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A comparative decision-making for electronic product purchases during a pandemic

Salgın sırasındaki elektronik ürün alımlarında karşılaştırmalı bir karar verme

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Abstract
During the Covid-19 pandemic, almost all courses from elementary education to universities are being modified for online education. Accordingly, the need for electronic products shows an increase in this pandemic condition. When students want to buy electronic products, i.e., tablets, laptops etc., they are faced with many different possible choices that vary in quality, features, and price. Multi-criteria decision-making methods are very usable tools for choosing the best possible alternative among many others in such situations. Therefore, in this work, two well-known method is taken into consideration so that students can choose the best possible electronic product to use them in online classes.

Keywords: Multicriteria decision making, Pandemic, TODIM, TOPSIS

Öz
Covid-19 salgını sürecinde ilköğretimden üniversitelere kadar neredeyse tüm dersler online eğitime dönüştürülmektedir. Dolayısıyla, bu salgın koşullarında elektronik ürünlere olan ihtiyaç artış göstermektedir. Öğrenciler elektronik ürünler, yani tabletler, dizüstü bilgisayarlar vb. satın almak istediklerinde kalite, özellik ve fiyat bakımından farklılık gösteren birçok farklı olası seçenekle karşı karşıya kalmaktadır. Çok kriterli karar verme yöntemleri, bu gibi durumlarda birçok alternatif arasından mümkün olan en iyi alternatifi seçmek için çok faydalı araçlardır. Bu nedenle, bu çalışmada, öğrencilerin çevrimiçi derslerde kullanmak üzere mümkün olan en iyi elektronik ürünü seçebilmeleri için iyi bilinen iki ÇKKV yöntemi ele alınmıştır.

***Anahtar kelimeler**: Çok kriterli karar verme, Salgın, TODIM, TOPSIS*

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1. Introduction

1. Giriş

Decision making is one of the most important fields in operation research which is based on mostly Churchman's studies (Churchman et al., 1957). Numerous works have been conducted since then, and very precious research have put a new complexion on literature. A MCDM problem contains a finite number of alternatives that is expressed with a finite number of criteria. To choose the best possible option, alternatives are evaluated under criteria using mathematical and computational tools. These tools are called MCDM methods. Mostly, these methods divide the problem data into smaller pieces, then process them with mathematical tools and finally give an output that can be ordered. Among the numerous MCDM methods, the most well-known ones are TOPSIS (Hwang & Yoon, 1981) and TODIM (Gomes & Lima, 1991).

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is known for its absence of complication and has drawn more attention compared to other well-known classical MCDM methods. The reason behind this situation is the easy implementation of the large number of criteria and alternatives to this method. It focuses on the distances from positive ideal solution and negative ideal solution to alternatives. The positive ideal solution maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Behzadian et al., 2012). This method has been applied in many areas such as supply chain management and logistics (Araz et al., 2008; Boran et al., 2009; Celik, 2010; Kahraman et al., 2007; Köseoğlu & Şahin, 2019), design, engineering and manufacturing systems (Chakravorty et al., 2013; C.-W. Chang, 2012; Zhang et al., 2010), health, safety and environment (Berger, 2006; Tzeng et al., 2005). Nevertheless, the application of this method continues today without any decrease. Looking at even only the last 3 years, it is seen that TOPSIS continues to be applied in supply chain management (Junaid et al., 2020; Ortiz-Barrios et al., 2020; Zulqarnain et al., 2021), manufacturing (Chatterjee & Stević, 2019; Jasiulewicz-Kaczmarek et al., 2021; Mathew et al., 2020), and health and safety (Hezer et al., 2021; Rajak & Shaw, 2019).

TODIM (Portuguese acronym for interactive and multicriteria decision-making) method is a discrete multicriteria method known with prospect theory (Kahneman & Tversky, 1979). It offers a solution that considers the behavioural expectations of an investor by considering this theory which was awarded the Nobel Prize for Economics in 2002. The main advantage of TODIM is that it includes the psychological character of the decision maker and can take into account the limited rationality of the decision makers. Moreover, this method contains an attenuation factor that can be changed during the decision-making process. TODIM method can be considered as an optimal method when a decision-making problem includes risk factors or when decision makers have different opinions while assessing the variables. TODIM method is applied to various real-life problems such as personnel selection (Ji et al., 2018), portfolio allocation (Alali & Tolga, 2019; Wu et al., 2022), supply chain (Abdel-Basset et al., 2020; Du et al., 2020; Kaur et al., 2022; Köseoğlu, 2022; Köseoğlu et al., 2020), and most commonly the risk management problems (Junaid et al., 2020; Mathew et al., 2020; Ortiz-Barrios et al., 2020; Wang et al., 2021).

