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A Decision Model for Supplier Selection Criteria in Healthcare Enterprises with Dematel ANP Method

Kadir Kaan Göncü and Onur Çetin *

Trakya University, Edirne 22200, Turkey
* Correspondence: onurcetin@trakya.edu.tr; Tel.: +90-5421021711

Abstract: The supplier selection decision, within the scope of supply chain management (SCM), is one of the key decisions that plays an important role in the success of the business. The supplier selection problem, which aims to determine the most suitable suppliers in line with the demands of the enterprises, can be defined as a Multi-Criteria Decision Making (MCDM) problem that includes both quantitative and non-quantitative criteria. While there is a large body of literature on supplier selection studies using MCDM methods, the number of studies in the health sector is relatively low compared to other sectors. Although much research can be found regarding the application of MCDM techniques in clinical operations, less research has been conducted on the problem of supplier selection in healthcare services, which has a high complexity level. The main purpose of the study is to develop a holistic MCDM model as a decision support system for supplier selection in the health sector. The decision-making trial and evaluation laboratory (DEMATEL) and Analytical Network Process (ANP) methods were used together to analyze the model. The main criteria used in the study are price, quality, logistics, sustainability, and occupational health and safety (OHS). As sustainability and OHS rarely exist in supplier selection studies in the health sector, this holistic model can contribute to the literature in that aspect. According to the findings and the main criteria ranking, the most important criteria, emerged as price, quality, sustainability, OHS, technique, and logistics. The results indicate the importance of sustainability in supplier selection in the health sector. The method proposed in this study may help health managers as a support system for making purchasing decisions.

Keywords: health sector; supplier selection; sustainability; DEMATEL; ANP

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1. Introduction

In order to create a competitive system in the international economic arena, purchasing and supply management functions must be at the standards of developed countries. Supply chain management (SCM) has the qualifications of a key code that will decrypt the organizational ecosystem in which it is involved [1]. The supplier selection decision, within the scope of SCM, is one of the key decisions that plays an important role in the success of the business. The supplier selection problem, which aims to determine the most suitable suppliers in line with the demands of the enterprises, can be defined as a MCDM problem that includes both quantitative and non-quantitative criteria [2]. The initial stage in the strategic supply process is the clear determination of expectations about materials, products, and services [3]. At this first step, besides raw material and product expenditures, all purchasing criteria, such as quality, maintenance, safety, and delivery speed, should be analyzed, a detailed comparison of current and potential suppliers should be made possible, and suppliers that correspond to the lowest total cost while meeting expectations should be selected.

The field of healthcare is in search of new and different quests to offer value at the lowest cost without a decrease in the standards of the service recipients. Hospitals and suppliers, aiming to fulfill their activities, endeavor to provide the services and materials

that are needed at the most appropriate time, place, price, and quality. Under these circumstances, much more emphasis is placed on SCM in today's health sector with the aim of lowering costs, reducing wastage, preventing medical errors, and supporting service quality [4]. In order to supply high-quality health service, medical equipment supply plays a vital role [5].

In the health sectors of many countries, the share of the public sector is higher than that of the private sector. For the year 2023, it is predicted that the share of the private sector will be 21.4% and the share of the public sector will be 78.6% in the total healthcare expenditure in Turkey [6]. Therefore, when examining the supply management issues in the health sector, laws, regulations, and principles that the public sector, unlike the private sector, needs to implement should be taken into account. The criteria to be considered in the selection of suppliers in the public health sector are regulated by laws. In accordance with the 40th article of the Public Procurement Law No. 4734, it is possible to determine the offer with the most economic advantage only on the basis of price. There is also an emphasis on the fact that, in addition to the price, it can be determined by other factors, such as maintenance and operating costs, cost-effectiveness, quality, efficiency, technical values, and similar factors apart from the price.

Supplier selection is one problem for the MCDM. While there is a large body of literature on supplier selection studies using MCDM methods, the number of studies in the health sector is relatively low compared to other sectors. Although many articles have been written about the application of MCDM techniques in clinical operations, fewer articles have been published on the problem of deciding on equipment used in healthcare services, which has a high complexity level per se [7]. For this reason, it has been recommended to conduct studies on MCDM in the health sector in recent years [8]. According to the findings of the in-depth review of the literature, although MCDM models are used extensively in many different sectors, fewer publications have been encountered in the health sector. Among these mentioned publications, the number dealing with supplier selection is even smaller [9]. It can be seen that the number of studies using hybrid MCDM methods in supplier selection problems in the health sector is much more limited [10]. The rationale of MCDM studies is to decide independently from a single criterion. While only the criterion of cost was at the forefront in the past, it has been seen that criteria apart from cost have gained more importance in the last 30 years. In addition, it has been observed that qualitative criteria have also gained more importance in recent years [11].

Moreover, it is suggested that new criteria in MCDM studies should be considered, especially for the health sector [12,13]. The health sector is responsible for 5% of global carbon emissions. Medical equipment can be regarded as the main source of carbon emissions in health supply chains [14].

Therefore, new criteria are included in new models in supplier selection studies with MCDM. One of these new criteria is sustainability. The process of applying environmental criteria to selection problems is becoming an increasingly important criterion when making purchasing decisions, and it is argued that purchasing managers will play an important role in selecting suppliers that incorporate environmentally friendly practices into their activities [15]. OHS can be observed as another criterion. Another important issue regarding supplier selection is the impact of waste, and even of the equipment used in the health sector, on human health [16]. Moreover, although MCDM models related to supplier selection have been created in many sectors, MCDM and supplier selection models are less common in the health sector, especially in public healthcare establishments, compared to other sectors [9]. In this study, two MCDM methods, namely the ANP and DEMATEL methods, were used together.

