Loading Time**

Once dental implant has been screwed, it will take about 3-6 months to heal. This time is longer in upper jaw than lower jaw. During healing period, the bone fuses around new implant process known as osseointegration. In routine, prosthetic crown is loaded over abutment after osseointegration. Misch has recommended a protocol, for progressive loading of dental implants which based on the observation of bone density. [9]

### **2.2.4. Implant Diameter**

Implant size is one of the critical factors influences stress distribution in surrounding jawbone. According to the catalogs and instruction for use, collected from companies, size of an implant can be defined by length in min:3.0, max:18.0 mm, and by diameter ranges min:2.5, max:15 mm. The choice of implant diameter depends on the amount of space available for the prosthetic reconstruction, the volume of the residual bone, and the type of occlusion. If the bone quality is low, the implant length and/or diameter should be considered carefully to achieve higher primary stability. [8]

### **2.2.5. Implant Length**

The optimum length of an endosteal implant is in the range of 8-12 mm. This range is suitable to withstand against the horizontal forces of occlusal loads, with bone adaptation at the bone-implant interface. Horizontal and vertical forces are generated during chewing. The forces generated in the vertical direction can be tolerated, horizontal direction forces are undesirable because this will affect the

stability of the implant. Thus, implant length is a determining factor to achieve more primary stability if low bone quality exists [8].

### **2.3. Osseointegration**

In 1985 Brånemark et.al defined the term osseointegration as “a direct structural and, functional connection between related living bone and the surface of a load - carrying implant” [11]. Osseointegration is demonstrated in two steps: Primary osseointegration occurs in the short term just after the implant is placed. Secondary osseointegration is observed when bone growth around the implant.[10] Insufficient osseointegration can occur the formation of fibrous tissues and causing to loose of the dental implants.[12] In 1981, osteointegration is identified under the consideration of six parameters by Albrektsson et al. (i) bone quality/quantity, (ii) implant surface, (iii) technique of surgery, (iv) design of implant, (v) implant material and (vi) loading conditions.[13] Bone quality/quantity, loading conditions and technique of surgery are out of the scope of this thesis.

### **2.4. Dental Implant Surface Properties**

The topography of the implant surface influences biomechanical locking with the bone named osseointegration. Implant surface properties are vital for osseointegration. Surface roughness is achieved by including substances such as titanium plasma spraying (TPS) and Hydroxyapatite (HA) to the surface. As a common fact rough implant surfaces provide better osseointegration compared with smooth surfaces. On the other hand, considering results from various studies show that the number of standardized and qualified researches should be increased to ensure which surface material is the ideal combination for osseointegration [7]. In this thesis we used fifteen different surface material properties as criteria in elimination phase : 1)Unpolished Surface, 2) Sandblast Surface, 3) Polished Surface, 4) Titanium Porous Oxide, 5) Acid Etching, 6) Resorbable Blast Media, 7) Sand Blast Large Grit Acid Etch, 8) Titanium Plasma Sprayed, 9) Biphasic Calcium Phosphate, 10) Anodic Oxidation, 11) TiO<sub>2</sub> blast + fluoride hydrofluoric acid, 12) Hydroxyapatite, 13) Wet Shot Blasting, 14) Soluble Blast Media, 15) Blasted with HA.

### 2.4.1. Plasma spraying

In order to enhance bioactivity of implant material, one of the most frequently used methods is Plasma-spraying. In this method,  $\text{Ca}_3(\text{PO}_4)_2$  coatings, such as hydroxyapatite (HA) is used for deposition. The density of HA coatings produced by plasma-spray. With plasma spraying procedure the surface area of titanium implant has increased up to around six times bigger than the original area. The documented responses of bone tissue to plasma sprayed HA coatings on titanium implant are satisfying when compared HA-coated implants with titanium implants, several experimental studies have demonstrated higher percentage of bone-implant contact for HA coated implants in different types of bones. [14].

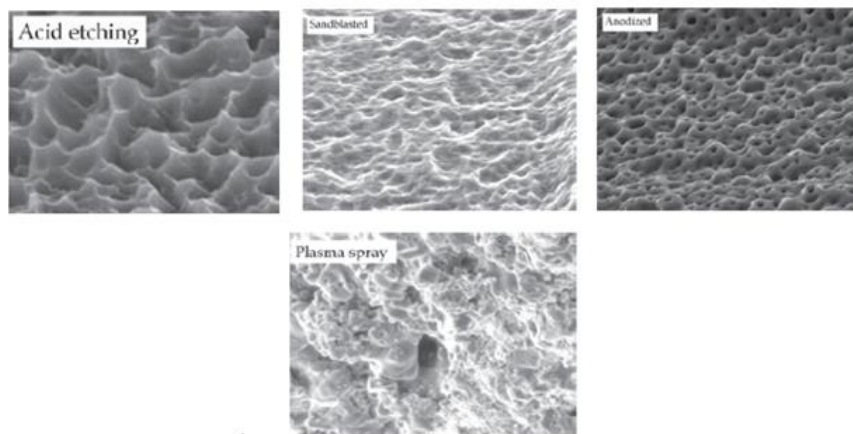


Figure 2.3 Acid Etching, Sandblasted, Anodized and Plasma Spraying Surfaces [19]

### 2.4.2. Acid Etching

It is possible to roughen dental implant surfaces by creating micro pits between 0.5um to 2 um in diameter with strong acids like HCl,  $\text{H}_2\text{SO}_4$ ,  $\text{HNO}_3$  and HF produces. Micro rough surface is produced by immersing titanium implants in concentrated solution of HCL and  $\text{H}_2\text{SO}_4$  when heated over  $100^\circ\text{C}$  which is called as dual acid etching. Dual acid-etching fasten osteoconductivity, by directly forming bone on the surface of the implant, through fibrin and osteogenic cell attachment. Cho et al. confirm that aforementioned procedure increases osseointegration and support success of implant treatment in the long run. [17]

### **2.4.3. Anodization**

Anodization or anodic oxidization is an electrochemical process occurs in an electrolyte. In this process oxide films are deposited on Ti implant surface and it is possible to thicken the oxide layer more than 1000 nm on Ti. In order to improve the osseointegration, according to Hall et al. different ions could be added in the oxide layer, such as phosphorous, calcium as mentioned by Frojd et al., and magnesium experimented by Sul et al. [16] Anodic oxidation results in the growth of a native titanium oxide layer and a porous topography, with the bone formation occurring directly on the moderately rough oxidized surface. [75]

### **2.4.4. Sand Blasted Acid Etched (SLA) Treatment**

Dental implants already placed on different markets, are usually both blasted by particles and afterwards etched by acids subsequently. This procedure is performed to obtain both a dual surface roughness and removal of embedded blasting particles. The etching causing reducing the highest peaks and creating smaller pits, therefore average surface roughness will be reduced. Sand blasted acid etched surfaces have a hydrophobic surface, but new SLA active implants have a hydrophilic surface which provides stronger bone response. Several studies have shown that when compared with SLA implants, SLA active implants achieve higher stability and bone linkage at earlier time (6 weeks), and additionally reduce healing time from 12 to 6 weeks. [16]

### **2.4.5. HA Coating**

In 1980s Hydroxyapatite coatings were introduced by Furlong et al. firstly for improved fixation between bone and implant. Since then HA is one of the most used materials that may form a direct and strong bonding between the implant and bone tissue. [14] Thomas et al. has shown improved bone formation around HA-layered implants in dogs when compared with non-coated implants. The bone implant interface presents better formation compared to other implant materials and with improved mineralization. [17]

There isn't any standardized manufacturing process guideline exists for depositing Hydroxyapatite on implant surfaces. Although, advantages of using Hydroxyapatite coated implants are documented in animal and in vitro studies, it also explained that detachment of HA-coating did not cause implant loss in short term. Moreover, many clinical studies did not include the chemical and structural characterization of the coatings. Therefore, comparisons between studies are almost impossible. In dental practices, it is recommended that HA-coated screw implants should be used for the anterior maxilla and posterior mandible where the bone depth exceeds 10 mm and when the cortical layer is thinner and spongiosa is less dense. When the cortical layer is very thin with low density, the use of HA-coated cylindrical implants is recommended. On the other hand, there are other hesitations regarding to use of HA-coated implants. The dentist has to consider the improved bacterial tendency of Hydroxyapatite coatings in comparison to titanium implants. Moreover, one of the common failures of Hydroxyapatite coating-substrate interface fracture has to be taken in to account by dentist. [75]

#### **2.4.6. Titanium Porous Oxide**

The mineral form of titanium dioxide ( $\text{TiO}_2$ ) is one of the most common crystalline forms of  $\text{TiO}_2$  which is generally manufactured by oxidation of titanium by means of anodizing or thermal oxidation.[18]