During the pandemic, most face-to-face classes have been modified for online education from elementary education to universities. Therefore, students have a need for items such as laptops, tablets while teachers have a need for products like cameras and laptops. As a natural consequence, demand of electronic goods has seen an incredible increase. Moreover, electronic brands turn this situation into an opportunity and offer their customers multi-choice products. Although most brands used to have a specific range of products, a sharp increase was observed in product variability during the pandemic. People who need these products but do not know much about their parts have difficulty in these choices. Under these circumstances, it has become a necessity to choose the best electronic product suitable for the person. Multi-criteria decision-making methods are very useful tools in such situations. There are numerous valuable works for selection in electronics (T. W. Chang et al., 2021; Gao et al., 2020; Hsu et al., 2014; Loganathan & Mani, 2018; Rani & Mishra, 2020), but they are mostly about supplier selection problems. In the literature review, no study related to people's direct choice of electronic goods has been spotted.

In this study, TOPSIS and TODIM methods are selected for an electronic selection problem to choose the best possible product for a student, as students are most affected by this situation. TOPSIS method is an easily applicable method in situations involving large amounts of problem data. Since product selection problems can include many alternatives and criteria, it is very convenient to use this method. Of course, like any choice, the choice of these products also involves some risks. TODIM method is perfect for dealing with such risky situations where the behaviour of the decision maker can change according to the risk. Therefore, the problem for the selection of electronic products is conducted from the features that anyone can easily see in online shopping sites or technology stores using TOPSIS and TODIM methods. Finally, the results of these two methods are compared in detail.

2. Multicriteria decision making methods

2. Çok kriterli karar verme metotları

All MCDM methods are based on choosing the best possible alternative by taking into consideration the criteria. For convenience in next sections, let $A = \{A_1, A_2, \dots, A_m\}$ be a set of alternatives, $C = \{C_1, C_2, \dots, C_n\}$ be a set of criteria and $w = [w_1, w_2, \dots, w_n]$ be a weight vector with respect to criteria where $\sum_{j=1}^{n} w_j = 1$ and $w_j \geq 0$. Then a decision matrix A is constructed as

$$A = \begin{array}{c c} & \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \dots \\ A_m \end{array} & \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \end{array} \tag{1}$$

2.1. TOPSIS method

2.1. TOPSIS metodu

TOPSIS (the technique for order performance by similarity to ideal solution) is one of the most well-known classical MCDM methods proposed by Hwang & Yoon (1981). TOPSIS method is based on choosing alternatives that simultaneously have the smallest distance from the positive ideal solution and the longest distance from the negative-ideal solution. Steps of TOPSIS method are given as follows:

Step 1. Normalize the decision-making matrix A by

$$R_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \quad (i = 1,2, \dots, m; j = 1,2, \dots, n) \tag{2}$$

and obtain the normalized matrix R:

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{3}$$

where $r_{ij} \in [0,1]$.

Step 2. Obtain weighted normalized decision matrix V:

$$V_{mn} = R_{mn} \otimes w_n = \begin{bmatrix} r_{11}w_1 & \cdots & r_{1n}w_n \\ \vdots & \ddots & \vdots \\ r_{m1}w_1 & \cdots & r_{mn}w_n \end{bmatrix} \tag{4}$$

where $w_i = (w_1, w_2, \dots w_n)^{\mathrm{T}}$ is the weight vector and $\sum_{i=1}^{n} w_i = 1$.

