Turkish Journal of Science & Technology
18(2), 487-502, 2023

Research Paper
https://doi.org/10.55525/tjst.1340408

R&D and Innovation Map of Turkey: Hybrid Model Approach

Muhammed ÇUBUK[1*],
[1] Fırat Development Agency, Elazığ, Türkiye
[*1] muhammedcubuk23@gmail.com

(Geliş/Received: 10/08/2023; Kabul/Accepted: 28/08/2023)

Abstract: R&D and innovation activities are among the areas of critical importance for a country's national development and pioneering technological developments. R&D and innovation, which is an important field of study in terms of contributing to the evaluation of technical skills and regional specialization, are concepts that aim to achieve goals such as technological development, creation of new products and services, improvement of existing processes and increase in competitiveness. Accordingly, in this study, which focuses on ranking the R&D and innovation potential of provinces in Turkey, DEMATEL, ARAS and COPRAS methods, which are multi-criteria decision-making methods, were used. The weighting of the 12 criteria was done by DEMATEL method and 81 provinces were ranked by ARAS and COPRAS methods using these weight values. Maps were created according to the scores of the provinces from each method. According to the results obtained, most of the 81 provinces in Turkey showed similar results in both methods. A general evaluation was made according to these results and criteria.

Key words: R&D, innovation, DEMATEL, ARAS, COPRAS.

Türkiye Ar-Ge ve İnovasyon Haritası: Hibrit Model Yaklaşımı

Öz: Ar-Ge ve inovasyon faaliyetleri bir ülkenin ulusal kalkınması ve teknolojik gelişmelere öncülük etmesi bakımından kritik öneme sahip alanlar arasındadır. Teknik becerilerin değerlendirilmesine ve bölgesel ihtisaslaşmaya katkı sağlaması açısından önemli bir çalışma alanı olan Ar-Ge ve inovasyon, teknolojik gelişme, yeni ürünler ve hizmetlerin yaratılması, mevcut süreçlerin iyileştirilmesi ve rekabetçilik artışı gibi hedeflere ulaşmayı amaçlayan kavramlardır. Bu doğrultuda, Türkiye'de illerin Ar-Ge ve inovasyon potansiyellerini sıralamaya odaklanan çalışmada çok kriterli karar verme yöntemlerinden DEMATEL, ARAS ve COPRAS yöntemleri kullanılmıştır. Belirlenen 12 kriterin ağırlıklandırılması DEMATEL yöntemiyle yapılmış ve 81 il bu ağırlık değerleri kullanılarak ARAS ve COPRAS yöntemleriyle sıralanmıştır. İllerin her bir yöntemden aldıkları skorlara göre haritalar oluşturulmuştur. Elde edilen sonuçlara göre Türkiye'deki 81 ilin büyük çoğunluğu iki yöntemde de benzer sonuçlar göstermiştir. Bu sonuçlara ve kriterlere göre genel değerlendirme yapılmıştır.

Anahtar kelimeler: Ar-Ge, inovasyon, DEMATEL, ARAS, COPRAS.

1. Introduction

Today, the productivity levels and production structures of countries in the field of economy are of great importance in increasing the welfare levels of societies and ensuring stable economic growth. In this direction, it is seen that countries tend to obtain maximum added value with minimum resources. This situation brings about a significant orientation towards activities and expenditures in the fields of research and development (R&D) and innovation [1].

With the rapid developments in the fields of science and technology, communication has become easier and more accessible, and with globalization, a world of competition based on R&D, innovation, high quality and low price has emerged. In this process of development and change, the scale on which countries and businesses compete has spread all over the world [2]. The emergence of global competitiveness has made it imperative for countries and businesses to take action in the fields of R&D and innovation. In particular, strengthening R&D and innovation ecosystems and improving competitive capabilities in almost all sectors have been among the main policy issues of countries.

R&D and innovation, which have a direct impact on the economic growth of countries, can also affect the competitiveness of regions, the gradation of incentives applied to investments, the training of qualified human resources and regional development. The importance of R&D and innovation in Turkey's growth targets is emphasized in many policy texts. This is also clearly stated in the Eleventh Development Plan: "In order for our country to keep pace with technological transformation, enriching qualified human resources in priority sectors and fields, increasing the diffusion of technology to enterprises, improving the organization and innovation capabilities of firms, and putting effective mechanisms in place for financing research and development (R&D) and innovation stand out as priority issues in the Plan period" [3]. All Five-Year Development Plans prepared in

* Corresponding author: muhammedcubuk23@gmail.com, ORCID Number of author: [1] ORCID 0000-0002-3655-8036

the planned period include targets for many innovation indicators such as the share of R&D expenditures in GDP, researcher labor force, and private sector R&D share. For example, the Eleventh Development Plan aims to increase the share of the private sector in R&D expenditures and the share of R&D personnel employed in the private sector to 67% [3].

Regional development activities implemented for the realization of the targets set in strategy and policy texts together with the potentials of all regions and the appropriate use of resources provide the opportunity to work in the field of R&D and innovation. Development agencies working for regional development at the scale of NUTS-2 regions also contribute to the development of important components of the technology ecosystem such as R&D, innovation, cooperation culture, resource efficiency and qualified labor force in their regions. In this direction, the development of a culture of partnership between the public sector, universities, civil society and the private sector will ensure the effective and efficient development of the technology ecosystem of regions and provinces.

In this context, this study, which focuses on proposing a new model for the decision-making processes of decision-makers at the policy level, regulatory and implementing agencies involved in the technology ecosystem at the central and local levels, compares the R&D and innovation capabilities of provinces and tries to contribute to the competitiveness of provinces in this field. First of all, the criteria to be used in comparing the R&D and innovation capabilities of 81 provinces were determined by reviewing the relevant literature. DEMATEL (The Decision Making Trial and Evaluation Laboratory) method was used to weight these criteria. With these criteria weights, the R&D and innovation capabilities of 81 provinces were compared with ARAS (Additive Ratio Assessment) and COPRAS (COmplex PRoportional ASsessment) methods. Finally, maps were created according to the values of the provinces and evaluations based on the recommendations were given.

In the first part of the study, an introduction to the topic is given. In the second section, a literature review on R&D and innovation fields and the multi-criteria decision making methods used in the study are given. In the third section, the steps to be followed in the application of the methods used in the study are explained and the criteria set is given. In the fourth section, the R&D and innovation capabilities of provinces in Turkey are ranked using multi-criteria decision making methods. The last section presents the results and evaluations obtained in the study.