The main question sought to be answered in this study is what the weights of the criteria will be in a holistic model that includes OHS and sustainability among the supplier selection criteria in the public health sector. The main purpose of the study is to develop a MCDM model proposal to apply in the health sector, including sustainability and occupational health and safety issues among the supplier selection criteria. It is thought that

this study will contribute to the literature by proposing a holistic MCDM support system, including sustainability and OHS criteria, which are rarely used in MCDM models, for health sector purchasing operations.

An in-depth analysis of the literature was conducted to determine the criteria to be used in supplier selection problems in the health sector. A group decision was appealed to discuss the determined criteria in the expert pool. Afterwards, the determined criteria were weighted with the help of the expert pool. Relationships among the criteria were determined using DEMATEL, and weights of criteria using ANP. This study has the qualification of being a reference work in terms of applying MCDM methods in purchasing, which is executed by considering non-price factors that are not being used even though related laws allow it, while public healthcare establishments fulfill their needs. Aside from this, the study also aims to gain the qualification of a reference work by adding the dimensions of Sustainability and OHS, which are not often taken into account during supplier selection, despite being valuable among criteria owing to the qualified nature of the sector.

2. Materials and Methods

2.1. Multi-Criteria Decision Making Method and Supplier Selection

Although the basic criteria used to evaluate suppliers today differ among businesses, the common goal is to identify the suppliers with the highest probability of supplying the product or service, and to choose the best one. Therefore, the supplier selection problem contains some difficulties. The reasons for these difficulties can be listed as the difficulty in expressing the criteria correctly, the criteria being complementary or contradictory to each other, and the number of suppliers being high [17].

The first study in which these criteria for supplier selection were classified and weighted was conducted by Dickson, and 23 basic criteria were determined [18]. A total of 74 articles published between 1966 and 1990 were examined, and the rankings of the basic criteria were compared in Weber 1991. The study conducted by Weber is important, as it showed the changes in rankings of such criteria as Price, Quality, Delivery, etc., over time [19].

The decision criteria used by organizational buyers in selecting suppliers have been examined in many studies, and it has been observed that the themes of product/quality, price, delivery, and service emerge consistently, although there are some differences in criteria between different purchasing situations and product types [20]. The weighting of these criteria, which may vary according to different sectors and conditions, is an important stage of supplier selection problems. Although many methods are used in this regard, the most often used method group is the Multi-Criteria Decision Making (MCDM) methods.

In MCDM methods, criteria other than price, such as quality, flexibility, delivery, etc., are also taken into account. One of the issues in the process of evaluating supplier selection criteria is that these criteria can be quantitative or qualitative performance [21].

2.2. Difficulties Regarding Multi-Criteria Decision Making and Supplier Selection in Health Sector

Processes related to health services can be quite complex, as they incorporate not only economic and technical factors, but also human factors [22]. Therefore, it is difficult to analyze the purchasing processes reliably and accurately using traditional methods that focus on one or two factors, especially in businesses that are affected by many factors, such as healthcare businesses. MCDM methods have been proposed for utilization in many public service areas, including the definitions of priorities in health programs or interventions and regulatory approvals of pharmaceuticals, but have not been successfully implemented as part of the Health Technology Assessment to measure the value of new health technologies [23]. Despite a great deal of work that has been conducted over the years, there is still a need to develop a decision support system for supplier selection that will improve the approach of the current system in the field of supplier selection, as the current system is quite inefficient in decision making. Although the supplier selection

process seems cost-based, there are many criteria to consider, including price, delivery, risk, quality, and service. This difficulty in decision-making causes health institutions to be out of stock frequently, resulting in order time and quantity problems, and thus the inability to meet the demand of patients adequately [8].

As in every field, making investments is necessary in the health sector to catch up with the developing technology. These aforementioned investments should be maintained in a way that is realistic and provides maximum benefit. In many countries, hospitals, predominantly, are places where publicly funded healthcare services are provided. As well as the efficient use of existing resources, these healthcare enterprises aim for different purposes, such as following the developing technological and scientific applications and increasing the quality of service. At this stage, the decisions related to the purchase of medical devices to be used become a complex decision problem that requires consideration of many criteria [24]. Purchasing models, in practice, are often unclear, and their results are difficult to interpret. Decisive separation of factors creating value from costs in MCDM models will increase the flexibility that can support implementation, the clarity of the model, and the transferability of the results. Further research and practical applications, as well as model development and multi-stakeholder discussions, are important in terms of reaching a consensus and fulfilling the promised potential of MCDM to evaluate health technologies in healthcare services [25]. MCDM methods are used as a valuable tool to support decision-making in healthcare services, and provide a more formal, structured, comprehensive, and transparent bargaining process [20]. Therefore, it can be understood that MCDM methods will be beneficial for purchasing decisions related to the health sector. However, when the subject is public health institutions, laws and regulations are also involved, and there are different limitations compared to other sectors.

In the course of making a selection among alternative courses of action, decision makers often have multiple conflicting objectives. For example, alternative routes to a destination may conflict due to different advantages, such as time, distance, traffic, and view [26]. There have been studies that reveal the dissatisfaction of decision makers in purchasing, about reaching the result by making only economic evaluations. Decision makers in England and Wales assess additional benefit parameters, highlighting the need to seek a broader and more transparent selection methodology in the context of value-based pricing, rather than focusing solely on price [23]. Therefore, in recent years, not only quantitative and economic criteria, but also qualitative criteria, have begun to gain importance in studies using MCDM methods in supplier selection [11].

2.3. Literature Related to Supplier Selection in Health Sector with MCDM

In the article study, the "Systematic Literature Review" method [27] was used in the examination and classification of the studies on the supplier selection literature in the health sector. As a result of the application of the aforementioned method in the study, a systematic review was provided by choosing the resources related to the research subject, after accessing all the related ones in the literature in the field of supplier selection in the health sector.