Step 3. Determine positive-ideal solution and negative ideal solution:

Let J_1 be a benefit criteria set and J_2 be a cost criteria set, then A^+ is the positive ideal solution and A^- is the negative ideal solution which are formulated as $A^+ = (v_1^+, v_2^+, \dots, v_n^+)$ and $A^- = (v_1^-, v_2^-, \dots, v_n^-)$ where

$$v_j^+ = \begin{cases} \max\limits_i v_{ij}, & j \in J^+ \\ \min\limits_i v_{ij}, & j \in J^- \end{cases} \qquad v_j^- = \begin{cases} \min\limits_i v_{ij}, & j \in J^+ \\ \max\limits_i v_{ij}, & j \in J^- \end{cases} \tag{5}$$

Step 4. Calculate the separation measures:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \qquad S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{6}$$

Step 5. Calculate the relative closeness coefficient to ideal solution:

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} \quad \text{where } 0 \leq C_i \leq 1. \tag{7}$$

Step 6. Rank the alternatives:

After the relative closeness coefficient of each alternative is determined, alternatives are ranked according to descending order of C_i. Note that, the use of benefit and cost criteria in TOPSIS method is in the third step while calculating the positive and negative ideal solution. Therefore, normalizing process is different from the TODIM method.

2.2. TODIM method

2.2. TODIM metodu

TODIM method (an acronym in Portuguese of Interactive and Multi-criteria Decision Making) is a discrete multi-criteria decision-making method based on Prospect Theory (Kahneman & Tversky, 1979) proposed by Gomes & Lima (1991). TODIM method can consider the bounded rationality of the decision makers based on Prospect Theory, so it can represent the decision maker's behaviors. The steps of TODIM method are given as follows:

Step 1: Normalize the decision matrix $A = (a_{ij})_{m\times n}$ into a matrix $X = (x_{ij})_{m\times n}$ using:

$$\begin{cases} x_{ij} = \dfrac{a_{ij} - min(a_{ij})}{max(a_{ij}) - min(a_{ij})} & (i = 1,2,\dots,m; j = 1,2,\dots,n), \text{ if } C_j \text{ is benefit criteria} \\ x_{ij} = \dfrac{max(a_{ij}) - a_{ij}}{max(a_{ij}) - min(a_{ij})} & (i = 1,2,\dots,m; j = 1,2,\dots,n), \text{ if } C_j \text{ is loss criteria} \end{cases} \tag{8}$$

Step 2: Calculate the relative weight w_{cr} of criterion C_c according to the expression $w_{cr} = \frac{w_c}{w_r}$ where $w_r = \max\{w_c | c = 1,2,\dots,n\}$

$$\delta(A_i, A_j) = \sum_{c=1}^{n} \Phi_c(A_i, A_j) \tag{9}$$

where:

Step 3: Calculate the dominance of each alternative A_i over each alternative A_j using the following expression:

$$\Phi_c(A_i, A_j) = \begin{cases} \sqrt{\dfrac{w_{cr}}{\sum_{c=1}^{m} w_{cr}} \cdot d(x_{ic}, x_{jc})}, & if\ x_{ic} > x_{jc} \\ 0, & if\ x_{ic} = x_{jc} \\ \dfrac{-1}{\theta}\sqrt{\dfrac{\sum_{c=1}^{m} w_{cr}}{w_{cr}} \cdot d(x_{jc}, x_{ic})}, & if\ x_{ic} < x_{jc} \end{cases} \tag{10}$$

Here, θ is the attenuation factor given by the decision maker. Although the optimal value of the attenuation factor of losses θ should be approximately 2.25 according to Qin et al. (2017), it is seen in many studies that the change of θ affects the results in terms of ranking.

Step 4: Calculate the global value of the alternative i by normalizing the final matrix of dominance according to the following expression:

$$\xi_i = \frac{\sum_{j=1}^{n} \delta(A_i, A_j) - \min_i\left(\sum_{j=1}^{n} \delta(A_i, A_j)\right)}{\max_i\left(\sum_{j=1}^{n} \delta(A_i, A_j)\right) - \min_i\left(\sum_{j=1}^{n} \delta(A_i, A_j)\right)} \tag{11}$$

Ordering the values ξ_i provides the rank of each alternative. The higher the ξ_i is, the better the alternative is.