2. Literature Review

The literature review conducted within the scope of the study has been handled in two dimensions. Firstly, the studies conducted in Turkey and abroad in the field of R&D and innovation, which constitute the subject of the study, were examined. Secondly, previous studies have been grouped and summarized with the methods used.

2.1. R&D and Innovation

When the studies on R&D and innovation are analyzed, it is observed that a wide range of topics such as expenditures, Technology Development Zones (TDZs), economic growth, cooperation, entrepreneurship and regional development are discussed. Accordingly, some studies on R&D and innovation have been compiled.

The study by Demir and Geyik [4] focused on explaining the concept of innovation, evaluating the success of East Asian countries in the field of innovation and examining the development process of innovation in Turkey. As a result of the study, it was concluded that R&D and innovation expenditures in Turkey are not at an adequate level and the number of patent applications and acceptances, which is a reflection of this, remains at very low levels.

Baykul et al. [5] aimed to evaluate the R&D and innovative efficiency of the management companies responsible for the management and operation of Technology Development Zones (TDZs) and the R&D and innovation efficiency of 39 TDZ management companies was evaluated by data envelopment analysis method. Four inputs, namely the number of key personnel, number of firms, stakeholder university score, innovation index score of the province, and two outputs, namely R&D revenues and total number of intellectual property, were used in the efficiency measurement. As a result of the study, 13 TDZs were found efficient according to the CCR (Charnes, Cooper and Rhodes) model and 24 TDZs were found efficient according to the BCC (Banker, Charnes and Cooper) model.

In the study by Kesikoğlu and Saraç [6] titled "The Impact of R&D Expenditures on Growth: Comparative Analysis of NUTS-1 Regions", comparative regional analysis results were obtained by using R&D expenditures and growth data of 12 regions for the period 2010-2014. The study concluded that there is a positive relationship between R&D expenditures and Gross Domestic Product (GDP) in all regions. The highest level of impact is found in the Northeast Anatolia NUTS-1 region.

In the study conducted by Belgin and Avşar [7], it was aimed to measure Turkey's R&D and innovation performance at the level of regions and provinces and Gray Relational Analysis Method, one of the multi-criteria decision-making methods, was used. 29 criteria were used to evaluate the performance levels obtained in the study.

According to the ranking results, the Marmara Region ranked first among the 7 geographical regions in the country with a gray relational degree value of 0.9725, which indicates R&D and Innovation performance. It was concluded that Central Anatolia Region, which ranked 2nd in the overall ranking, scored higher than the regions following it in all sub-components after the Marmara Region.

Dağlı [8] focuses on the determination of innovation efficiency at the regional level in Turkey and the performance ranking of efficient regions. The output-oriented BCC and Super Efficiency Model of data envelopment analysis was used as the methodology. For the analysis, three input (R&D Expenditure, R&D Human Resources, Higher Education Resources) and three output (Advanced Technology Exports, Patent, Trademark) variables for regional innovation measurement were utilized. As a result of the analysis, 10 of the 26 NUTS-2 regions were found to be efficient regions in terms of regional innovation. The performance ranking of these efficient regions according to their super efficiency scores are TR10, TRC1, TR72, TR83, TR41, TR22, TR33, TR63, TRC2 and TRC3 regions.

Sánchez-Sellero and Bataineh [9] examined the link between green innovation and R&D practices inside and outside firms over time. The study concluded that internal and external R&D efforts improve green innovation activities.

Cao et al. [10] investigated the effects of implementing innovation-based development strategies on corporate R&D under political uncertainty. It is concluded that firms' implementation of innovation-based development strategies directly increases R&D investments and the resulting effects are stronger for firms with high growth potential.

2.2. Multi-Criteria Decision Making Methods

The literature on DEMATEL, ARAS, and COPRAS multi-criteria decision making methods used in the study is reviewed and summarized and presented under this heading.

In the study conducted by Çakın and Özdemir [11], the innovation performances of 12 regions in NUTS-1 of the Classification of Territorial Units for Statistics (NUTS) in Turkey in 2010, 2011 and 2012 were evaluated by taking into account basic R&D and innovation indicators. Regression analysis, DEMATEL-based Analytical Network Process (DANP) and TOPSIS methods were used in the study. The regression coefficients obtained through regression analysis were used in DEMATEL method to weight the criteria and TOPSIS method was used to rank the performance of the regions.

In the study conducted by Bulğurcu and Koçak [12], with the help of the fuzzy DEMATEL method, the internal and external risk factors faced by the companies in Adana province that carry out new product development studies in the new product development process and the success factors that affect the project success corresponding to these factors were evaluated and the importance relationship between them was examined.

In the study titled "Analysis of Value-Added Production and Macroeconomic Performance of Turkic World Countries with DEMATEL and COPRAS Methods" by Uludağ and Ümit [13], the macroeconomic and value-added production performances of Azerbaijan, Kazakhstan, Turkmenistan, Uzbekistan and Turkey in the 2008-2016 period were evaluated with DEMATEL and COPRAS methods.

In their study, Yakut and Kuru [14] evaluated the gender equality of the European Union (EU) member countries included in the Global Gender Gap Report (GGDR) prepared annually by the World Economic Forum (WEF-World Economic Forum). Using data from the 2017, 2018 and 2020 reports, a total of 14 criteria were used under 4 main headings, and the rankings of EU member states among themselves were made using Gray Relational Analysis (GRA), ARAS and COPRAS methods.

Çakır and Gök Kısa [15] focused on the internship selection problem for a logistics company with the integrated application of DEMATEL and COPRAS methods and proposed a model for personnel selection processes.

In their study, Goswami et al. [16] proposed hybrid model proposals based on the idea that the use of multi-criteria decision-making techniques alone would not be efficient. In the study, TOPSIS-ARAS and COPRAS-ARAS hybrid methods were applied to the robot selection problem and the results of the hybrid models were compared.

In the study by Özdağoğlu et al. [17], an application was made on the motorcycle selection problem. Six different multi-criteria decision making methods were used to evaluate motorcycle alternatives and the ranking results obtained from these methods were combined with the COPELAND method.

In the study introduced to the literature by Ecer [18], a hybrid model based on SECA, MARCOS, MAIRCA, COCOSO, ARAS and COPRAS methods for the selection of battery electric vehicles was focused on and the results obtained were combined using the Borda Counting Method and COPELAND method.

When the related literature is evaluated, it is seen that the application areas of multi-criteria decision making methods are wide. In recent studies, it is possible to observe that the application of traditional methods alone is less preferred than hybrid model approaches in which more than one method is used together. It is evaluated that hybrid models created by comparing the results obtained by applying more than one method with each other and including the methods used in combining the results together with the methods tested within themselves will provide more qualified data to decision makers.