Since the number of studies on supplier selection in health sector is quite limited, the start date has been defined as 2001 and the end date as 2021, in order to keep the review process wide.

Considering that the supplier selection in health sector covers many different disciplines due to its qualified nature, a comprehensive study was carried out in order to examine various application areas, as well as Scopus, Science Citation Index, ScienceDirect, Social Sciences Citation Index, IEEE Xplore Digital Library, Arts and Humanities Citation Index, and British Library EThOS.

In order to select large-scale and unbiased sample of the literature, the keywords "Supplier Selection", "Vendor Selection", "Supply Chain", "Multi Criteria", "Supplier Selection Criteria", "MCDM", "MCDA", "Health", "Healthcare", "Hospital", "Medical Device", "Sustainability", and "Occupational Health and Safety" were used. The number

of articles that were reached as a result of the searches made according to the constraints specified through keywords, in the databases specified by using the EBSCOhost system infrastructure, as well as in the specified time intervals, are as follows (keywords were searched in the "Title", "Abstract", and "Keywords" sections of the articles).

The literature findings are summarized as follows:

The number of articles gained by specifying the search constraint ("supplier selection" OR "vendor selection") AND ("health" OR "healthcare" OR "hospital") is 97.

The number of articles gained by specifying the search constraint ("supplier selection" OR "vendor selection") AND ("health" OR "healthcare" OR "hospital") AND ("occupational health and safety" OR "sustainability") is 14.

The number of articles gained by specifying the search constraint "supplier selection criteria" AND ("sustainability" OR "health and safety") is 10.

The number of articles gained by specifying the search constraint "multi criteria decision" AND "supply chain" AND ("healthcare" OR "health" OR "health care" OR "hospital" OR "medical device") is 25.

The number of articles gained by specifying the search constraint (("mcdm" OR "mcda") AND ("supplier selection" OR "vendor selection")) AND ("health" OR "healthcare" OR "hospital") is 13.

The number of articles gained by specifying the search constraint (("mcdm" OR "mcda") AND ("supplier selection" OR "vendor selection")) AND ("health" OR "healthcare" OR "hospital") AND ("occupational health and safety" OR "sustainability") is 5.

The number of articles gained by specifying the search constraint "multi criteria decision" AND "supply chain" AND ("healthcare" OR "health" OR "health care" OR "hospital" OR "medical device") AND ("occupational health and safety" OR "sustainability") is 4.

With in-depth research of the literature, the studies whose numbers are given in detail above were reached. Although the total number of studies accessed seems to be 168, when we remove the duplicate articles that intersect with different criteria titles, the total number of articles included in the evaluation is 126. When these studies are examined in detail, 9 studies that are accepted as reference and used in supplier selection in the health sector have been obtained. The criteria obtained according to these studies are listed as follows.

Ucal, Bozat and Cayir (2017) applied the DEMATEL method in order to be able to measure the sustainability performance of suppliers during supplier selection in the sustainable SC of a company operating in the field of health. In the study, with the help of the multi-criteria decision making method, the performance criterion that would increase the performance of sustainable SC at maximum among the given criteria was studied. As a result of the literature research and expert opinion, the criteria used in practice were determined as: (1) On-time delivery, (2) Price, (3) Pollution control, (4) Quality, (5) Service performance, (6) Flexibility, (7) Technology capacity, (8) Work safety, (9) Green supply chain, (10) Resource consumption, (11) Hazardous substance management, and (12) Waste management [28].

In the study implemented by Carland, Goentzel, and Montibeller (2018) for a Humanitarian Organization (HO) collaboration, which was aimed at facilitating the availability of rapid malaria diagnostic tests for the private sector in Uganda, it was shown how the criterion weights and value functions of MAVA (Multi Attribute Value Analysis) could be used for project evaluation of HOs. As a result of the literature research and participant interviews, the criteria examined in the study were determined as: (1) Training, (2) Time per sale, (3) Awareness/Advertisements, (4) Customer satisfaction, (5) Delivery time, (6) Quality, (7) Device price, (8) Device cost, (9) Sales of other products (Cross-sell), (10) Other opportunities, (11) Sales volume, (12) Expiration date, (13) Productivity(Distribution), (14) Profit, (15) Training cost, (16) Relationship with NGOs, and (17) Administrative period [29].

In addition to the sustainability criteria, Moradi and Jolai (2018) investigated other criteria and sub-criteria involved in the selection of drug suppliers for hemophilia patients. The Graph Theoretical Matrix Permanent Decision Making (GT-MP-DM) approach was used for ranking in supplier selection, and the problem solution was achieved with the

fuzzy MAX-MIN method and GAMS software. The criteria used in the study, which were also confirmed by the sensitivity analysis using the literature study and the filed evaluations of the experts, were determined as: (1) Green competence, (2) Social competences, (3) Economic goals, (4) Production competence and technological capabilities, (5) Quality, (6) Delivery time, (7) Health, (8) Customer service, and (9) Risk [30].

Akcan and Guldes (2019) presented various hybrid multi-criteria models (AHP-TOPSIS, AHP-ELECTRE, AHP-GRA, and AHP-SAW) to select the best supplier for hospitals. As a result of the expert interview, the criteria used in the supplier evaluation and selection process were determined as: (1) Logistics, (11) Network organization and order delivery time, (12) Quick response and service quality, (2) Quality, (21) ISO 9000, (22) Certificates, (23) Packaging quality, (3) Cost, (31) Product price, (32) Process costs, (33) Quantity discount rate, (4) Flexibility, (41) Technology, (42) Response to changes, (43) Responsiveness to changes, (44) Responsiveness to changes in product variety, (5) Reliability, (51) Integrity, (52) On-time delivery, and (53) Right product [10].

MCDM techniques in the in-hospital SC, and, specifically, in the operating room, were discussed. The criteria examined in the study were determined as: (1) Quality, (2) Time, (3) Finance, and (4) Productivity [31].