#### **2.4.7. Calcium Phosphate**

$\text{Ca}_3(\text{PO}_4)_2$  coatings, mainly composed by HA, has been used as osteoconductive, biocompatible and resorbable blasting materials. Clinical use of HA depends on using a material with a similar chemical composition. The mineral phase of the bone can avoid connective tissue encapsulation and supports peri-implant bone apposition.[19] Similar to the behavior of mineral phase of the bone,  $\text{Ca}_3(\text{PO}_4)_2$  coatings reveal osteoconductive properties allowing for the formation of bone on its surface by differentiation, migration, and proliferation of bone-forming cells. [76]



#### **2.4.8. Surface Treatment with Fluoride**

Fluoride ions have known because of their osteoinductive behaviour dominating to advance bone calcification. Biphasic nature is a well-known characteristic of fluoride. Fluoride has useful effects when used in low densities whereas toxic effects as well when used in high densities. Fluoride can provide vast amount of cortical and trabecular bone when used in therapeutic doses. If used in exaggerated doses, it can cause bone deficiency in collagen crosslinks and with increased solubility. Fluoride increases differentiation of osteoblasts, and proliferation, improves alkaline phosphatase and collagen synthesis. [77] Additionally, in this study combinations are also used such as TiO<sub>2</sub> blast + fluoride hydrofluoric acid, and Sandblast + Acid etch. In addition to aforementioned properties, patient-based risk factors such as not having acceptable supporting bone quality, smoking, diabetes, osteoporosis or periodontitis is the other factors can affect implant success.

#### **2.5. Bone Status and Other Factors Affecting Implant Success**

Bone identified as an organ that is capable of changing depending on a number of factors, such as vitamins, hormones, and mechanical parameters. Regardless of the high success rates of implant therapy, certain risk factors related with individuals such as smoking, diabetes or periodontitis can cause patient to lower success rates. An inevitable requirement for dental implant therapy is an acceptable supporting bone quality with optimal height, width, and density. Additionally, osteoporosis represents an important chronic disease in which bone density is affected by an excessively fast degradation of hard tissue structure. A limited use of dental implants should be expected, related to the osteoporotic changes of the bone structure [22]. To ensure the bone quality and minimize the risks before initiating the treatment, our experts insisted on having Cone Beam Computerized Tomography (CBCT) images as a must before making any decision.

As a general inference from the literature research, it has to be noted that implant success is not only depends on optimal implant brand selection but also related with the patient overall condition, clinician experience and socioeconomic factors such as income rate of the patient. Some of the useful studies we utilized are summarized as follow;

Pye et. al. classify dental implant failure factors under five main categories: 1) Implant Factor (surface roughness and sterility, oral exposure time, early loading), 2) Mechanical Overloading (traumatic occlusion due to inadequate restorations), 3) Patient-oral Factors (oral hygiene, gingivitis, bone quantity/quality, adjacent infection/inflammation, Periodontal status of natural teeth), 4) Patient-systemic Factors(smoking addiction, alcohol abuse, obesity, steroid therapy, malnutrition, diabetes, age), 5) Surgical technique/environment (Perioperative bacterial contamination, e.g. via saliva, instruments, gloves) [26]. Derks et.al showed that, performed on 3361 patients selected randomly from national data registry of the Swedish Social Insurance Agency, the ratio of early implant loss (nine years before implantation) in smokers is 2,2% whereas, 0,9 in nonsmokers. Early loss ratio for the implants shorter than 10mm is 3%, while it is 1, 2% for the implants  $\geq$  10mm. No information shared for the ratio of late implant loss (nine years after implantation) regarding smoking and implant length. In the same study early loss ratio (0.7%, 1.3%, 1.5% and 3.5%) and late loss ratio (0.5%, 2.4%, 2.5% and 3.8%) have been shared belong to four implant brands which are also exist in our database. In the same study, the difference among those four brands might be occurred because of progressive marginal bone, damages on the interface between the implant and the bone tissue, or harm to the implant, including implant fracture [23]. The literature review carried out by Porter et.al mentions the four criteria, which we included in our study too, as the success factor of dental implantation: size, surface properties and implant loading time [24]. The study by Karthik et.al titled "Evaluation of implant success: A review of past and present concepts", claims that "A wider implant has long-term success than a narrow implant. Patient-systemic factors and smoking addiction are significant parameters affect the implant treatment success and stability. [25]

## **2.6. Decision Making**

Decision making is kind of a tool to support decision makers while considering alternatives based on desires and/or values. Decision making facilitates the process of analyzing decision problems by breaking them down into more manageable parts. Making a decision suggests that there are other options to be considered, and in such a case decision makers don't want to identify as many of these options as

possible but also to choose the one that best fits with the needs, objectives and values.[27] According to Baker's study decision making should start with the determination of stakeholders, then continue coming to a consensus on problem definition, defining the requirements, goals and criteria. Depends on Baker's study, general decision making steps can be summarized as in Table 2.1. [27]

Table 2.1. General Decision Making Process

Decision Making Process
1. Identifying the problem
2. Determine requirements
3. Establish goals
4. Determine alternatives
5. Determine criteria
6. Select a decision making tool
7. Evaluate other options against criteria
8. Validate solutions against problem statement

### 2.6.1. Multiple Criteria Decision Analysis (MCDA)

Multiple criteria decision analysis (MCDA) suggests selections among alternatives from a definite set of criteria identified by decision making bodies. MCDA offers a number of methods of identifying the data on individual criteria to provide indicators of the overall performance of options. MCDA might be utilized either retrospective studies to evaluate outcomes have already been presented or exist, or prospectively to assess data or outcomes that are revealed recently or real time. [2] While an optimal solution can be obtained from a definite objective in classical decision making models, decision theory helps to find satisfactory solutions for real life problems. MCDA is a decision support tool focusing on complex problems involving various forms of data, conflicting objectives, high uncertainty and heterogeneous interests [1]. MCDA first appeared in the 1960s and it has grown significantly since

1976 by Keeney and Raffia's book. Following the year of 1976, increasing numbers of applications of MCDA has been used and implemented by both private industry and governmental authorities in different areas of health such as product design, health “technologies” funding (i.e., drugs, devices, procedures, etc.), economic evaluation of disease management programs, healthcare infrastructure location, service quality assessment, coverage decisions etc. [3][4].

Different kinds of methods are available to solve MCDA problems are taken into consideration to achieve the optimal decision. The most utilized methods of MCDA in the literature is the Analytic Hierarchy Process (AHP), the Simple Additive Weighting (SAW), the Preference Ranking Organization Methods for Enrichment Evaluations (PROMETHEE), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the Weighted Product Model (WPM), the Analytic Network Process (ANP), the Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR), and the Elimination Et Choix Traduisant la Realite (ELECTRE).[28]

### 2.6.1.1. MCDA in Healthcare and Biomedical Applications

MCDA methods can be utilized in various areas of healthcare. Table 2.2 shows some of the studies performed in last eight year period.

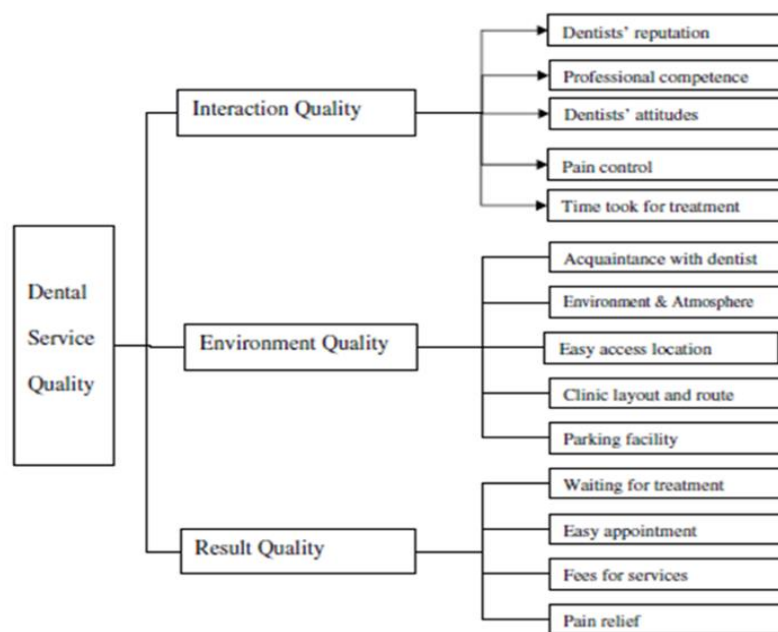


Figure 2.4 Classification Diagram, Quality Assessment of Dental Clinics [63]