On the other hand, it is possible to see that studies in the field of R&D and innovation are handled in a similarly broad framework. In the literature, there are studies comparing provinces and regions at various levels in terms of R&D and innovation. However, it is observed that these studies are mostly addressed using a single method. It is considered that the relevant literature is not sufficient in terms of studies based on a hybrid model that will contribute to the development of competitiveness at the provincial level, to the provision of data that will enable decision-makers at the local or central level to create an efficient R&D ecosystem, and to the forward-looking actions of all stakeholders involved in the R&D/innovation ecosystem.

3. Methodology

In this study, the R&D and innovation capacities of provinces in Turkey were compared and R&D and innovation maps, which are considered to contribute to the competitiveness of provinces according to their index values, were created. Multi-criteria decision-making techniques were used in the comparison of provinces. The criteria used in the comparison of provinces were determined and the DEMATEL method based on expert opinion was used to weight these criteria. With the weight values obtained, 81 provinces were ranked according to ARAS and COPRAS methods. Information on the applications of the methods and the criteria used in the comparison is given below.

3.1. DEMATEL Method

DEMATEL (The Decision Making Trial and Evaluation Laboratory) is a criteria weighting method developed by the Battelle Memorial Institute in Geneva in 1972. The method was introduced by Fontela and Gabus [19]. The DEMATEL method is a comprehensive method that establishes and analyzes the causal relationship between complex factors in a structural model and uses not only raw data, but data obtained based on the opinions of decision makers/expert groups [20]-[21]. The application steps of the method are given below:

Step 1: In the first step of the method, a direct relationship matrix is created. In the creation of this matrix, the pairwise comparison scale consisting of 5 levels shown in Table 1 is used.

Table 1. Pairwise comparison scale

Numerical Values	Linguistic Expression
0	Ineffective
1	Low Impact
2	Medium Impact
3	High Impact
4	Very High Impact

The relationship between the criteria is determined by the expert group using a pairwise comparison scale. A direct relationship matrix is obtained as a result of the comparisons.

Step 2: In this step where the normalized direct relationship matrix is created, the normalized direct relationship matrix (M) is obtained with the smallest value (k) in the row and column using Equation 1 and Equation 2 depending on the direct relationship matrix (A).

$$M = k \times A \tag{1}$$

$$k = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}, i, j = 1,2, \dots, n \tag{2}$$

Step 3: In this step, Equation 3 is used to obtain the total relationship matrix.

$$T = X.(I - X)^{-1} \tag{3}$$

Step 4: In this step, the influencing and influenced criteria groups are identified. The sum of the rows of the total relationship matrix (D_i) expresses the total degree of direct influence of criterion i on the other criteria. The sum of the column sums (R_i) expresses the total degree to which criterion i is influenced by other criteria. $(D_i + R_i)$ is the sum of the degrees of influence and impact of criterion i and it is called the central role degree. $(D_i - R_i)$ represents the net impact of criterion i. If $(D_i - R_i)> 0$, criterion i is affecting, and if $(D_i - R_i)< 0$, criterion i is affected.

Step 5: Since considering all elements in the total relationship matrix would increase the complexity of the problem, a threshold value (α) is determined to remove the effects that are considered insignificant before drawing the relationship map [22]. The threshold value can be determined by decision makers or it can be obtained with the help of Equation 4.

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{N} \tag{4}$$

If each element of the total relationship matrix is less than this threshold value, they are replaced by zero to prevent them from being taken into account. After this process, the matrix organized according to the threshold value $(T_{(\alpha)})$ is obtained. According to this matrix, the influence diagram is drawn with $(D_i + R_i)$ on the horizontal axis and $(D_i - R_i)$ on the vertical axis.

Step 6: Calculation of criteria weights using $(D_i + R_i)$ and $(D_i - R_i)$ values is done with the help of Equation 5 and Equation 6. The w_i values are the final weight values of the criteria.

$$S_i = \sqrt{(D_i + R_i)^2 + (D_i - R_i)^2}, i = 1,2, \dots, n \tag{5}$$

$$w_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \tag{6}$$

3.2. ARAS Method

ARAS (Additive Ratio Assesment) method is a multi-criteria decision-making method introduced to the literature by Zavadskas and Turskis [23]. The application steps of the method are as follows [24]:

Step 1: As the first step of the method, the decision matrix is created as shown in Equation 7. In the ARAS method, a row consisting of the optimal values for each criterion is included in the initial decision matrix. Optimum values can be determined using Equation 8 and Equation 9.

$$X = \begin{bmatrix} x_{01} & x_{02} & \cdots & x_{0n} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} (i = 1,2, \dots, m) \text{ ve } (j = 1,2, \dots, n) \tag{7}$$

$$x_{0j} = max_i x_{ij} \quad \text{utility (maximization)} \tag{8}$$

$$x_{0j} = min_i x_{ij} \quad \text{cost (minimization)} \tag{9}$$

Step 2: The decision matrix created in the first step is normalized using Equation 10 if the criteria are benefit-oriented and using Equation 11 if they are cost-oriented.

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{10}$$

$$x^*{}_{ij} = \frac{1}{x_{ij}}\ ;\ \bar{x}_{ij} = \frac{x^*{}_{ij}}{\sum_{i=0}^{m} x^*{}_{ij}} \tag{11}$$

Step 3: In this step, the normalized decision matrix ($\bar{X}$) is multiplied by the criteria weights w_j in the step to obtain the weighted normalized decision matrix ($\hat{X}$).

Step 4: Using Equation 12 in the weighted normalized matrix, the optimality value S_i is calculated for each decision value.

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}\ \ (i = 0,1,2,\dots,m) \text{ and } (j = 1,2,\dots,n) \tag{12}$$

Step 5: The optimality function values S_i of the alternatives are found by using the ratio of their utility values K_i to the best optimal value S_0 using Equation 13. The K_i values obtained for the alternatives are ranked from highest to lowest.

$$K_i = \frac{s_i}{s_0} \quad i = 0,1,2,\dots,m \tag{13}$$

3.3. COPRAS Method

COPRAS (Complex Proportional Assessment) method was developed by Zavadskas and Kaklauskas in 1996 to evaluate qualitative and quantitative factors. It is used to rank and evaluate decision options by considering the positive (benefit) and negative (cost) aspects of the criteria [24]. The application steps of this method are given below:

Step 1: In the first step of the method, the decision matrix is created as shown in Equation 14.