In a study in a dental polyclinic operating in the health sector, MCDM methods were used in order to make the healthiest decision. The supplier selection criteria, which were evaluated as a result of the literature research and expert opinions, were determined as: (1) Quality, (2) Price–Cost, (3) Distance, (4) Past performance, (5) Technology, (6) Flexibility, (7) Compliance with delivery date, and (8) Repair–Maintenance services [13].

In a recent study, the combination of artificial neural network and Fuzzy VIKOR was used in order to provide a model for selecting the best supplier in a hospital setting. In this descriptive application, which was carried out in three stages in a military hospital in 2016, the criteria used for supplier selection, as a result of the literature research and expert opinions, were determined as: (1) Price, (2) Quality, (3) Timely delivery, (4) Payment terms, (5) Supplier's past, and (6) Packaging and transportation quality [32].

Ref. [30] aimed to provide a comprehensive MCDM method for selecting the best potential supplier, specific to VMI (Vendor Managed Inventory), which is an effective and important tool to reduce demand volatility, time, and operating cost of inventory problems in the healthcare industry. In the study, in which the Fuzzy Delphi approach was used to select the appropriate evaluation criteria for supplier selection, a fuzzy step-wise weight assessment ratio analysis (SWARA) was preferred to determine the relative importance weight of the evaluation criteria, and a fuzzy complex proportional assessment of alternatives (COPRAS) was used to compare, rank, and select the most suitable supplier. As a result of the literature research, the supplier evaluation criteria used in the study were determined as: (1) Institutional trust, (2) Information sharing and exchange, (3) Information technology readiness, (4) Supply chain process integration, (5) Supplier flexibility, (6) Risk/Reward sharing, (7) Past delivery performance, (8) Investment cost, and (9) Project implementation period [33].

Ref. [31] explained how to use the MARCOS method for sustainable supplier selection in the health sector (an outpatient clinic) in Bosnia and Herzegovina. As a result of the comprehensive study of the literature, the supplier evaluation criteria used in the study were determined as: *Economic Criteria:* (1) Price, (2) Quality, (3) Product range, (4) Timely delivery, (5) Innovation, (6) Organization and management, and (7) Reliability; *Social Criteria:* (8) Reputation, (9) OHS, (10) Information disclosure, (11) Employee interests and rights, (12) Discipline and security practices, (13) Education, and (14) Respect for policies; *Environmental Criteria:* (15) Environmental competencies, (16) Environmental management system, (17) Recycling, (18) Pollution control, (19) Green R&D, (20) Green products, and (21) Number of ISO standards received [34].

In the studies examined, it has been determined that the most used criteria for the product are price, technique, and quality, while the delivery criterion is used more in supplier-oriented criteria, and it has been determined that sustainability and OHS are

the least mentioned criteria. Although the number of studies in which the sustainability criterion is included is relatively few, taking society's sensitivities into account, it can be said that the priority of this criterion has been on the rise in recent years. Although the OHS criteria were included at the minimum level, a solid necessity of its examination has emerged in preliminary interviews with the sector experts, considering the specific structure of the work area and the sanctioning aspect of the Occupational Health and Safety Law No 6331. In the second part, the OHS title, which is not well known in SCM, is detailed.

2.4. Methodology

In the study, a MCDM model was created for supplier selection in the health sector by using DEMATEL ANP methods. The following steps were followed in the methodology.

1. Forming the expert pool;
2. Creation of the MCDM model;
3. Determination of relations with DEMATEL;
4. Determination of criterion weights with ANP.

Selected articles were compared and analyzed in detail through meticulous examination, and publications containing criteria and methods used in supplier selection in the health sector were identified. The main and sub-criteria in the hierarchical table in Figure 1 were determined as a result of taking the opinion of a group of four experts for the criteria to be used in the aforementioned area.

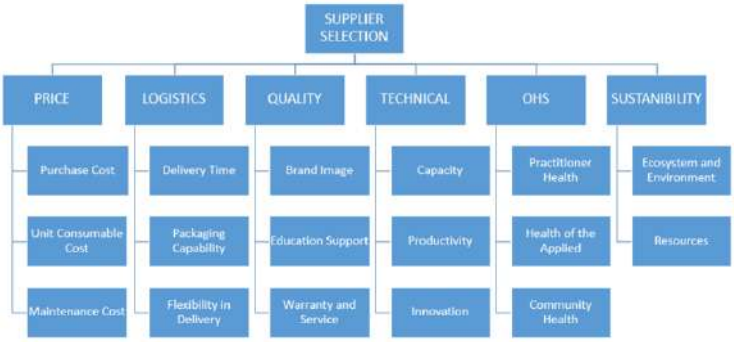

Figure 1. Supplier selection criteria.

Before the experts made a group decision, the findings obtained from the literature were submitted for their information in detail, and their evaluations were requested for the health sector, which is a specific field. In MCDM applications, group decision is important, as mutual sharing of ideas will generally provide a better understanding of the subject and a better representation of the problem [35].

As the study focused on the public health sector, the lines of rules and practices are drawn by laws and regulations. As a result, the purchasing authority was obliged to procure the most affordable product that complied with the technical specifications and conformed to the standards. It was deemed appropriate to select a pool of experts with the following technical experience and competence, considering that the contribution of technically experienced sector specialists is required at the highest level when establishing the standards related to the specific and specialization-required aspects of the products to be procured, as well as conveying them to the purchasing unit in a systematic coordination.

Two of the experts in question are geneticists with doctorate degrees in the field of health, and before their current work at a university hospital for the last 5 years, they worked for 5 years as expert staff at a national company supplying examination and diagnostic products for health institutions. Another expert is a specialist biologist with a master's degree, who has worked in different departments at a university hospital for more than 20 years, and was involved in the definition of technical specifications of many medical products that were decided, at the purchasing stages of different projects, to be

purchased for use. The last specialist, who has the title of engineer, is the owner of a regional supply company and has been marketing medical products in the private sector for more than 8 years.