Table 2.2 The List of Last Eight Years Studies in Health Care

Author(s)	TITLE	TOPIC
Büyükoçkan et al.(2011) [29]	Strategic analysis of healthcare service quality using fuzzy AHP methodology	Healthcare service quality
Mirfakhreddiny et al.(2011) [30]	Identification and ranking of factors affecting quality improvement of health & treatment services using Multiple Attribute Decision Making (MADM): a case study.	Quality improvement in healthcare & treatment services
Kuo et al.(2011) [31]	Improving outpatient services for elderly patients in Taiwan	Outpatient services for elderly patients
Danner et al.(2011) [32]	Integrating Patients' Views into Health Technology Assessment: Analytic Hierarchy Process (AHP) as a Method to Elicit Patient Preferences	Integrating Patients' Opinion into HTA
Wijk et al.(2012) [33]	A Comparison of Two Multiple-Characteristic Decision-Making Models for the Comparison of Antihypertensive Drug Classes	Antihypertensive Drug Classes
Bahadori et al.(2012) [34]	Priority of Determinants Influencing the Behavior of Purchasing the Capital Medical Equipments using AHP Model	Purchasing the Capital Medical Equipments
Miah et al.(2013) [35]	An Approach of Purchasing Decision Support in Healthcare Supply Chain Management	Healthcare Supply Chain Management
Zeng et al.(2013) [36]	VIKOR Method with Enhanced Accuracy for Multiple Criteria Decision Making in Healthcare Management	Healthcare Management
Lu et al.(2013) [37]	Improving RFID adoption in Taiwan's healthcare industry based on a DEMATEL technique with a hybrid MCDM model	Acceptance of RFID application in Taiwan's healthcare system
Pecchia et al.(2013) [38]	User needs elicitation via analytic hierarchy process (AHP). A case study on a Computed Tomography (CT) scanner	Computed Tomography (CT) scanner
Abolhallaje et al.(2014) [39]	Assessing Health Inequalities in Iran: A Focus on the Distribution of Health Care Facilities	Distribution of Health Care Facilities
Ahmadi et al.(2014) [40]	Fuzzy Multi-Criteria Approaches for Evaluating the Critical Factors of Electronic Medical Record Adoption	Critical Factors of Electronic Medical Record Adoption
Tadić et al.(2014) [41]	The evaluation and ranking of medical device suppliers by using fuzzy topsis methodology	Ranking medical device providers
Djordjevic et al.(2014) [42]	Evaluation and Ranking Of Artificial Hip Prothesis Suppliers by using a Fuzzy TOPSIS Methodology	Ranking Artificial Hip Prothesis Suppliers
Chen et al.(2014) [43]	Development of a Decision Support Engine to Assist Patients with Hospital Selection	Hospital Selection
Dubey et al.(2015) [44]	Supplier selection in blood bags manufacturing industry using TOPSIS model	Blood Bag Producers Selection
Ivlev et al.(2015) [45]	Method for selecting expert groups and determining the importance of experts' judgments for the purpose of managerial decision-making tasks in health system	Management Level decision-making duties in healthcare system
Ivlev et al.(2015) [46]	Multi-criteria decision analysis for supporting the selection of medical devices under uncertainty	Selection of medical devices under uncertainty
Mosadeghrad et al. (2015) [47]	Prioritizing Factors Influencing Medical Equipment Purchase in Selected Hospitals in Tehran	Prioritizing Factors Influencing Medical Equipment Purchase
Ortiz Barrios et al. (2016) [48]	An AHP-Topsis Integrated Model for Selecting the Most Appropriate Tomography Equipment	Most Appropriate Tomography Selection
Ahmadi et al.(2016) [49]	Ranking the Meso Level Critical Factors of Electronic Medical Records Adoption Using Fuzzy Topsis Method	Meso Level Critical Factors Ranking for Electronic Medical Records Acceptance
Larasati et al.(2016) [50]	Development Decision Support System of Choosing Medicine Using TOPSIS Method (Case Study: RSIA Tiara)	Choosing Medicine
Nag et al. (2016) [51]	A Fuzzy TOPSIS approach in multi-criteria decision making for supplier selection in a pharmaceutical distributor	Supplier selection in a pharmaceutical distributor
Singh et al. (2017) [52]	Measuring healthcare service quality from patients' perspective: using Fuzzy AHP application	Measuring healthcare service quality
Lee et al. (2017) [53]	Performance Evaluation of Medical Device Manufacturers Using a Hybrid Fuzzy MCDM	Performance Evaluation of Medical Device Manufacturers
Chen et al.(2017) [54]	Clinical Decision Support System for Diabetes Based on Ontology	Diabetes Based on Ontology
Puneeta et al.(2017) [55]	Ranking the strategies for Indian medical tourism sector through the integration of SWOT analysis and TOPSIS method	Ranking the strategies for medical tourism
Hancerliogullari et al.(2017) [56]	The use of multi-criteria decision making models in evaluating anesthesia method options in circumcision surgery	Evaluating anesthesia method options
Medeiros et al. (2018) [57]	Development of a purchasing portfolio model: an empirical study in a Brazilian hospital	Development of a procurement catalog model
Ortiz-Barrios et al. (2018) [58]	An integrated approach to evaluate the risk of adverse events in hospital sector	Evaluation of the risk of adverse events
Abdel-Basset et al.(2019) [59]	A Group Decision Making Framework Based on Neutrosophic TOPSIS Approach for Smart Medical Device Selection	Smart Medical Device Selection
Felix et al. (2019) [60]	Soft computing decision making system to analyze the risk factors of T2DM(Type2 Diabetes Mellitus)	Analyze the risk factors of Type2 Diabetes Mellitus

In the study performed by Ilev et al. a model is developed for methodological support using MRI systems. Delphi methods and Analytic hierarchy process (AHP) are used to define experts' choices. 13 different MRI brands and 14 pieces of specifications are utilized when hospitals select MRIs to procure. Strong conformity ( $W \geq 0.6$ ,  $p < 0.05$ ) within the experts' judgments was revealed. An anticipation pertaining to other options, weights and changes over the following 8 years have been presented. The model is considered useful in decision support when selecting medical devices under conditions of uncertainty by hospitals.[46]

MCDA use for material selection development performed by Jahan et. al, claims that decision-making techniques that points out objective based criteria as well as monetary and utilization criteria can help manufacturing engineers produce better informed choices of materials. Despite the improvements made in the ranking of materials for objective-based criteria, there isn't any uniform and formalized technique for evaluating the weighting dependency when objective criteria must be taken into account for material selection problems. Thus, to overcome this drawback, the approach of using dependent weightings is extended in the study.[61]

In a study performed by Girginer et. al, a real case study performed in a university hospital. Medical device buying decision steps applied in a university hospital, and priorities of the medical devices which are planned to be bought were identified via Analytic Hierarchy Process (AHP). Options are compared in terms of financial values, utilities and requirements. Options are: open bed, EMG, Hemodialysis, Neleformeter, and Colored Doppler. [62]

Another use of MCDA method is done by Tsuen-Ho et al, the assessment of the quality of dental clinics are performed by using ranking of AHP in Monte Carlo. Classification diagram. Figure 2.4.[63]

The study performed by Abdel-Basset et.al, suggests combining neutrosophics using bipolar numbers with TOPSIS under group decision making (GDM). Taken in to consideration the decisions criteria in the data collected by the decision makers (DMs), neutrosophics with TOPSIS approach is integrated in the decision making process to deal with the ambiguity, incomplete data and the uncertainty. [59]

Main goal of the she study done by Ortiz-Barrios et. al is to provide a decision-making tool to evaluate the risk of adverse events hospital services. Ortiz-Barrios used combination of AHP, DEMATEL and VIKOR methods .[58] Author claims that the tool is useful and effective to for hospitals.

Another MDCA included study is performed by Ajmera P named Ranking aim to determine strategies and priotirities for Indian medical tourism by integrating SWOT analysis in to TOPSIS method. [55]

#### **2.6.1.2. Utilization of MCDA in Different Countries**

MCDA has been implemented and adopted in therapeutic areas and various kinds of healthcare decisions, such as resource allocation, coverage and reimbursement decisions, in whole world. Since MCDA enables to measure attributes other than monetary analysis, for example cost-utility or budget impact analysis, and ensures that ethical values, epidemiological priorities and social preferences do not underestimated in the decision-making procedure.[1] The approach has been adopted and proposed by several private and public healthcare authorities like the English National Institute for Health and Care Excellence (NICE), the German Institute for Quality and Efficiency (IQWiG), the Canadian Agency for Drugs and Technologies (CADTH). Some of the promisin implementation examples mentioned in this section are related to a decision support Framework, IQWiG HTA process renovation, an HTA assessment path, Hungary's evaluation of new hospital medical technologies.