3. Numerical application and results

3. Sayısal uygulama ve sonuçlar

Due to the Covid-19 pandemic, the educational systems of both Turkey and the most countries in the world have moved to online education. But still, most of the students and the teachers are not ready to embrace the online system due to lack of equipment such as laptops. Although this situation affects everyone in the world, considering the economic situation of the students, it would be more appropriate to consider an example for them. Therefore, let us consider a multicriteria decision making problem that determines the most suitable laptop for a student.

Suppose a student needs a laptop for online classes and is not good with computers. The most salient parts of a laptop to be used in online courses are usually its screen size and price. However, these laptops offered for sale have many different parts and features such as processor, ram, and operating system. Many criteria can be discussed here, but to reduce confusion and not spoil the main idea of the research, let's consider the 9 most frequently viewed criteria. Let C_j shows the criteria for $j = 1,2,\dots,9$ and A_i shows the alternatives to buy for $i = 1,2,\dots 6$.

C_1: Size of the monitor (Inches). The bigger is the better.
C_2: Processor type (Intel). It is ordered as i3, i5 and i7.
C_3: Ram size (GB). The bigger is the better.
C_4: Hard drive (MB). The bigger is the better.
C_5: Graphic Processor (GeForce). The bigger is the better.
C_6: Price (₺)
C_7: Brand credibility (1-5). 1 is the lowest and 5 is the highest.
C_8: Estimated failure rate (1-5). 1 is the best and 5 is the worst.
C_9: Estimated service repair time (1-5). 1 is the best and 5 is the worst.

The student who will choose among these alternatives according to the criteria should rate which criteria are important to him or not. He assigns a higher value to whichever criterion is more important to him, and a lower value to whichever criterion is less important to him. Scoring the criteria so that they add up to 100 and then dividing these values by 100 is an easy way to determine the criteria weights. Let the student determines the criteria weights as $w = [0.13\ 0.09\ 0.08\ 0.08\ 0.10\ 0.20\ 0.09\ 0.11\ 0.12]$. Here, price is the most important criteria for a student when compared to others. Similarly, ram size or hard drive size are less important ones when compared to others. In addition, whether a criterion is a benefit or loss criterion is also important when using decision-making methods. For example, the price criterion is a loss criterion because it causes us a loss in terms of money. For this problem, C_6, C_8 and C_9 are the loss criteria. The decision matrix A is constructed as Table 1 according to the student's preferences with respect to criteria.

Table 1. Decision matrix A
Tablo 1. *A karar matrisi*

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	15.6	5	8	512	1650	10000	4	2	1
A_2	17	7	16	1000	1660	13000	5	3	2
A_3	14	3	12	512	250	12500	3	5	3
A_4	13.3	3	8	256	250	9500	3	5	3
A_5	15.6	7	16	1000	2060	14500	5	4	2
A_6	17	5	8	512	2070	15250	4	5	4

3.1. Decision making with TOPSIS
3.1. TOPSIS ile karar verme

Using the student's preferences from Table 1, the steps of TOPSIS method are performed in MATLAB. First, the decision matrix A is normalized using the Eq. (2) and (4) together. The weighted normalized matrix V is obtained as:

$$V = \begin{bmatrix} 0.0535 & 0.0349 & 0.0220 & 0.0243 & 0.0439 & 0.0646 & 0.0360 & 0.0216 & 0.0183 \\ 0.0583 & 0.0489 & 0.0440 & 0.0474 & 0.0442 & 0.0840 & 0.0450 & 0.0324 & 0.0366 \\ 0.0480 & 0.0210 & 0.0330 & 0.0243 & 0.0067 & 0.0808 & 0.0270 & 0.0539 & 0.0549 \\ 0.0456 & 0.0210 & 0.0220 & 0.0121 & 0.0067 & 0.0614 & 0.0270 & 0.0539 & 0.0549 \\ 0.0535 & 0.0489 & 0.0440 & 0.0474 & 0.0548 & 0.0937 & 0.0450 & 0.0431 & 0.0366 \\ 0.0583 & 0.0349 & 0.0220 & 0.0243 & 0.0551 & 0.0985 & 0.0360 & 0.0539 & 0.0732 \end{bmatrix}$$