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} (i = 1,2,\dots,m) \text{ and } (j = 1,2,\dots,n) \tag{14}$$

Step 2: Using Equation 15, the decision matrix is normalized with w_j being the criteria weights.

$$d_{ji} = \frac{x_{ij} w_j}{\sum_{i=1}^{m} x_{ij}}\ (i = 1,2,\dots,m) \text{ and } (j = 1,2,\dots,n) \tag{15}$$

Step 3: The weighted normalized indices are summed in this step. In Equation 16, the smaller the s_{-i} calculated according to the cost-side criteria and the higher the s_{+i} calculated according to the benefit-side criteria, the easier it is to achieve the objective.

$$s_{-i} = \sum_{j=1}^{n} d_{-ji}\ ;\ s_{+i} = \sum_{j=1}^{n} d_{+ji}\ \ (i = 1,2,\dots,m) \text{ and } (j = 1,2,\dots,n) \tag{16}$$

Step 4: With the help of Equation 17, the value of Q_j, which indicates the relative importance of the alternatives, is calculated.

$$Q_i = s_{+i} + \frac{s_{-min} \sum_{i=1}^{m} s_{-i}}{s_{-i} \sum_{i=1}^{m} \frac{s_{-min}}{s_{-i}}}\ \ (i = 1,2,\dots,m) \text{ and } (j = 1,2,\dots,n) \tag{17}$$

Step 5: The degree of utility of the alternatives is determined using Equation 18. The alternative with a utility of 100 becomes the best alternative and the other alternatives are determined according to the best.

$$N_i = \left(\frac{Q_i}{Q_{max}}\right) \times 100 \quad (18)$$

4. Application

In R&D and innovation index calculations, different indicators can be taken into account depending on the purpose or scope of the study. In this context, basic indicators such as innovation environment, innovation subject, knowledge acquisition capacity, knowledge creation capacity, R&D and innovation performance and sub-indicators within these indicators can be determined in determining R&D and innovation capacity at country, regional and/or provincial level (Belgin and Avsar, 2019).

In this study, R&D and innovation performance at the provincial level in Turkey was measured and provinces were mapped. In the performance analysis of the provinces, 12 criteria were used. These criteria values were compiled from the data of Turkish Statistical Institute (TURKSTAT), Small and Medium Enterprises Development Organization (KOSGEB), Scientific and Technological Research Council of Turkey (TÜBİTAK), Turkish Patent and Trademark Office (TURKPATENT) and Ministry of Industry and Technology.

4.1. Criteria Set

In comparing the R&D and innovation capabilities of provinces in Turkey, criteria that are considered to be important indicators in this field have been identified and explanations on each of them are given below.

Table 2. Criteria set

Abbreviation	Criteria	Year	Source	Unit
C1	Number of Design-Patent-Utility Model Applications	2022	TURKPATENT	Number
C2	KOSGEB R&D Innovation Support Amount	2010-2022	KOSGEB	1.000 TL
C3	TÜBİTAK TEYDEB Support Amount	2016-2022	TÜBİTAK	1.000 TL
C4	TÜBİTAK ARDEB Support Amount	2016-2022	TÜBİTAK	1.000 TL
C5	Number of Academic Staff	2022	TURKSTAT	Person
C6	Number of Doctoral Degree Graduates	2022	TURKSTAT	Person
C7	Number of Graduates with Master's Degree	2022	TURKSTAT	Person
C8	Total Number of Technology Development Zones, R&D and Design Centers	2022	Ministry of Industry and Technology	Person
C9	Number of Personnel Employed in R&D and Design Centers	2022	Ministry of Industry and Technology	Person
C10	Socio-Economic Development Index Ranking (SEGE)	2019	Ministry of Industry and Technology	Rank
C11	URAK Interprovincial Competitiveness Index Ranking	2018	URAK	Rank
C12	Brand Skills and Innovation Ranking	2019	FORBES	Rank

Number of Design, Patent, Utility Model Applications (C1): It shows the total number of design, patent and utility model applications for 2022 announced by the Turkish Patent and Trademark Office (TURKPATENT). In the study, the maximum direction (the biggest is the best) is considered.

KOSGEB R&D Innovation Support Amount (C2): It shows the total amount of support in TL given to provinces within the scope of the R&D Innovation Support Program implemented by the Small and Medium Enterprises Development Organization (KOSGEB) between 2010-2022. In the study, the maximum direction (the biggest is the best) is considered.

TÜBİTAK TEYDEB Support Amount (C3): It shows the total amount of support by province for the projects completed between 2016 and 2022 within the scope of 1501-TÜBİTAK Industrial R&D Projects Support Program, 1505-University-Industry Cooperation Support Program, 1507-TÜBİTAK SME R&D Start-up Support Program and 1511-TÜBİTAK Priority Areas Research Technology Development and Innovation Support Program implemented by the Directorate of Technology and Innovation Support Programs (TEYDEB) within the Scientific and Technological Research Council of Turkey (TÜBİTAK). In the study, the maximum direction (the biggest is the best) is considered.

TÜBİTAK ARDEB Support Amount (C4): It shows the total amount of support given to the projects supported within the scope of ARDEB programs between 2016-2022 within the scope of different support programs carried out by TÜBİTAK Research Support Programs Directorate (ARDEB). In the study, the maximum direction (the largest is the best) was considered.

Number of Academic Staff (C5): In the higher education statistics announced by the Turkish Statistical Institute (TurkStat), it shows the total number of academic staff in all titles working in their own units in higher education institutions. In the study, the maximum direction (the largest is the best) is considered.

Number of Doctoral Degree Graduates (C6): It shows the total number of graduates with doctoral degrees in the province obtained from TurkStat. In the study, the maximum direction (the largest is the best) is considered.

Number of Graduates with Master's Degree (C7): It shows the total number of graduates with master's degree in the province taken from TurkStat. In the study, the maximum direction (the largest is the best) is considered.

Total Number of Technology Development Zones (TDZ), R&D and Design Centers (C8): It refers to the total number of TDZs (including those in the establishment phase), R&D centers and design centers in the province in 2022, taken from the statistics of the Ministry of Industry and Technology (MoIT). In the study, the maximum direction (the largest is the best) is considered.

Number of Personnel Employed in R&D and Design Centers (C9): It refers to the total number of personnel employed in R&D centers and design centers in the province for the year 2022 taken from the data of the General Directorate of R&D Incentives of the Ministry of Industry and Technology. In the study, the maximum direction (the biggest is the best) is considered.

SEGE Ranking (C10): This criterion, which was created using the 2017 Socio-Economic Development Index (SEGE) ranking published by the Ministry of Industry and Technology in 2019, is considered as minimum directional (the lowest is the best) in the study.