The aim of the study done by Tony et. al is assess the utility of a decision support framework (EVIDEM) and evaluate its reliability through time. Tramadol, drug for chronic non-cancer pain, is selected in this study. Depending on literature review, to provide evidence for each of the attributes, fourteen attributes for the MCDA Core Model and six qualitative attribute for the Contextual Tool, a HTA report was

published. Throughout workshops, the framework was tested in three steps by assigning: 1) weights to each criterion of the MCDA Core Model representing individual perspective; 2) scores for tramadol for each criterion of the MCDA Core Model using synthesized data; 3) qualitative impacts of criteria of the Contextual Tool on the appraisal. Utility and reliability of the framework were evaluated with discussions, test-retest and survey. Agreement between test and retest data was analyzed by calculating intra-rater correlation coefficients (ICCs) for weights, MCDA value estimates and scores. [65]

In 2010, IQWiG has started a study to analyze the implementation of MCDA methods via integrating patient outcomes into HTA process. Patient participation is getting crucial and widely taken in to consideration by different healthcare decision-making bodies. However, measurable results to determine patients' opinions for treatment endpoints are not established yet. AHP and conjoint analysis (CA) as preference-elicitation methods are utilized for use in HTA. [66]

By Radaelli et.al, a new health technology assessment (HTA) framework has been suggested. The framework, called VTS (Valutazione delle Tecnologie Sanitarie) in local language, introduced by Regione Lombardia to regulate the entering of new technologies. The HTA assessment path based on three steps; (1) prioritization of requests, (2) assessment of prioritized technology, (3) appraisal of technology in support of decision making. The HTA framework includes parameters from the EUnetHTA Core Model and the EVIDEM framework. Additionally, The HTA framework includes dimensions, topics, and issues presented by the EUnetHTA Core Model to collect data and process the assessment. However, decision-making is supported by Multiple Criteria Decision Analysis technique from the EVIDEM consortium [67]. The framework was adopted by the end of 2011 and from that time twenty-six technologies have been evaluated.

A real-life study carried out in Hungary for the evaluation of new hospital medical technologies. To evaluate six criteria determined by healthcare financing agency, MoH, clinical experts, and health economists, MDCA is utilized. Manufacturers submit a formal HTA report, including an economic analysis, clinical evaluation, key opinion leader's report, and monetary calculation. Six criteria are; healthcare priorities, severity of disease, budget impact, equity, cost-effectiveness, quality of



life and international reputation. Between 2010 and 2013, fourteen applications were in consideration using the MCDA method. Six of them were declared as supported or rejected in formal letters. Three of them were finalized as a result lack of information. Five of them are still in scrutiny.[68]

### 2.6.2. Multiple Criteria Decision Analysis: TOPSIS

One of the most frequently used MCDA methods TOPSIS has been used in this study since TOPSIS is very suitable for supplier selection and easy to code and execute in software. The methodology of TOPSIS is based on ranking alternatives from a definite set of alternatives. The methodology of TOPSIS is based on ranking the alternatives by simultaneously measuring their distances to the -positive-ideal solution (PIS) and to the negative-ideal solution (NIS). [5] PIS is the ideal solution by the decision maker (DM), whereas NIS is the least ideal solution when consider our study. In other words, PIS can be interpreted maximizing the benefit criteria and minimizing the monetary parameters, while, NIS is the least preferred solution which maximizes the monetary parameters and minimizes the benefits. The preference order is then calculated according to the relative proximity of the other options to PIS, which is a numeric attribute that combines these two distance measures.

In our study, TOPSIS advantages can be classified in three main topics: 1) A measurable value that provides for the best and worst options concurrently; 2) A simple calculation steps easy to create a simple software and 3) TOPSIS enables to use as much criteria as user demands [3]. Thus, TOPSIS is utilized in this study to create a decision support tool during procurement. Therotical background of TOPSIS expression can be summarized in 6 steps;

Step 1. Transforming decision-making matrix into a dimensionless matrix:

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^m r_{ij}^2}} \quad (2.6.2.1)$$

Step 2. Creation of a weighted dimensionless matrix with W vector assumed as an input to the algorithm.

$$\text{Dimensionless weighted matrix} = V = N_D \times W_{n \times n} = \begin{bmatrix} V_{11} & \cdots & V_{1j} & V_{1n} \\ \vdots & & \ddots & \vdots \\ V_{m1} & V_{mj} & \cdots & V_{mn} \end{bmatrix} \quad (2.6.2.2)$$

$W = [w_1, w_2, \dots, w_n]$  a weight vector, and  $w_1 + w_2 + \dots + w_n = 1$

$N_D$  is a matrix wherein the rates of the indices are dimensionless and comparable,  $W_{n \times n}$  is a diagonal matrix where only the elements of its original diameter will be non-zero.

Step 3. The positive ideal solution (PIS) and the negative ideal solutions (NIS):

$$\begin{aligned} \text{PIS} &= \{ (\max V_{ij} \mid j \in J), (\min V_{ij} \mid j \in J') \mid i = 1, 2, \dots, m \} = \{V_1^+, V_2^+, \dots, V_j^+, \dots, V_n^+\} \\ \text{NIS} &= \{ (\min V_{ij} \mid j \in J), (\max V_{ij} \mid j \in J') \mid i = 1, 2, \dots, m \} = \{V_1^-, V_2^-, \dots, V_j^-, \dots, V_n^-\} \end{aligned} \quad (2.6.2.3)$$

Step 4. The Euclidian distances from PIS and NIS is calculated.

$$d_{i+} = \left\{ \sum_{j=1}^n (V_{ij} - V_j^+)^2 \right\}^{0.5}; i = 1, 2, \dots, m \quad (2.6.2.4)$$

$$d_{i-} = \left\{ \sum_{j=1}^n (V_{ij} - V_j^-)^2 \right\}^{0.5}; i = 1, 2, \dots, m \quad (2.6.2.5)$$

Step 5. Calculating the relative proximity to the ideal solution defined with equation;

$$cl_{i+} = \frac{d_{i-}}{((d_{i+}) + (d_{i-}))}; 0 \leq cl_{i+} \leq 1; i = 1, 2, \dots, m \quad (2.6.2.6)$$

Step 6. The possible alternatives can be ranked based on the downside order of  $cl_{j+}$

As the seventh step in addition to six TOPSIS steps, Sensitivity Analysis carried out to observe whether our system is sensitive to small changes in users' preferences.

### 2.6.3. Sensitivity Analysis

Some of the values of multicriteria decision analysis models might be subjective sometimes. Thus, it is important to obtain whether final ranking and/or other options are sensitive to the changes of some input values.

In our study, sensitivity analysis is performed as the seventh step after completing the TOPSIS scores. Our aim is to observe the impact of a change in a weight of a single criterion or criteria on the overall TOPSIS performance scores and ranks. Mathematical background of sensitivity analysis starts with the assuming that the weight of the  $p^{th}$  criterion changes from  $w_p$  to  $w_p'$  as:

$$w_p' = w_p + \Delta \quad (2.6.3.1)$$

Then, the weight of other criteria would change as:

$$w_j' = w_j + \Delta_j \quad j = 1, \dots, k; j \neq p \quad (2.6.3.2)$$

and:

$$w_j' = \frac{1 - w_p - \Delta_p}{1 - w_p} w_j = \frac{1 - w_p'}{1 - w_p} w_j \quad (2.6.3.3)$$

$$j = 1, \dots, k; j \neq p$$

According to Alinezhada and Amini (2011) [69], if the weight of the  $p^{th}$  criterion changes from  $w_p$  to  $w_p'$ , new vector for weights of the criteria would be:

$$W^t = \begin{cases} w_j + \Delta_p & j = p \\ \frac{1 - w'_p}{1 - w_p} w_j & j = 1, \dots, k; \quad j \neq p \end{cases} \quad (2.6.3.4)$$

$$w'_p = w_p + \Delta_p \Rightarrow \begin{cases} \text{if } w'_p > w_p \Rightarrow w'_j < w_j; \\ \text{if } w'_p < w_p \Rightarrow w'_j > w_j; \end{cases} \quad (2.6.3.5)$$