The positive-ideal solution and negative ideal solution are obtained using the Eq. (5) as:

$$v_j^+ = [0.0583 \quad 0.0489 \quad 0.0440 \quad 0.0474 \quad 0.0551 \quad 0.0614 \quad 0.0450 \quad 0.0216 \quad 0.0183]$$
$$v_j^- = [0.0456 \quad 0.0210 \quad 0.0220 \quad 0.0121 \quad 0.0067 \quad 0.0985 \quad 0.0270 \quad 0.0539 \quad 0.0732]$$

From the Eq. (6), separation measures are calculated as:

$S_i^+ = [0.0381 \quad 0.0329 \quad 0.0835 \quad 0.0879 \quad 0.0432 \quad 0.0821]$
$S_i^- = [0.0842 \quad 0.0801 \quad 0.0304 \quad 0.0414 \quad 0.0818 \quad 0.0541]$

Finally, using the Eq. (7) the relative closeness coefficient to ideal solution is calculated as:

$C_i = [0.6884 \quad 0.7089 \quad 0.2669 \quad 0.3203 \quad 0.6543 \quad 0.3974]$

According to relative closeness coefficient, the alternatives are ordered as

$A_2 > A_1 > A_5 > A_6 > A_4 > A_3$.

According to this order, A_2 is a good option for a student to buy a laptop.

3.2. Decision making with TODIM
3.2. TODIM ile karar verme

Using the student's preferences from Table 1, the steps of TODIM method are also performed in MATLAB. First, the decision matrix A is normalized using the Eq.(8). The normalized matrix X is obtained as:

$$X = \begin{bmatrix} 0.6216 & 0.5000 & 0.0000 & 0.3441 & 0.7692 & 0.9130 & 0.5000 & 1.0000 & 1.0000 \\ 1.0000 & 1.0000 & 1.0000 & 1.0000 & 0.7747 & 0.3913 & 1.0000 & 0.6667 & 0.6667 \\ 0.1892 & 0.0000 & 0.5000 & 0.3441 & 0.0000 & 0.4783 & 0.0000 & 0.0000 & 0.3333 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000 & 0.0000 & 0.3333 \\ 0.6216 & 1.0000 & 1.0000 & 1.0000 & 0.9945 & 0.1304 & 1.0000 & 0.3333 & 0.6667 \\ 1.0000 & 0.5000 & 0.0000 & 0.3441 & 1.0000 & 0.0000 & 0.5000 & 0.0000 & 0.0000 \end{bmatrix}$$

Then, relative weight w_{cr} is calculated as:

$w_{cr} = [0.6500 \quad 0.4500 \quad 0.4000 \quad 0.4000 \quad 0.5000 \quad 1.0000 \quad 0.4500 \quad 0.5500 \quad 0.6000]$

Taking $\theta = 2.25$, the dominance of each alternative A_i over each alternative A_j is evaluated using Eq. (9) and (10) as

$$\delta(A_i, A_j) = \begin{bmatrix} 0 & -5.0870 & 0.7370 & 1.4732 & -4.7397 & -0.3280 \\ -1.0509 & 0 & 1.8098 & 1.5000 & -0.0172 & 1.1025 \\ -6.9813 & -9.3967 & 0 & -0.1951 & -8.8095 & -3.9013 \\ -7.4771 & -10.0614 & -2.2460 & 0 & -9.5765 & -5.0078 \\ -1.6278 & -1.8913 & 1.3869 & 1.2301 & 0 & 0.7096 \\ -3.1990 & -7.5524 & -1.4740 & -0.4676 & -6.8740 & 0 \end{bmatrix}$$

Since the distance between two same alternatives is 0 according to Eq. (10), each $\Phi_c(A_i, A_i) = 0$ and thus the diagonal of matrix $\delta(A_i, A_j)$ is 0. Finally, using the Eq. (11), global values of the alternatives are obtained as:

$\xi_i = [0.7007 \quad 1.0000 \quad 0.1348 \quad 0 \quad 0.9062 \quad 0.3925]$

According to global values of the alternatives, the alternatives are ordered as $A_2 > A_5 > A_1 > A_6 > A_3 > A_4$. Then, A_2 is also the appropriate alternative for the student to purchase.