URAK Interprovincial Competitiveness Index Ranking (C11): This criterion, which was developed by the International Competitiveness Research Council in 2018 by using 85 different criteria, was included in the study as it is an important indicator on a national scale and was evaluated as minimum directional (the lowest is the best).

Brand Skills and Innovation Ranking (C12): This criterion, which was created using the ranking results of the provinces included in the 2019 FORBES survey, was evaluated as minimum directional (lowest is best) in the study.

4.2. Calculation of Criteria Weights with DEMATEL Method

In this part of the study, the criteria in Table 2 were weighted with the DEMATEL method to be used in ranking the R&D and innovation skills of the provinces according to the determined set of criteria. With the help of the pairwise comparison scale in Table 1, the opinions of an expert team consisting of ten people working in R&D, design centers and Technology Development Zones were taken. The direct relationship matrix in Table 3 was obtained by averaging these expert opinions.

Table 3. Direct relationship matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1		2,6	2,7	3	1	1	1,2	1,9	2,1	2,4	2,4	2,7
C2	3		1,9	2	0,8	1	1,1	2	2,4	2,4	2,1	2,3
C3	3	0,9		1,2	1,1	1,3	1,3	1,7	2	2,2	2	2,3
C4	2,9	0,9	1,1		1,2	1,5	1,5	1,3	1,7	2,2	2,1	2,3
C5	2,6	1,5	1,6	1,8		2,4	2,3	1,4	1,4	2	1,8	1,9
C6	2,3	1,7	1,8	1,9	2,1		2,2	1,3	1,7	2,3	2,2	2,3
C7	2	1,5	1,5	1,7	1,7	2,1		1,1	1,7	2,1	2,1	2,1
C8	3	2,5	2,5	2,3	1,4	1,5	1,5		3,4	2,4	2,7	2,9
C9	2,8	2,3	2,2	2	1,1	1,4	1,4	1,5		2,3	2,5	2,8
C10	2,8	2,1	2,1	2,3	2,2	2,3	2	2,5	2,5		2,9	3,1
C11	2,8	2,1	2,2	2,4	2,3	2,3	2,1	2,2	2,4	2,7		2,9
C12	2,8	2,2	2,2	2,4	2,1	2,2	2,2	2,7	2,7	3,1	3,1	

To calculate the normalized direct relationship matrix, Equation 1 and Equation 2 were applied to the direct relationship matrix in Table 3. The normalized direct relationship matrix obtained in this way is given in Table 4.

Table 4. Normalized direct relationship matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1		0,094	0,097	0,108	0,036	0,036	0,043	0,069	0,076	0,087	0,087	0,097
C2	0,108		0,069	0,072	0,029	0,036	0,040	0,072	0,087	0,087	0,076	0,083
C3	0,108	0,032		0,043	0,040	0,047	0,047	0,061	0,072	0,079	0,072	0,083
C4	0,105	0,032	0,040		0,043	0,054	0,054	0,047	0,061	0,079	0,076	0,083
C5	0,094	0,054	0,058	0,065		0,087	0,083	0,051	0,051	0,072	0,065	0,069
C6	0,083	0,061	0,065	0,069	0,076		0,079	0,047	0,061	0,083	0,079	0,083
C7	0,072	0,054	0,054	0,061	0,061	0,076		0,040	0,061	0,076	0,076	0,076
C8	0,108	0,090	0,090	0,083	0,051	0,054	0,054		0,123	0,087	0,097	0,105
C9	0,101	0,083	0,079	0,072	0,040	0,051	0,051	0,054		0,083	0,090	0,101
C10	0,101	0,076	0,076	0,083	0,079	0,083	0,072	0,090	0,090		0,105	0,112
C11	0,101	0,076	0,079	0,087	0,083	0,083	0,076	0,079	0,087	0,097		0,105
C12	0,101	0,079	0,079	0,087	0,076	0,079	0,079	0,097	0,097	0,112	0,112	

In the next step, the total relationship matrix was calculated using Equation 3 and is given in Table 5.

Table 5. Total relationship matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,443	0,397	0,422	0,449	0,294	0,320	0,324	0,370	0,434	0,471	0,469	0,502
C2	0,509	0,291	0,374	0,394	0,269	0,299	0,300	0,351	0,417	0,443	0,433	0,460
C3	0,473	0,299	0,284	0,341	0,259	0,287	0,285	0,317	0,375	0,405	0,398	0,427
C4	0,463	0,294	0,317	0,294	0,259	0,290	0,288	0,299	0,359	0,400	0,396	0,421
C5	0,481	0,332	0,353	0,376	0,234	0,338	0,332	0,320	0,372	0,418	0,410	0,434
C6	0,494	0,353	0,376	0,397	0,318	0,272	0,343	0,333	0,400	0,447	0,442	0,467
C7	0,446	0,320	0,337	0,360	0,283	0,318	0,245	0,300	0,368	0,406	0,405	0,424
C8	0,598	0,437	0,460	0,474	0,341	0,373	0,370	0,344	0,521	0,522	0,529	0,562
C9	0,524	0,382	0,400	0,411	0,292	0,327	0,324	0,350	0,355	0,459	0,464	0,496
C10	0,603	0,432	0,456	0,483	0,375	0,408	0,395	0,435	0,502	0,452	0,546	0,578
C11	0,593	0,425	0,451	0,479	0,372	0,402	0,393	0,419	0,491	0,533	0,442	0,563
C12	0,618	0,446	0,470	0,498	0,381	0,415	0,411	0,452	0,521	0,567	0,565	0,492

By obtaining the total relationship matrix, affecting and affected criteria groups were identified. The affecting and affected criteria are given in Table 6. The threshold value was determined as 0.272 by averaging the total relationship matrix.

Table 6. $D_i + R_i$ and $D_i - R_i$ values

Criteria	$\mathbf{D_i}$	$\mathbf{R_i}$	$\mathbf{D_i + R_i}$	$\mathbf{D_i - R_i}$	Impact Group
C1	3,284	4,196	7,480	-0,911	Affected
C2	3,043	2,953	5,996	0,090	Affecting
C3	2,780	3,150	5,931	-0,370	Affected
C4	2,732	3,323	6,055	-0,590	Affected
C5	2,953	2,465	5,418	0,489	Affecting
C6	3,113	2,717	5,831	0,396	Affecting
C7	2,823	2,690	5,513	0,134	Affecting
C8	3,711	2,873	6,584	0,838	Affecting
C9	3,209	3,431	6,640	-0,223	Affected
C10	3,803	3,707	7,510	0,096	Affecting
C11	3,735	3,691	7,426	0,044	Affecting
C12	3,919	3,911	7,830	0,008	Affecting

The Influence Diagram in Figure 1 and the Relationship Diagram in Figure 2 showing the relationship between the criteria were created. The D+R and D-R values in Table 6 are shown in Figure 1 as x-axis and y-axis on the coordinate plane. The criteria above the x-axis (C2, C5, C6, C7, C8, C10, C11, C12) were found to be influencing criteria, while the criteria below the x-axis (C1, C3, C4, C9) were found to be influencing criteria. The relationship between the criteria is visualized in Figure 2.