$$j = 1, \dots, k; j \neq p$$

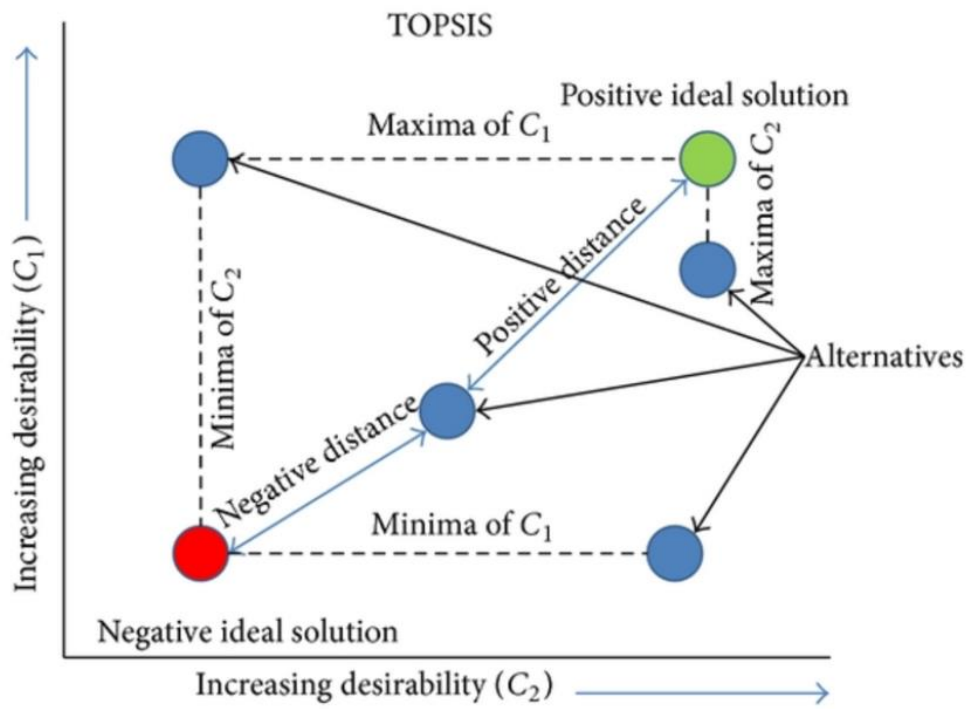


Figure 2.5 TOPSIS Distances [86]

### **3. METHOD**

#### **3.1. MATLAB based Procurement Tool**

In this thesis, face-to-face interviews have been performed with the experts as a first step. The aim of interviews is collecting their opinion to determine criteria. Afterwards, literature and market research have been performed with the aim determining dental implant brands still in use in Turkish market and collect technical specification for each. At the end of the interviews, literature and market research phase, we entered the collected data in to our database. After structuring the database, elimination phase and TOPSIS execution code via MATLAB and GUI has been created. Main block diagram of the above-mentioned steps is illustrated as in Figure 3.1.

Afterwards sensitivity analysis is performed to assess overall performance of the system. A real case study is simulated with the help of two hospitals. They have been required to carry out a tender and result are discussed from the perspective of health policy. The boxes illustrated in Figure 3.1, explained in the section of 3.1.1, 3.1.2, 3.1.3, 3.1.4 and 3.1.5.

##### **3.1.1. Collecting Expert Opinion**

We got valuable inputs from experts participated in the face-to-face interview. Face-to-face interviews have been performed to determine most of the important criteria while purchasing dental implants. We interviewed with twelve people totally. Ten of them are dentists in different expertise areas and two of them are the procurement specialists working in procurement department of the hospitals. Five of the dentists are surgeron, two of them is orthodontics, one of them is periodontitics and one of them is prostetician. Please refer to Table 3.1 for the number and expertise area of experts. Experts have been chosen from one of the long-established, and reputable universities. We preferred to include dentists which are not only have experience in hospitals but also have experience in private practices.

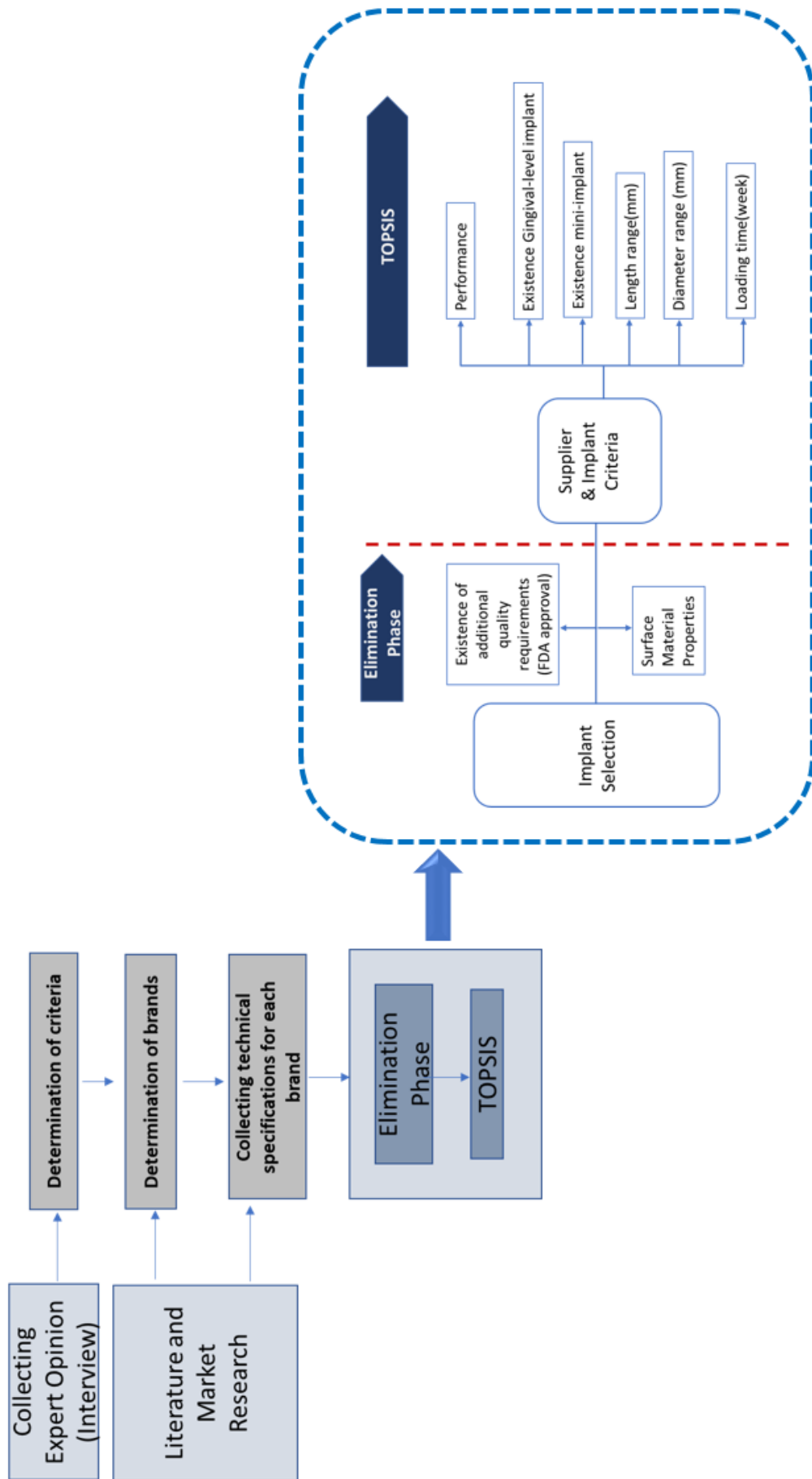


Figure 3.1 Main Block Diagram of the Proposed Tool

### 3.1.2. Determination of Criteria

As a result of interviews, six criteria have been accepted as inclusion criteria for our study. 1) Length range, 2) Diameter range, 3) Implant Loading Time, 4) Performance (Provider), 5) Gingival level, and 6) Mini implant. In addition to the six criteria, experts suggest and point out other criteria as well such as, risk of implant fracture and recall etc, but we must exclude some of the suggested criteria since it is not possible to convert them in to numerical values and there is lack of data regarding to some criteria. To formulate and standardize acceptance decision of a criterion, we determine a threshold value for inclusion/acceptance. Treshold value is determined as 55%. Length range and Diameter range are the included criteria with the highest ratio of 91, 6%, Performance of provider, Gingival Level and existence of mini implant is the second ones with the ratio of 66.6% and implant loading time is the other criterion accepted with 58,3%.

Table 3.1 Number and Expertise Areas of Experts

Participant number	Expertise Area	Affiliation
3	Dental Surgeon	University Hospital, Private Hospital
2	Dental Surgeon	University Hospital, Private Practice
2	Orthodontist	University Hospital, Private Practice, Private Hosp.
1	Periodontist	University Hospital, Private Practice
2	Prosthetic	University Hospital, Private Hosp.
2	Procurement Specialist	University Hospital, Private Hosp.