2.4.1. Determining the Criteria and Creating the MCDM Model

Upon the evaluation of the supplier selection criteria obtained from the literature by the expert group, the criteria encountered in most supplier selection studies, such as price, quality, technical specifications, and delivery, are included in the hierarchical table. In addition, the two criteria, namely OHS and sustainability, which are not frequently encountered as the main criteria among the supplier selection criteria, and which are evaluated in fewer studies, but whose specific effects in the health sector are clearly revealed in the group study, were included in the evaluation along with their sub-dimensions. The MCDM model can be seen in Figure 1.

2.4.2. Weighting of Criteria with DEMATEL and ANP

According to the model obtained, first, the relationships between the criteria were determined by using DEMATEL. Then, criterion weights were determined using ANP.

DEMATEL

The DEMATEL method is a MCDM method developed by the Battelle Memorial Institute (BMI) between the years 1972 and 1976 [36]. This method, which was put forward by BMI, a company that develops science and technology regarding energy, health, life sciences, national security, defense, etc., aimed at solving complex problems in international issues by taking the opinions of experts. This method visualizes complex causal relationships in the form of matrices and diagrams. In this way, DEMATEL makes the system more understandable by separating the criteria into sender and receiver groups [37]. Thanks to the DEMATEL method, the interaction levels of criteria in complex systems with other criteria can be examined and ranked according to their priority. The criterion with the greatest impact among the criteria is defined as the high priority criterion. The DEMATEL method enables a problem to be solved by grouping the decision-making problems, which are difficult to solve, according to their importance. This method allows an environment to be objective in the evaluation of criterion weights, and also to use weights found by various multi-criteria methods [38].

Execution of the DEMATEL method is carried out in 5 steps [39].

Step 1: The relationships between the criteria are scored by the experts according to the pairwise comparison scale. As a result of evaluation of the criteria, an asymmetric matrix with a diagonal of "0" is obtained. This matrix is called "Direct Relationship Matrix" (D). In case the criteria evaluations are made with more than one expert, this matrix is formed by taking the arithmetic average of the answers given.

$$D = \begin{bmatrix} 0 & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{1n} & \cdots & 0 \end{bmatrix}$$

Step 2: After obtaining the direct relationship matrix, the greatest sum of the rows and columns is found.

$$S = max\left(\sum_{i=1}^{n} x_{ij}, \sum_{j=1}^{n} x_{ij}\right)$$

Then, each matrix element is normalized by dividing it by the value of "S", and the "*normalized direct relationship*" matrix "X" is obtained. $X = \frac{D}{S}$.

Step 3: The X matrix is subtracted from the unit matrix, and its inverse is then multiplied by the X matrix. This matrix is called the "Total Relation Matrix (T)".

$$T = X + X^2 + \cdots + X^n = X(I - X)^{-1}$$

Step 4: In order to determine the affecting and affected factor groups, and to calculate the net effect degrees, the sums of the rows and columns of the total relationship matrix (T) are obtained. These obtained values for each criterion are:

Each row sum (Di) indicates the effect of a criterion on other criteria, both directly and indirectly. Each column total (Rj) indicates the criterion being directly or indirectly affected by other criteria. The sum of (Di+Rj) for each criterion shows the total effect value sent and received, as well as the importance of the criterion in the system. The difference ($Di-Rj$) for each criterion shows the total effect of the criterion on the system. If the ($Di-Rj$) difference value is positive, it is defined as affecting; if it is negative, it is defined as affected (Table 1).

Table 1. Total relationship matrix.

		Di	**Rj**	**Di+Rj**	**Di−Rj**	
PRICE	F1	1.878125	3.014562	4.892687	−1.13644	affected
	F2	2.277389	1.999609	4.276998	0.27778	affecting
	F3	1.987306	1.875904	3.863209	0.111402	affecting
LOGISTICS	L1	1.82799	1.774687	3.602677	0.053303	affecting
	L2	2.179614	1.659585	3.8392	0.520029	affecting
	L3	1.652494	1.680904	3.333398	−0.02841	affected
QUALITY	K1	1.910271	2.877534	4.787805	−0.96726	affected
	K2	2.142375	1.415844	3.558219	0.72653	affecting
	K3	2.249033	1.643915	3.892948	0.605118	affecting
TECHNICAL	T1	1.909504	2.018933	3.928437	−0.10943	affected
	T2	1.94151	1.946048	3.887558	−0.00454	affected
	T3	2.519678	1.658125	4.177803	0.861553	affecting
OHS	I1	2.196652	2.143045	4.339697	0.053607	affecting
	I2	2.131856	2.497386	4.629242	−0.36553	affected
	I3	1.562358	2.105382	3.667739	−0.54302	affected
SUSTAINABILITY	S1	2.166784	2.336688	4.503472	−0.1699	affected
	S2	2.447625	2.332412	4.780037	0.115213	affecting

Step 5: The threshold value (P) needs to be determined. Threshold value can be determined by experts. However, if there is no such possibility, it can be determined by taking the arithmetic average of all the values in the total relationship matrix (T).

When the execution steps of the aforementioned DEMATEL method were carried out, Table 2 was created as a result of the calculations. Table 2 has been prepared by taking the relationships above the threshold value (P) into account, and the areas of the relationships that will not be included in the ANP method, which will be used in the next stage of the study, are shown with X.

Table 2. Total effect matrix.