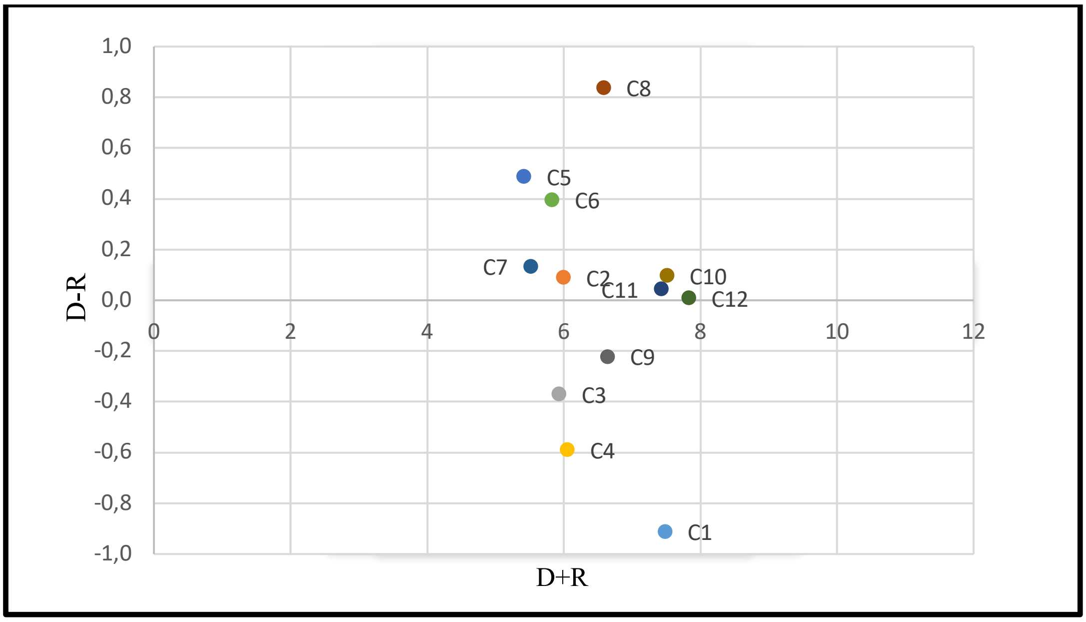

Figure 1. Impact diagram

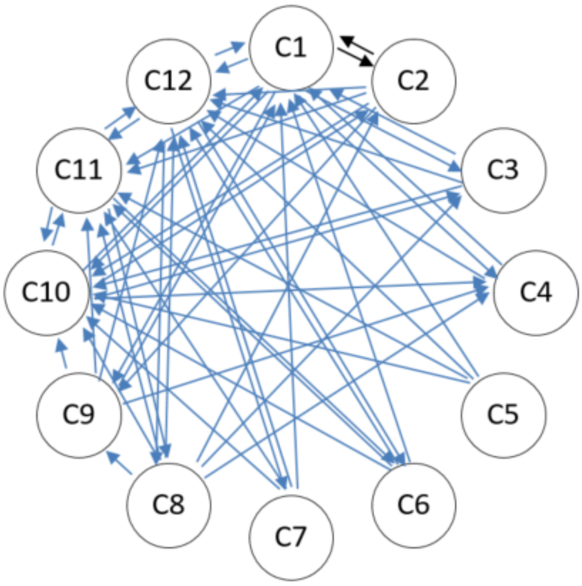

Figure 2. Relationship diagram

In the last step of the DEMATEL method, criteria weights were calculated with the help of Equation 5 and Equation 6 and given in Table 7.

Table 7. Criteria weights

Criteria	w_i	Criteria	w_i	Criteria	w_i	Criteria	w_i
C1	0,096	**C4**	0,078	**C7**	0,070	**C10**	0,096
C2	0,076	**C5**	0,069	**C8**	0,085	**C11**	0,095
C3	0,076	**C6**	0,075	**C9**	0,085	**C12**	0,100

4.3. Calculation of R&D and Innovation Performance of Provinces

Using the criterion weights obtained by DEMATEL method, the R&D and innovation skills of 81 provinces were ranked by ARAS and COPRAS methods. R&D and innovation maps were created according to the results obtained from these methods.

Using the criteria values of 81 provinces and the weights obtained by the DEMATEL method, the process steps of the ARAS method were first applied and the performance ranking of the provinces was made. The performance ranking results obtained are given in Table 8.

Table 8. ARAS method performance ranking

Rank	Province	Score	Rank	Province	Score	Rank	Province	Score
1	İstanbul	0,4431	**28**	Kahramanmaraş	0,0100	**55**	Aksaray	0,0044
2	Ankara	0,2678	**29**	Kütahya	0,0096	**56**	Nevşehir	0,0042
3	İzmir	0,1044	**30**	Çanakkale	0,0093	**57**	Adıyaman	0,0040
4	Kocaeli	0,0904	**31**	Hatay	0,0090	**58**	Erzincan	0,0040
5	Bursa	0,0834	**32**	Edirne	0,0089	**59**	Yozgat	0,0040
6	Konya	0,0439	**33**	Düzce	0,0085	**60**	Osmaniye	0,0040
7	Kayseri	0,0369	**34**	Elazığ	0,0084	**61**	Kastamonu	0,0039
8	Eskişehir	0,0359	**35**	Karabük	0,0081	**62**	Çankırı	0,0037
9	Antalya	0,0338	**36**	Şanlıurfa	0,0081	**63**	Mardin	0,0035
10	Manisa	0,0249	**37**	Diyarbakır	0,0076	**64**	Sinop	0,0035
11	Gaziantep	0,0247	**38**	Zonguldak	0,0073	**65**	Bartın	0,0030
12	Tekirdağ	0,0244	**39**	Kırklareli	0,0072	**66**	Kars	0,0030
13	Sakarya	0,0241	**40**	Rize	0,0066	**67**	Artvin	0,0029
14	Adana	0,0214	**41**	Van	0,0063	**68**	Tunceli	0,0028
15	Denizli	0,0211	**42**	Afyonkarahisar	0,0060	**69**	Batman	0,0028
16	Mersin	0,0202	**43**	Bilecik	0,0060	**70**	Gümüşhane	0,0026
17	Trabzon	0,0160	**44**	Tokat	0,0055	**71**	Bingöl	0,0026
18	Samsun	0,0159	**45**	Uşak	0,0055	**72**	Siirt	0,0025
19	Isparta	0,0141	**46**	Giresun	0,0054	**73**	Kilis	0,0024
20	Balıkesir	0,0128	**47**	Çorum	0,0053	**74**	Muş	0,0024
21	Muğla	0,0126	**48**	Burdur	0,0050	**75**	Şırnak	0,0023
22	Aydın	0,0124	**49**	Kırıkkale	0,0050	**76**	Bitlis	0,0023
23	Bolu	0,0108	**50**	Karaman	0,0049	**77**	Ağrı	0,0023
24	Yalova	0,0106	**51**	Niğde	0,0048	**78**	Iğdır	0,0022
25	Malatya	0,0106	**52**	Kırşehir	0,0047	**79**	Bayburt	0,0022
26	Erzurum	0,0104	**53**	Amasya	0,0046	**80**	Ardahan	0,0020
27	Sivas	0,0101	**54**	Ordu	0,0046	**81**	Hakkâri	0,0019