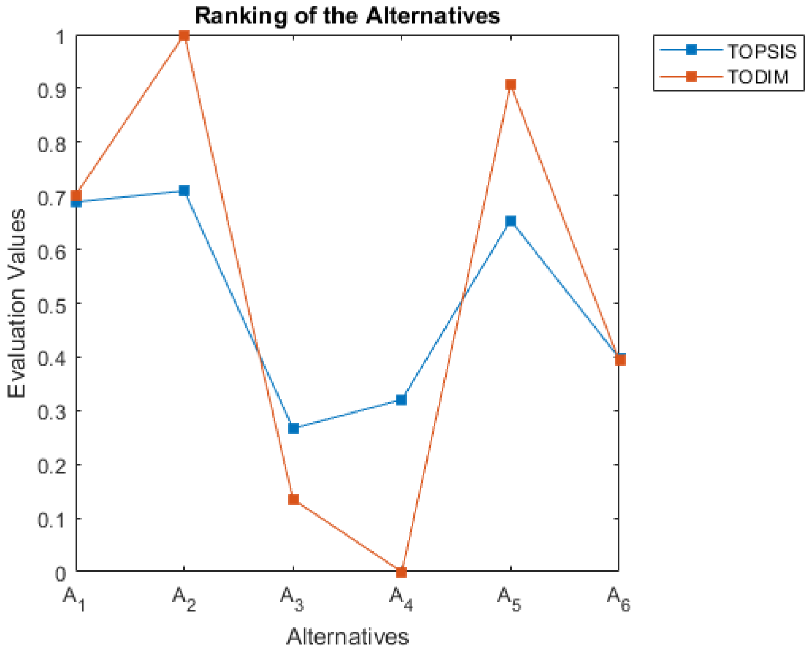

Figure 1. Ranking comparison of the alternatives with TOPSIS and TODIM
Şekil 1. *TOPSIS ve TODIM ile alternatiflerin sıralamalarının karşılaştırılması*

When both methods are compared, rankings and evaluation values are close to each other except slight differences as can be seen in Figure 1 and Table 2. One of the reasons of these differences is, although the evaluation values of both methods are in the [0,1] interval, TODIM's values are certain values such as the best one is 1 and worst one is 0. The other reason is the change of the ranking order. The order of A_1 and A_5, and A_4 and A_3 changes when different methods are used. The reason behind this is of course that TOPSIS and TODIM are two different methods. They have their own advantages and disadvantages. If the information in the problem is too much, it is more advantageous to use the TOPSIS method. However, if the problem includes risk factors, it may be more advantageous to use the TODIM method. So, it is almost impossible to say that one method is the best compared to the others. Moreover, these methods give a consistent result, except for minor differences that we can see from the ranking.

Table 2. Comparison of rankings
Tablo 2. *Sıralamaların karşılaştırılması*

Methods	Rankings
TOPSIS	$A_2 > A_1 > A_5 > A_6 > A_4 > A_3$
TODIM	$A_2 > A_5 > A_1 > A_6 > A_3 > A_4$

4. Conclusion
4. Sonuç

In this paper, TOPSIS method and TODIM method are taken into consideration for a decision-making problem regarding all students worldwide. The case of increasing electronic sales is picked for numerical example. Especially the need for laptop purchases is addressed during the pandemic. Six laptop alternatives are selected with respect to nine criteria. First, a decision matrix is created in accordance with a student's necessities and the importance of each criterion is identified. Then, the best possible alternative is acquired with TOPSIS method. Using same inputs, the decision matrix is put into process with TODIM method. The quite similar results are obtained, and these results also show the consistency of the MCDM methods. Thus, a student can use one of these methods to buy not only laptops but also different kinds of electronics if required. However, each method has its own advantages. It should be noted that the best alternative may vary with slight differences, although the rankings may look similar when different methods are used.

In future studies, this problem can be adapted to other MCDM methods such as MABAC, ELECTREE, and COPRAS. Furthermore, fuzzy, intuitionistic fuzzy and neutrosophic extensions of these MCDM methods can also be used to solve this kind of problems.

Author contribution
Yazar katkısı

All authors contributed equally to the study.

Declaration of ethical code
Etik beyanı

The authors of this article declare that the materials and methods used in this study do not require any ethical committee approval and/or legal-specific permission.

Conflicts of interest
Çıkar çatışması beyanı

The authors declare that there is no conflict of interest.

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