T > P		PRICE			LOGISTICS			QUALITY			TECHNICAL			OHS			SUSTAINABILITY	
		F1	F2	F3	L1	L2	L3	K1	K2	K3	T1	T2	T3	I1	I2	I3	S1	S2
PRICE	F1	X	0.1279	0.1227	X	X	X	0.1420	X	X	X	X	X	X	X	X	0.1416	0.1414
	F2	0.2052	X	X	X	0.1290	0.1295	0.1650	X	X	0.1438	0.1391	X	0.1480	0.1640	0.1467	0.1574	0.1566
	F3	0.1715	X	X	X	X	X	0.1652	X	0.1374	X	X	X	X	0.1319	X	0.1457	0.1456
LOGISTICS	L1	0.1622	X	X	X	X	X	0.1739	X	X	X	X	X	X	0.1588	X	X	X
	L2	0.1821	0.1397	X	X	X	0.1264	0.1937	X	X	X	X	X	0.1438	0.1585	0.1257	0.1703	0.1528
	L3	0.1515	X	X	X	X	X	0.1470	X	X	X	X	X	X	0.1337	X	X	X
QUALITY	K1	0.1836	X	X	X	X	X	X	X	X	X	X	X	X	0.1287	X	0.1247	0.1246
	K2	0.1803	X	X	X	X	X	0.1751	X	X	X	0.1536	X	0.1602	0.1751	0.1431	0.1515	0.1685
	K3	0.2037	X	0.1558	X	X	X	0.1800	X	X	0.1423	0.1227	X	0.1479	0.1613	0.1282	0.1578	0.1576
TECHNICAL	T1	0.1842	0.1303	X	X	X	X	0.1603	X	X	X	X	X	0.1327	0.1456	X	0.1234	0.1232
	T2	0.1865	0.1312	X	X	X	X	0.1792	X	X	0.1303	X	X	X	0.1632	0.1334	0.1237	0.1236
	T3	0.2029	0.1522	0.1469	0.1235	X	X	0.1950	0.1242	0.1358	0.1539	0.1505	X	0.1596	0.1764	0.1580	0.1689	0.1693
OHS	I1	0.1841	0.1223	0.1357	X	X	X	0.1775	X	0.1253	0.1230	0.1385	X	X	0.1602	0.1271	0.1552	0.1553
	I2	0.1962	X	X	0.1468	X	0.1418	0.1904	X	X	X	X	X	0.1402	X	0.1400	X	X
	I3	0.1285	X	X	X	X	X	0.1414	X	X	X	X	X	X	X	X	X	X
SUSTAINABILITY	S1	0.1654	0.1396	X	X	0.1248	X	0.1924	X	X	0.1225	X	0.1254	0.1287	0.1418	0.12660	X	0.1710
	S2	0.2144	0.1337	0.1269	0.1397	X	0.1343	0.1916	X	X	0.1508	0.1284	0.1337	0.1549	0.1717	0.15358	0.1820	X

ANP

ANP was developed by Thomas L. Saaty, and is a generalized version of AHP. Thomas L. Saaty brought ANP, which includes AHP and uses the network structure in modeling distinctively, to the literature. ANP is an approach that takes the interdependence of the factors in decision problems into account [40]. The application process in the ANP method is carried out similarly to the AHP. However, in AHP, the criteria are considered independent and are analyzed in a hierarchical structure from top to bottom, while in ANP, horizontal and vertical interactions between the criteria are taken into account and analyzed within a network structure instead of a hierarchical structure. The most important advantage of the ANP method over other MCDM methods is that the method is suitable for qualitative and quantitative data, as well as responding to the dependency and feedback problems between criteria and options [41].

In the Analytical Network Process, as in the Analytical Hierarchy Process, the relative importance of the impact underlies the system. In order to form a judgment from the basic scale of the AHP, two types of questions based on the strength degree of superiority must be answered in the ANP: For a given criterion, which of the two elements being compared is more important? According to this criterion, which of these two elements affects the third element more significantly? In order to synthesize the judgments used in the evaluation here, it is important to use the same criteria in comparisons. This criterion is called the "control criterion" [42]. The execution stages of ANP are explained in 6 steps below:

1. During the first step, the decision problem is defined. At the initial stage, the aim is to state the main criteria, sub-criteria, and alternatives clearly.

2. By determining the interactions between the criteria, internal and external dependencies and, if any exists, the feedback between the criteria.

3. At this stage, the priorities vector is determined by making pairwise comparisons between the criteria. Priority vectors are calculated from pairwise comparisons between criteria. This matrix is obtained by using the data provided by experts. While making the calculation, the pairwise comparison scale in the AHP is taken as a basis.

4. The consistency of the comparison matrices obtained during the previous step is questioned. Upon calculating the consistency ratio (CR) for each matrix, pairwise comparisons are considered to be consistent if the resulting value is less than or equal to 0.10; otherwise, comparisons should be reviewed. The following formulas are used to calculate the consistency ratio (CR). In the formula, the consistency index is CI, the largest

value in the matrix is λmax, and the number of elements in each matrix is n. Once the consistency index has been determined, the consistency ratio (CR) is obtained by dividing the consistency index by the corresponding random index (RI) of the matrix of the same size [43].

5. A super matrix is created. A super matrix is a piecewise matrix. Each part of the super matrix shows the relationship between two factors within a system. The long-term relative effects of the criteria on each other are determined by taking the power of the super matrix.

6. At the last stage, the importance levels (weights) of the alternatives and criteria are determined. The alternative with the highest weight in the selection problem is the best alternative; in the weighting problem, the criterion with the highest weight is determined as the most important criterion [35].

If the ANP is critically regarded, it takes quite a long time to determine the internal and external dependencies, and, accordingly, to create the network structure of the decision problem. Again, due to the dependency relations in ANP, it takes a rather significant amount of time to make more pairwise comparisons when compared to AHP [41].