According to the performance ranking based on the ARAS method, Istanbul ranked first among 81 provinces. Ankara ranked 2nd, Izmir 3rd, Kocaeli 4th and Bursa 5th. Ağrı, Iğdır, Bayburt, Ardahan and Hakkâri were ranked last. The map created according to the scores obtained with the ARAS method is given in Figure 3.

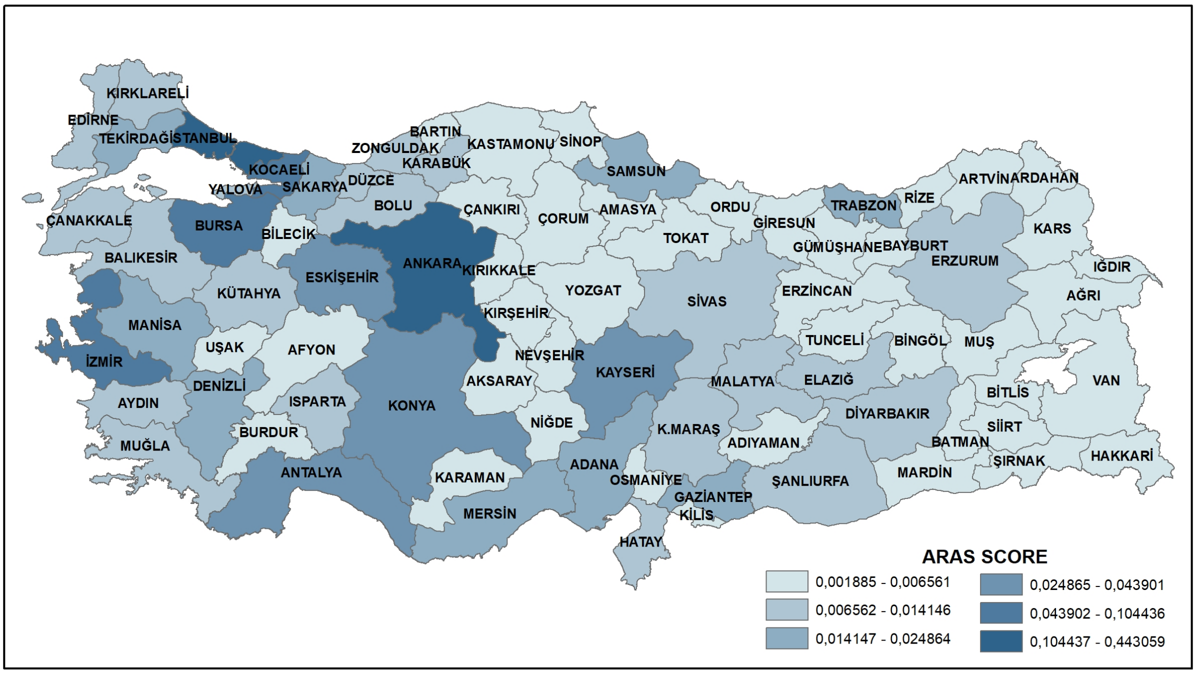

Figure 3. Performance map of provinces according to ARAS results

Similar to the ARAS method, the R&D and innovation performances of 81 provinces were ranked by the COPRAS method using the criteria values of 81 provinces and the criteria weights obtained by the DEMATEL method. The scores and rankings of the provinces from the COPRAS method are shown in Table 9.

The results of the COPRAS method are largely similar to the results of the ARAS method. According to the COPRAS ranking, Istanbul ranked 1st, Ankara 2nd, Izmir 3rd, Kocaeli 4th and Bursa 5th. Şırnak, Iğdır, Bayburt, Ardahan and Hakkâri were ranked last. The R&D innovation map created according to the results of the COPRAS method is shown in Figure 4.