On the other hand, although some of the criteria have been considered very important, couldn't be included in this study and classified as excluded criteria. Excluded criteria are Price, Risk of Implant Fracture, Patient Comfort and Dental Patient Reported Outcome (dPROs), Product Recall and Osseointegration.

#### 3.1.2.1. Price

As the main goal of this thesis is to design MATLAB based Procurement Tool based on qualification of dental implant rather than its price, price is excluded to cause any

possible manipulation of payer. In our model, price is presented as “optimal price” at the final stage after TOPSIS is executed at the backside of the software.

### **3.1.2.2. Risk of Implant Fracture**

Experts think that one of the most important criteria is “risk of implant fracture”, but implant quality or design is not the only the reason affects this criterion but also surgeon capability, patient-based risk factors are also play important roles. Moreover, it is almost impossible to take “risk of implant fracture” as countable criterion as there isn’t any defined scalar value related to.

### **3.1.2.3. Patient Comfort and Dental Patient Reported Outcome (dPROs)**

Any report pertaining to oral health condition that comes directly from patients is considered dental patient-related outcome (dPRO). [78] dPROs can be classified under the instruments of Patient Reported Outcomes (PRO). PROs are identified by USA Department of Health and Human Services; "people's comfort when sleeping, eating, and engaging in social interaction; their self-esteem; and their satisfaction with respect to their oral health" [72]. Most widely used dPRO measure tool is Oral health-related quality of life (OHRQoL) and The Oral Health Impact Profile (OHIP) is the most widely used OHRQoL questionnaire. OHIP consists of set of 49 items, OHIP- 49 reduced to OHIP-14, aims to measure patients' physical and psychological discomfort, functional limitation, and social disability. [71] [72].

It has been observed during face-to-face interviews, dPROs are not familiar by experts and lack of national data has been found regarding to PRO of each dental implant brands. Thus, PROs are taken as excluded criteria. Additionally, experts think that it is hard to measure and quantify patient comfort as it is subjective and differs from patient to patient. Therefore, patient comfort is excluded in this study as well.

### **3.1.2.4. Product Recall**

Recall information of dental implants is another excluded criterion in this study. The EU regulation of 2017/745 Medical Devices identifies the term “recall”: “any measure



aims to achieve the return of a device that has already been made available to the end user". Although dentists are quite familiar with the term of recall and its significance, they do not know where or how to access that information. We found that some of the Regulatory Authorities provides recall notification of certain medical devices over their official websites. Turkish Medicine and Medical Devices Agency periodically announces the recalled medical devices over website, but scarce recall declaration has been found specific to dental implants in Turkish Market. Therefore, "recall" has been classified as one of the excluded criteria in this study.

#### **3.1.2.5. Osseointegration**

Although experts are eager to include osseointegration as a criterion in this study, it is very difficult to identify osseointegration as a scalar criterion. The reason why this is not possible to take osseointegration because it depends not only specification of dental implants (surface material and properties etc.) but also oral condition (bone quality and quantity), systemic diseases (diabetes) and addiction of patients (smoking). As a result, osseointegration has been excluded in our study.

#### **3.1.3. Dental Implant Market Research**

As for the dental implant market research, most recent globally published dental implant reports have been searched. From compant visits technical specification sheets using in tenders (~3), instruction for use (IFU~25), websites and, catalogs (~40) were collected for each implant brand. It has been defined that almost sixty different dental implant brands have been placed on Turkish market and still in operation for more than 5 years minimum. We included forty-nine of them among sixty since rest are not selected by dentists the reason of low performance of clinical support and lack of distribution network.

While forty-nine of implant brands are in compliance with EC and FDA requirements , only eight of the implant brands have EC certificate. The performance criteria related with clinical support has been represented from 1 to 10 on MATLAB code, depending on operation period of the company and 7/24 providing clinical support or not. One of the important points of our study is that since dental market is a dynamic environment, MATLAB database is designed as flexible to be able to

change or add new criteria in case needed in the future. The flex database structure facilitates the adoption of our model and software in to different local markets.

#### **3.1.4. Elimination Phase**

As presented in the stage of elimination phase, quality requirements (EC and FDA) and Surface Material Properties can be chosen by user via GUI checkboxes. GUI is demonstrated in Figure 3.3. EC (European Confirmittee) and FDA (US Food and Drug Administration) are taken as quality requirements since these are the most accepted ones in worldwide.

In the EU zone and candidate countries, medical devices must be confirmed with the applicable legal requirements. These requirments are presented by the CE mark. CE mark opens the way of free circulation of goods and means that aforomentioned device meets optimum quality requirements. On the other hand, FDA regulatory requirements is more complicated. The majority of medical devices subject to FDA regulation enters to USA market via one of the three ways: Premarket Notification a.k.a 510(k) Clearance, Premarket Approval (PMA), and Humanitarian Device Exemption (HDE).

Before executing TOPSIS at the backside of our software, user have to enter the weights via GUI. The weights are one of the most important inputs for the result of TOPSIS. The weights, can be called recognition values, depends on the desires of hospital/procurer/buyer.

#### **3.1.5. Creating User Interface**

MATLAB is a way of expressing computational mathematics with matrix-based language. In our study a user-friendly interface has been established on MATLAB GUI. GUI constitutes of four main sections; 1) Qualification, 2) Surface Properties, 3) Weights and 4) Results.

In elimination phase, qualification requirement and surface material properties are the main items should be selected by user via GUI. In elimination phase, Quality checkbox is optional. If qualification checkbox left empty, means only EC certification is required by the procurer otherwise software selects the brands which

have both CE and FDA. However, surface material properties must be chosen, otherwise, the program doesn't allow user to continue other parts on GUI.

After completing elimination phase, user should score each criterion with a recognition weight (value) regarding to desire of hospital. Weights scale is between 1 (least important) and 10 (most important) and each number must be integer.

MATLAB code is designed to be able to plot scores up to 6 alternatives among bidders. As soon as the user push "Calculate" button placed in the bottom right hand side of GUI, the optimal choice appears on GUI with the details of Optimal Brand Name, Optimal Price and Country of Origin. If the user push "Rank the Results" button the scores of other bidders' proximity to the presented one, which means PIS, appears on the screen with a bar graph and their C\* scores are written above each bar. MATLAB flowchart presented in Figure 3.2.

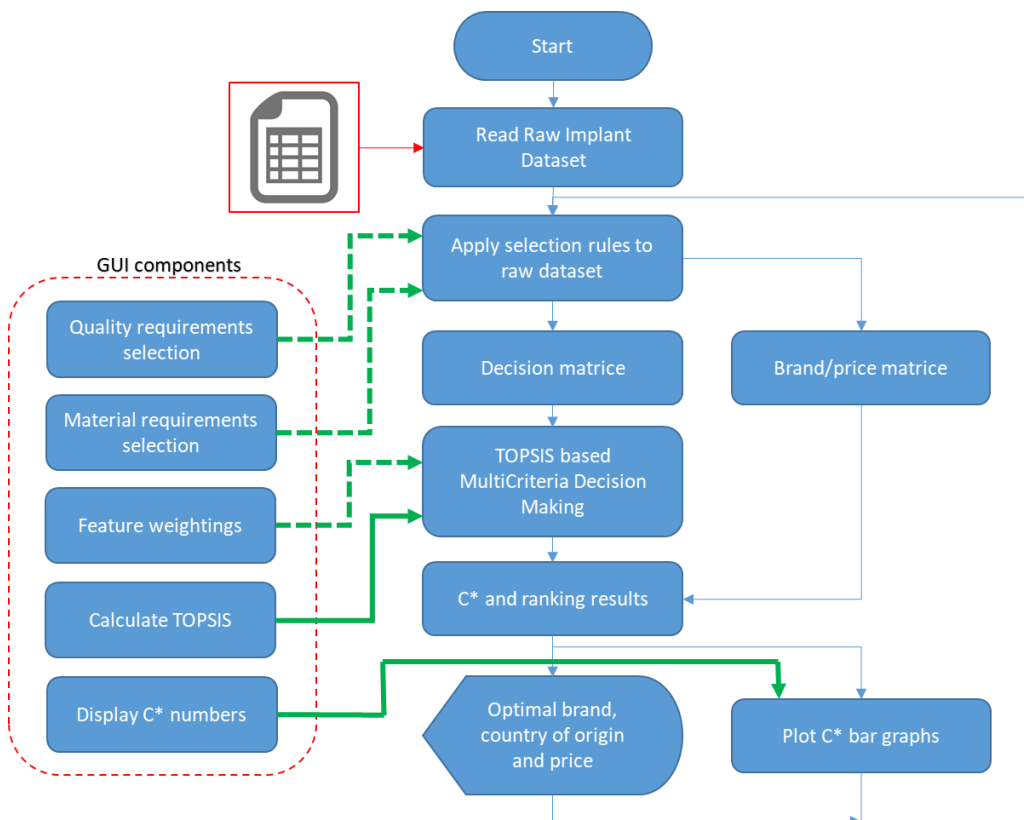


Figure 3.2 Flow chart of MATLAB

All of the components of GUI are designed to be in one page for the user experience as shown in Figure 3.3.