After the data which were obtained with the DEMATEL application, as well as the data obtained through the creation of the effect matrix specified in the first step of the execution of the ANP method, were entered into the SuperDecisions program, the network structure shown in Figure 2 was created. The arrows in this network structure are drawn from the side of the affecting cluster to the affected cluster. As can be seen in Figure 2, in the ANP network structure, there are 6 main criteria, which are Price, Quality, Technique, Logistics, Sustainability, and OHS. There are a total of 17 sub-criteria, consisting of 2 sub-criteria belonging to the main criteria title of technique, and 3 sub-criteria each for all other main criteria. When the network structure is examined, it can be seen that the sub-factors of all clusters interact with each other; that is, they have internal dependencies. Dependencies and feedbacks between other criteria are indicated by the directions of the arrows in Figure 2.

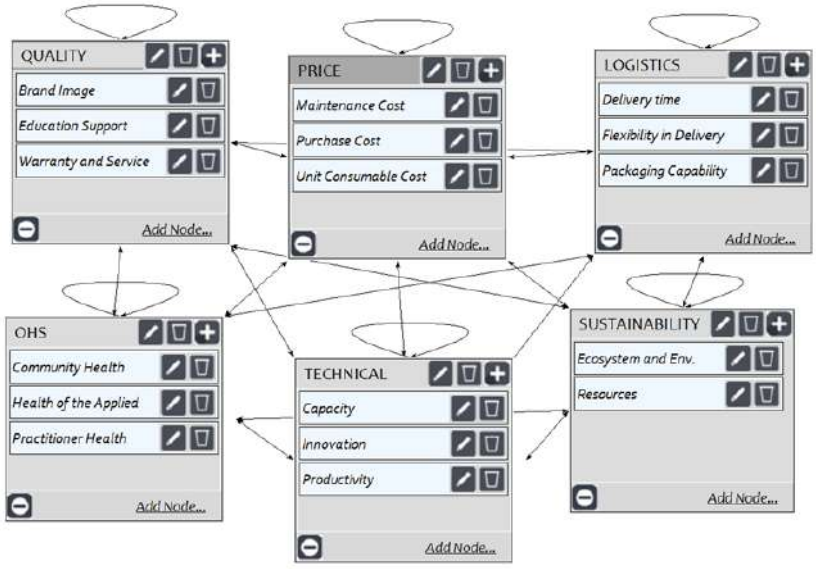

Figure 2. Network structure that shows inter-criteria dependencies and feedbacks.

3. Results

The importance values of the sub-criteria are given in Table 3. Values in the "Normalized by Cluster" column signify the weight represented by the related sub-criterion within the cluster in which it is included. When the sub-criteria belonging to the cluster are added, it is seen that a result of 1 is reached. Values in the "Limiting" column, on the other hand,

signify the value represented by the related sub-criteria among all sub-criteria, and when all sub-values are added, it can be seen that a result of 1 is reached.

Table 3. ANP weight values of sub-criteria.

	The Priorities	
Name	**Normalized by Cluster**	**Limiting**
Delivery Time	0.60402	0.017819
Flexibility in Delivery	0.21278	0.006275
Packaging Capability	0.18300	0.005397
Community Health	0.07838	0.013020
Health of the Applied	0.63953	0.106234
Practitioner Health	0.28209	0.046859
Maintenance Cost	0.04587	0.015504
Purchase Cost	0.66071	0.223319
Unit Consumable Cost	0.29342	0.099176
Brand Image	0.94933	0.284799
Education Support	0.00067	0.000200
Warranty and Service	0.05001	0.015002
Ecosystem and Env.	0.57183	0.061174
Resources	0.42817	0.045805
Capacity	0.60867	0.036165
Innovation	0.17288	0.010272
Productivity	0.21844	0.012979

4. Discussion

In this study, the most important criteria, according to the ranking of the main criteria, emerged as price, quality, sustainability, OHS, technique, and logistics. The results were compared with the MCDM models obtained in the literature analysis, as well as the studies on supplier selection in the health sector. Comparisons are analyzed in this section.

Ref. [28] examined the relationship between supplier selection criteria in an international company in the health sector in Turkey, and they found that the weight rankings of the criteria were on-time delivery, price, technology capacity, service performance, flexibility, and green supply chain. In this study, cost appeared as the most important criterion, and the quality criterion, which was not included in [28], was found to be the second-most important criterion. In the study, while the green supply chain criterion is in sixth place, in the middle among 12 criteria, it is also in fourth place out of six main criteria in this study. In this respect, sustainability, and its congener, green supply chain, were in the middle in both studies conducted in Turkey. This shows that in Turkey, the mentioned criteria are at the stage of being considered, since they are not in last place. In addition, while delivery date was among the important criteria in [28], in this study, delivery time, which is a similar sub-criterion, was in the middle of the importance rankings of the sub-criteria. Since this study was carried out in the public sector, where there are strict obligations regarding delivery time, it may seem normal that this criterion is less important. Therefore, the fact that the importance rankings of delivery time show differences based on the literature can be thought to be due to the distinction between the private and public sectors.

The criteria used by [10] are similar to the criteria in this study, and this study also examined the sustainability and OHS criteria holistically. In [13], which was concerned with the study of supplier selection in the health sector, the importance levels of the criteria were cost, quality, historical performance, and on-time delivery. Although the first two

rankings were similar to the current study, Ref. [13] used eight criteria, while the current study used six main and seventeen sub-criteria.

Ref. [32] used six criteria in the MCDM ranking related to the supply of medical equipment, and the importance rankings of criteria were determined as quality, cost, on-time delivery, and packaging transport quality. The first two criteria are the same as the first two criteria in this study. On-time delivery was in the middle of the rankings in both [32] and in this study.