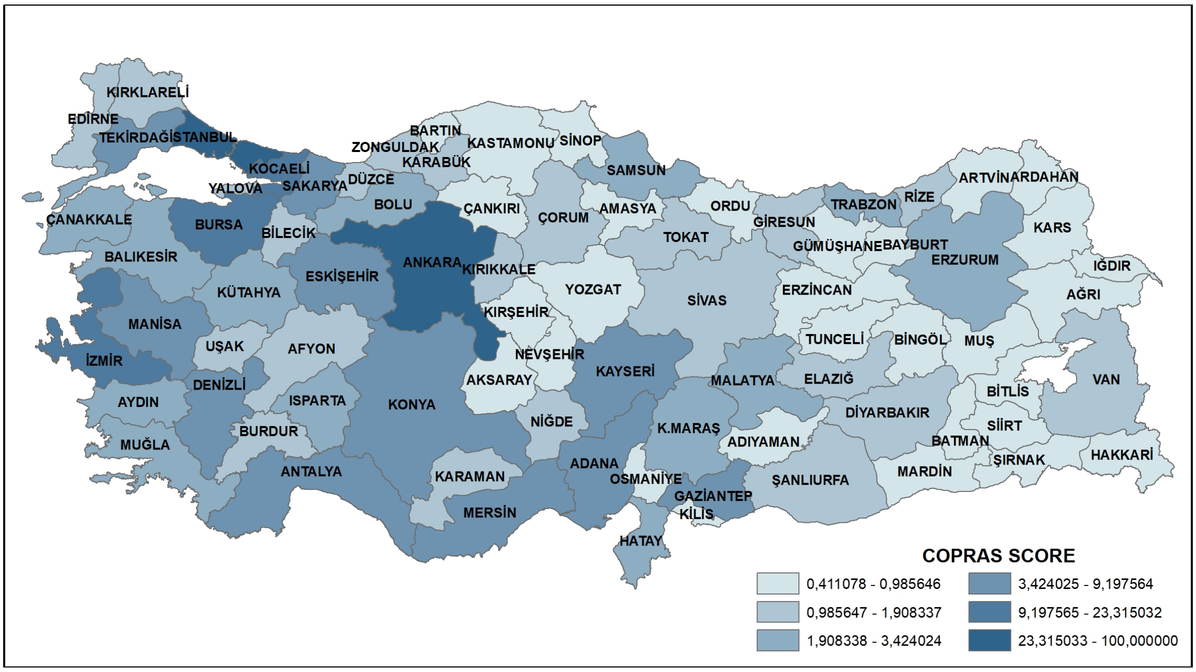

Figure 4. Performance map of provinces according to COPRAS Results

Table 9. COPRAS method performance ranking

Rank	Province	Score	Rank	Province	Score	Rank	Province	Score
1	İstanbul	100,000	**28**	Çanakkale	2,016	**55**	Kırşehir	0,912
2	Ankara	60,874	**29**	Hatay	1,975	**56**	Nevşehir	0,892
3	İzmir	23,315	**30**	Sivas	1,908	**57**	Adıyaman	0,878
4	Kocaeli	20,529	**31**	Düzce	1,879	**58**	Osmaniye	0,872
5	Bursa	18,690	**32**	Elazığ	1,812	**59**	Yozgat	0,858
6	Konya	9,198	**33**	Karabük	1,730	**60**	Erzincan	0,845
7	Kayseri	7,886	**34**	Yalova	1,710	**61**	Kastamonu	0,837
8	Eskişehir	7,391	**35**	Edirne	1,708	**62**	Çankırı	0,813
9	Antalya	7,241	**36**	Şanlıurfa	1,661	**63**	Mardin	0,765
10	Manisa	5,264	**37**	Diyarbakır	1,641	**64**	Sinop	0,746
11	Tekirdağ	5,229	**38**	Zonguldak	1,600	**65**	Bartın	0,646
12	Gaziantep	5,154	**39**	Kırklareli	1,444	**66**	Kars	0,643
13	Sakarya	5,067	**40**	Rize	1,393	**67**	Artvin	0,615
14	Adana	4,690	**41**	Van	1,344	**68**	Batman	0,610
15	Denizli	4,642	**42**	Afyonkarahisar	1,288	**69**	Tunceli	0,567
16	Mersin	4,413	**43**	Bilecik	1,243	**70**	Gümüşhane	0,562
17	Samsun	3,424	**44**	Tokat	1,197	**71**	Bingöl	0,557
18	Trabzon	3,287	**45**	Uşak	1,154	**72**	Siirt	0,541
19	Isparta	2,922	**46**	Çorum	1,150	**73**	Kilis	0,531
20	Balıkesir	2,774	**47**	Giresun	1,090	**74**	Muş	0,525
21	Aydın	2,668	**48**	Kırıkkale	1,072	**75**	Bitlis	0,510
22	Bolu	2,305	**49**	Burdur	1,068	**76**	Ağrı	0,507
23	Muğla	2,243	**50**	Niğde	1,063	**77**	Şırnak	0,507
24	Erzurum	2,171	**51**	Karaman	1,063	**78**	Iğdır	0,487
25	Kahramanmaraş	2,155	**52**	Amasya	0,986	**79**	Bayburt	0,474
26	Kütahya	2,126	**53**	Ordu	0,976	**80**	Ardahan	0,433
27	Malatya	2,053	**54**	Aksaray	0,970	**81**	Hakkâri	0,411

4. Results and Discussion

Since high and sustainable productivity growth driven by R&D and innovation is the main factor determining competitiveness, the ability to create and disseminate new ideas and transform them into new and profitable products, processes and services, and hence the development of infrastructure for R&D and innovation, is fundamental to increasing the value added generated. Since technological innovations cause changes in the competition structure, in products and processes as well as in markets, competition for scientific and technological competence has emerged among countries. Therefore, Technology Development Zones and R&D Centers have been established in many countries in order to rapidly put new knowledge into the service of technology by strengthening the cooperation between universities, the public sector and the business world. These centers contribute significantly to the development of countries through their functions such as increasing the productivity and competitiveness of enterprises in the region through R&D-oriented activities, providing high technology and innovation infrastructure, transferring technology, diversifying the economic activities of the region, and providing new job opportunities [7].

In order to achieve rapid progress in the field of R&D and innovation and to ensure a balanced development process in Turkey, not only macroeconomic policies and projections but also projections affecting the geographical spread of development are needed.

Within the scope of this study, DEMATEL, ARAS and COPRAS methods, which are multi-criteria decision-making techniques, were used to reveal Turkey's R&D and innovation potential and to make performance comparisons at provincial level. The model proposed for provinces to create an R&D and innovation performance index is based on the performance components Number of Design-Patent-Utility Model Applications, KOSGEB R&D Innovation Support Amount, TÜBİTAK TEYDEB Support Amount, TÜBİTAK ARDEB Support Amount, Number of Academic Staff, Number of Doctoral Degree Graduates, Number of Graduates with Master's Degree, Total Number of Technology Development Zones, R&D and Design Centers, Number of Personnel Employed in R&D and Design Centers, Socio-Economic Development Index Ranking (SEGE), URAK Interprovincial Competitiveness Index Ranking and Brand Skills and Innovation Ranking. According to the criteria weighting made with the DEMATEL method, the criterion with the highest importance was determined as Brand Skills and Innovation Ranking with 10%. The weights of the other criteria were found to be close to each other.

According to the 81 provincial R&D and innovation performance ranking results, Istanbul ranked first in both ARAS and COPRAS methods. Istanbul is followed by Ankara and Izmir, respectively. In addition to Istanbul, Ankara and Izmir, Kocaeli, Bursa, Konya, Kayseri and Eskişehir also have high performance.

In general, there are no major differences between the other provinces. The provinces of Ağrı, Iğdır, Bayburt and Hakkâri ranked last in both methods. When the distribution of R&D and innovation performance of provinces according to ARAS and COPRAS methods is analyzed, it is found that the provinces ranking first in the performance rankings are similar, and in general, the majority of provinces perform close to each other. It can also be said that provinces such as Manisa, Antalya, Gaziantep and Tekirdağ are developing in terms of R&D and innovation and follow the provinces in the first rankings.

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