Figure 3.3 Developed GUI, Procurement Tool for Dental Implant Selection

### 3.2. Proposed Tool for a Real Case Study

In real case study, two of the biggest Dental Hospitals are carried out tenders to test and understand how MATLAB-based procurement tool is working and whether results are reasonable or not. When compared both hospitals in monetary aspect, Dental university hospital is funded by Government with a limited annual budget. However, private dental hospital has its own budget. University hospital scientific environment is more important than patient circulation, on the contrary, private hospital is more focused on income and service quality. Step by step use of GUI use is illustrated in Figure 3.4. As a result of the meetings of real case study, determined award weights are shown as in Table 3.2

Table 3.2 Weights of Real Case Study

Weight	Gingival Level	Mini Implant	Performance	Diameter Range(mm)	Implant Loading Time(week)	Length Range (mm)
University Hospital	5	10	10	10	2	10
Private Hospital	10	10	10	10	8	10

**2. Step**

**1. Step**

**3. Step**

**3. Step**

**4. Step**

**5. Step**

**Results vs Brands**

Brand	Value
Brand 1	0.65981
Brand 2	0.63307
Brand 3	0.58718
Brand 4	0.37743
Brand 5	0.24166

Figure 3.4 Step by Step GUI Use

### 3.2.1. Discussion and Results

First and second steps are placed for the selection of quality requirements and surface material properties. These two steps refers to the elimination phase which explained in previously and shown in Figure 3.1. In the real case of university hospital, both CE and FDA requirements are selected and Titanium based surface materials are preferred as surface material property. Afterwards, weights are given in the third step. Other than Gingival Level and Implant Loading Time, four of the criteria, Mini Implant, Performance, Diameter and Length Range, are awarded with 10. On the other hand weight of the Gingival Level is given 5 (1: less important and 10: most important) and Implant Loading Time is 2. As shown in Figure 3.4, when the user click “Calculate” button, TOPSIS is executed in the back and presents the optimal brand for the procurement decision. In the real case of university hospital, Company A is presented as the optimal brand. The country of origin is Sweden and the price of Company A is 450 Euro, which is the highest price among five bidders. When the user of university hospital click “Rank the Results” button in step five, other possible brands’ scores (C\*) are presented in bar graph. C\* scores can be seen above of each brand bar.



Figure 3.7 Scores of Real Case Study



In real case study, at elimination phase, both university and private hospital, choose Ti (Titanium) as the main surface property and both quality requirements, CE and FDA. "Implant Loading Time" and "Gingival Level" are distinguishing criteria in this study. "Implant Loading Time" has been selected as the least important criteria for university hospital since dentists prefer to obey clinical guidelines and wait between 8 to 12 weeks for each patient. On the other hand, private hospital prefers to obey "Loading Time" indicated by the manufacturer if provided shorter time for implant loading. The less they waited to load the implant crown the more and newer patient they can receive. Therefore, private hospital recognizes implant loading time with the point of 8 because the criterion is important for patient circulation means money income. According to the experts of university hospital, weight of "Gingival Level" is 5 whereas it is 10 for the private hospital experts which makes "Gingival Level" being a distinguishing criterion between them. The difference might be interpreted as aesthetic reasons linked with socioeconomic differences of patients. Rest of the four criteria, "Mini Implant", "Performance", "Diameter Range" and "Length Range" are scored with 10. GUI images are shown in Figure 3.5 for Private Hospital and Figure 3.6 for University Hospital. Scores regarding to our real case' weights are plotted in MATLAB presented in Figure 3.7.

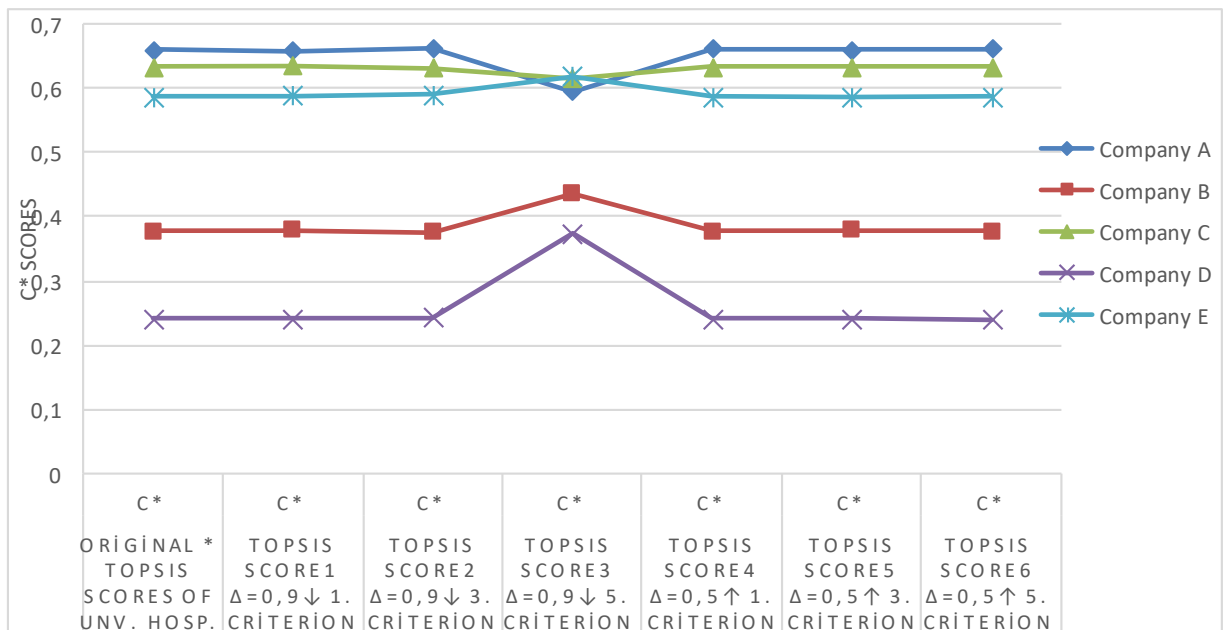


Figure 3.8 Scores of Sensitivity Analyzes



According to bar graph of university hospital, scores of Company A ( $C^*$ : 0.65981) and B ( $C^*$ : 0.63307) means that first two suppliers are the best possible options for purchasing of dental implants. Referring to other three options proposed by our tool, dramatic change observed for the Company C ( $C^*$ : 0.58718), Company D ( $C^*$ : 0.37743), Company E ( $C^*$ : 0.24166).

On the side of private hospital, unlike university hospital, Company B is provided as first of option with the score of 0, 64878. Company C ( $C^*$ : 0.62319) comes as second option very close to Company B. While Company A ( $C^*$ : 0.58351) is the selected one for university hospital, it is provided as third option for private hospital. Company D ( $C^*$ : 0.44512) and Company E ( $C^*$ : 0.30766) are the less possible options for procurement.

As 7th step of TOPSIS, Sensitivity Analysis has been performed for the real case of university hospital to assess how small changes in users' criteria weights affect the overall scores and ranking.

### **3.3. Sensitivity Analysis**

After TOPSIS steps are executed, sensitivity analysis is performed for the results of university hospital. The aim of sensitivity analysis is to observe how overall rank and  $C^*$  scores are changing when weights are change. The weights of the 1. (Gingival Level), 3. (Performance) and 5. (Implant Loading Time) criteria are decreased 0.9 points in the first three scenario and same criteria are increased 0.5 points in the last three case. The cases are presented in Table 3.3.

#### **3.1.1. Results**

As a result of sensitivity analysis, we observed that in only one case affects the original ranks. 0.9 points decrease in criterion 5 (Implant Loading Time), affects the overall score of TOPSIS and rank. The original TOPSIS Score ranking is: Company A > Company B > Company C > Company D > Company E, whereas with the 0, 9-point decrease in criteria 5, new ranking is: Company C > B > A > D > E. While

Company A ( $C^*$ : 0, 659813282) is provided as the optimum one in real case, it is provided as third option ( $C^*$ : 0, 594049058) in sensitivity analysis when decrease criterion 5.