Ref. [34] used 21 criteria in their study concerning supplier selection in the health sector, and OHS and sustainability-related criteria are both among these criteria. Quality, price, reliability, on-time delivery, and supplier reputation were the top five criteria in the study. The first two criteria are similar to this study. While the on-time delivery criterion was high in rank in the mentioned study [34], it was ranked in the middle in this study. In addition, the criterion of supplier reputation is defined as the general opinion of the stakeholders about the supplier. In a way, this definition can be understood as the supplier image. In this study, therefore, the brand image criterion is also considered to be related to the supplier image, since each supplier is a distributor of a brand.

Ref. [33] created and evaluated the criteria for supplier selection specific to VMI. The most important criterion was determined to be supplier reputation. In this study, the most important sub-criteria has been determined to be brand image, which can also be interpreted as the supplier image. In the health sector, especially in the supply of machinery and equipment, the brand image and the supplier image can be interpreted as similar. This is because in the health sector, the suppliers of machinery and equipment are often distributors, and each brand is sold by only one distributor. As a result of this, the supplier may become integrated with the brand, and the brand image and the supplier image may begin to represent a similar subject. From this point of view, it is seen that the criteria related to the supplier image emerged as important both in the literature and in this study.

5. Conclusions

In this study, the concept of "procurement management in the health sector" was examined in depth, and upon determining the criteria that are extremely important for supplier selection, analyses were carried out using DEMATEL and ANP methods, which are among the MCDM methods. By providing integration between the methods used, we have attempted to eliminate the weaknesses that may arise as a result of using each method on its own. Since the public sector is both the largest service provider and customer in the health sector, the focus in the research is on the public health sector. Rules and practices on the public side were limited by laws and regulations, and as a result, the purchasing officer was obliged to procure the most affordable product that complied with the technical specifications in a way that conforms to the standards. An expert pool with sufficient technical experience and competence, which is a necessity for the study, was created. This was carried out considering that the contribution of technically experienced sector specialists is required at the highest level in establishing the standards related to the specific and specialization-required aspects of the products to be procured, conveying them to the purchasing unit, and executing the process with systematic coordination.

As a result of the evaluation of the supplier selection criteria obtained from the literature by the expert group, the criteria encountered in most supplier selection studies, such as price, quality, technical specifications, and delivery, are included in the hierarchical table. In addition, the criteria of OHS and sustainability, which are not frequently encountered as main supplier selection criteria and which are evaluated in fewer studies, but whose specific effects in the health sector are clearly revealed as a result of the group study, were evaluated with their sub-dimensions.

The most important advantage of the ANP method over other MCDM methods is that the method is suitable for qualitative and quantitative data, as well as responding to the dependency and feedback problems between criteria and option [37]. However, it takes a significant amount of time to determine the internal and external dependencies,

to create the network structure of the decision problem accordingly, and to make more pairwise comparisons compared to AHP. In order to eliminate this weak side of the ANP, the DEMATEL method was used to determine the relationships between the criteria, and the relationships below the threshold determined by the experts were not taken into consideration.

It has been calculated that the number of pairwise comparison questions to be evaluated by the expert group would increase to 362 if the study were implemented without using the DEMATEL method. As a result of the application of the DEMATEL method, for the main criteria and sub-criteria, a questionnaire consisting of a total of 148 paired comparison questions and 50 evaluation titles was obtained. The aforementioned questionnaire forms consist of comparison questions that arise as a result of the network of relationships entered into the SuperDecisions program.

As detailed in the first part of the study, the public procurement system in Turkey also provides an opportunity to prefer the "Most Economically Advantageous Offer" method over the "Lowest Price" method, which is widely used. In order to use the "Most Economically Advantageous Offer" system, non-price criteria should be determined. This study proposes a model that helps to determine both what non-price criteria and the weights of these criteria could be in public procurement in the health sector in Turkey. It is believed that this model will make a practical contribution to a transformation in public procurement in the health sector.

In the literature, the OHS criterion is one of the least emphasized criteria in the studies on purchasing in the health sector. In addition, the public health aspect of OHS has not been used in any study, to the best of our knowledge. It is thought that examining this aspect in this study will both contribute to the literature and support practical practitioners.

When the main criteria are examined, it can be seen that the main criterion of price is in first place, with a weight value of 0.337 and the highest importance score; and the main criterion of quality is just behind the main criterion of price, with a weight value of 0.300. While public procurement is carried out on a single criterion, non-cost criteria have also been added to the cost criterion in public procurement in the European Union. At the end of this study, it was revealed that in the improvements to be made in public procurement in Turkey, the quality criterion is the one that should be taken into account, following the cost. In future studies, the model proposed in this study can be used in private hospitals as well as in public hospitals in the field of health.

One of the limitations of the study is that it was conducted in the public health sector. Therefore, the expert pool was selected from experts who are experienced in public procurement. Since criteria such as technical criteria and logistics (delivery time) in procurement activities in the public health sector are obligatory by the specifications, it is expected that weight rankings of the criteria in the studies conducted in the public sector will be different from those in other studies. Indeed, it can be seen that while on-time delivery was among the most important criteria in the studies of [13,28] conducted in firms, in this study, delivery time, which is a similar sub-criterion, was in the middle in terms of importance. It has been previously stated that this may be due to the difference between the public and private sectors. However, future research can analyze this difference by testing this model on private sector businesses.

The brand image sub-criterion emerged as the most important sub-criterion. This may be due to the similar perception of two different concepts, namely brand image and supplier image, particular to the health sector. Simply because each brand has a distributor in the public sector, the brand and the supplier can be matched. In future studies, the relationship between brand image and supplier image should be investigated in the public health sector and the non-public health sector.

Decision makers in the health sector may practically use the model proposed in this study in order to make purchasing decisions. They can revise the criteria according to their sector or company.

In further studies, the model presented in this study can be used for supplier selection in the healthcare industry for specific products. Moreover, this model may be used for specific products or product families in different health companies, operating in both the public sector and the private sector.

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