Table 3.3 Sensitivity Analysis

	Original * TOPSIS Scores of Unv. Hosp.	TOPSIS Score1 $\Delta=0,9\downarrow$ 1. criterion	TOPSIS Score2 $\Delta=0,9\downarrow$ 3. criterion	TOPSIS Score3 $\Delta=0,9\downarrow$ 5. criterion	TOPSIS Score4 $\Delta=0,5\uparrow$ 1. criterion	TOPSIS Score5 $\Delta=0,5\uparrow$ 3. criterion	TOPSIS Score6 $\Delta=0,5\uparrow$ 5. criterion
	$C^*$	$C^*$	$C^*$	$C^*$	$C^*$	$C^*$	$C^*$
Company A	0,659813282	0,65747167	0,661966148	0,594049058	0,66068492	0,65878501	0,660703449
Company D	0,377434881	0,379445792	0,374884484	0,435551681	0,37668763	0,37865495	0,376671759
Company B	0,633072064	0,634279741	0,632158524	0,61466691	0,63262429	0,63351099	0,633297956
Company E	0,241656111	0,241007045	0,242309972	0,374138409	0,24189629	0,24134196	0,239220878
Company C	0,58717747	0,588153203	0,589506183	0,617725906	0,58681645	0,58606444	0,586808789

\*Represents the real case study scores of university hospital

#### 4. DISCUSSION AND CONCLUSION

Developed MATLAB based Procurement are successfully utilized by hospitals and results are consistent with the given weights. Therefore, we can say that developed software is a promising tool to be used in the application of 'most economically advantageous tender' concept.

Determination of exclusion criteria and acceptance of inclusion criteria is another challenging part of this thesis. Experts opinion plays a key role when defining the criteria. During criteria determination, we also made a literature research to confirm the criteria suggested by experts. Moreover, look for another possible criteria from literature to include our study. Other than price, even patient comfort and dPRO, risk of implant fracture, recall of dental implant, osseointegrity are very important criteria, we have to exclude them since scarce data prevents them to integrate in to our database. There are some clinical research shows the superiority of some of the implant brands. But not all the clinical research carried out at the same conditions, for example, in one study patient cohort consists of smoker whereas in another one patient is selected with diabetes only. In this case it is not possible to take one the criteria mentioned above and convert it in to a scalar value.

Price has been taken out of scope means accepted as excluded criteria with a purpose of preventing any intention of purchasing the lowest price bidder supplier.

During literature research, PRO has been determined as one of the rising trends among decision authorities. Therefore, we tried to include dPRO in to our thesis. We revisited experts to get their opinion on dPRO and look for local data regarding dental patient satisfaction. Unfortunately, few of the dentists have limited idea what dPRO is. The reason why dentists are not familiar with dPRO might be because dPROs are not taken as one of the compulsory parameters in procurement or coverage decisions. Besides, scarce local data regarding dPRO makes it impossible to take it as criterion and express in a quantifiable way. This point raises us the importance of local registry systems. Although a few of our experts have a simple software system in their own practice to communicate their patients for traceability purposes in compliance with ISO standards, they suffer from not having a national dental implant registry system. According to experts' claims, national registry system

should be able to provide information not only specific to implant material and manufacturer such as recalls, material properties, and authorized representative details but also information specific to patient satisfaction rates regarding to device implemented, patient mobility, or patient condition such as age, smoking, history of periodontal disease, diabetes mellitus, auto-immune diseases (such as Lupus or HIV) , and osteoporosis etc. [79]Dental Associations should advocate for the establishment of dental implant registry system specific to Turkey. In the respect of health policy, industry and dental associations should create awareness on the registry systems' usefulness and their impact on decision making and try to take attention of Governmental Bodies.

Given weights by hospitals in the real-life case, TOPSIS results show that, Company A with the highest price is selected in university hospital. On the other hand, Company is selected in private hospital tender with the third highest price. Original price rank among bidders is Company A > C = D > B > E. However, if the tenders would be an ordinary tender and didn't use our tool, hospitals buy from the bidder with the lowest price which is Company E.

To evaluate and analyze overall system, sensitivity analysis is performed. In sensitivity analysis it is observed that when weights are given for awarding purposes, ranks change. This indicates that proposed tool is capable of determining the optimal provider when criteria are awarded by integer weight values. Additionally, results for six different cases presented in Table 3.3, slight changes in weights range, do not change the original TOPSIS ranking except "TOPSIS Score3" case. This outcome indicates that our system is robust to slight changes. As also mentioned in the study carried out by Yurdakul et. al [74], if sensitive system is preferred for the provider selection in our study, we may utilize fuzzy TOPSIS. But it is very clear that in our study considering the outcome of sensitivity analysis, results are consistent according to the given weights by procurer.

In this thesis, a MATLAB based Procurement Tool was developed with the aim of standardization and to facilitate selection of appropriate dental implant provider. The hidden aim is also to prove that not the lowest price supplier is the best option for procurement decisions since lowest price option might always not meet minimum quality requirements.

In addition to use of procurement decisions, MCDA might be a supportive tool when discussing on resource allocation decisions such as reimbursement or coverage. [80] Today, patient advocacy groups, clinical associations and non-governmental organizations declare their serious concerns about lack of transparency on reimbursement decisions especially. Since MCDA can evaluate ethical values, PROs, social preferences etc. if appropriately transformed in to numerical values, MCDA might be taken a superior tool rather than currently used ones, such as cost-effectiveness or budget impact. [1] The approach of MCDA has been adopted by Several Government Authorities such as NICE, IQWiG, and CADTH.[81] Considering this thesis, MCDA might be a safe and practical tool when included OHRQoL measures, combined with behavioural indicators, with an appropriate economical analysis. [80]

Moreover, the approach of this thesis can be combined with MCDA based deep learning programming. While, deep learning algorithms continue to develop on medical imaging, there are promising studies in the area of resource planning, prediction of mortality risk, predicting healthcare trajectories etc. Study done by Qin Song et al. suggests a different approach from traditional approaches of drug procurement. Due to the uncertainty of diseases, drug procurement planning fails mostly drug understocking or overstocking at hospitals. This situation causes wasting the limited resources of hospitals. The study suggests using a deep neural network to predict morbidities of acute gastrointestinal infections based on a vast amount of environmental data. At the end, two real cases in Central China demonstrate that the average anticipation error of the approach is only 8% and the estimated recovery rate at 99%. [82] For predicting healthcare trajectories, deep neural networks are utilized by Pham et. al. [83] Another use of gradient boosted trees and neural networks is the study performed by Darabi et. al. The study predicts a 30-day mortality risk of post-admission time to a single hospital's ICUs. The results show capability of using even limited number of specifications can generate decent and adequate outputs. [84]

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## APPENDICES

### ANNEX 1 - Pseudo Code

```
% --- Executes on button press in checkbox_qualification.
function checkbox_qualification_Callback(hObject, eventdata, handles)

% --- Executes on button press in checkbox_Sandblast.
function checkbox_Sandblast_Callback(hObject, eventdata, handles)
)
% --- Executes on button press in checkbox_SLA. ...

% --- Executes during object creation, after setting all properties.
function edit_gingival_level_CreateFcn(hObject, eventdata, handles)

function edit_mini_implant_Callback(hObject, eventdata, handles)

function edit_performance_Callback(hObject, eventdata, handles)

function edit_diameter_range_Callback(hObject, eventdata, handles)

function edit_implant_loading_time_Callback(hObject, eventdata, handles)
.
.
.
.

% TOPSIS CALCULATION %
d=sqrt(sum(handles.select_decision_matrice.^2));
e=sum(handles.weights);
f=handles.weights/e;
g=handles.select_decision_matrice./d;
h=f.*g;
k=max(h);
l=min(h);
m=sqrt(sum((h-k).^2));
n=sqrt(sum((h-l).^2));
o=n./(m+n);
[~,p]=sort(o,'descend')
r=1:length(o);
r(p)=r

function figure1_CloseRequestFcn(hObject, eventdata, handles)
function checkbox_qualification_ButtonDownFcn(hObject, eventdata,
handles)

figure;
bar(handles.c_numbers_sorted,0.6);
text(1:length(handles.c_numbers_sorted),handles.c_numbers_sorted,num2str(
handles.c_numbers_sorted'),'vert','bottom','horiz','center');
ax=gca;
ax.YLim=[ax.YLim(1) ax.YLim(2)*1.1];
ax.XTickLabel=handles.select_brand_matrice_sorted(:,1);
ax.XTickLabelRotation=270;
ax.YGrid='on';
title('Results vs Brands');
```