Bitlis Eren Üniversitesi Fen Bilimleri Dergisi
BİTLİS EREN UNIVERSITY JOURNAL OF SCIENCE
ISSN: 2147-3129/e-ISSN: 2147-3188
VOLUME: 12 NO: 4 PAGE: 1117-1127 YEAR: 2023
DOI:10.17798/bitlisfen.1340121

The Selection of the Appropriate Conductive Yarn Using Analytical Hierarchy Process

Duygu ERDEM AKGÜN[1*], Münire Sibel ÇETİN[2]

[1]*Selcuk University, Faculty of Architecture and Design, Fashion Design Department, Konya, Turkey*
[2]*Istanbul Technical University, Faculty of Textile Technologies and Design, Textile Engineering Department, Istanbul, Turkey*
(ORCID: 0000-0002-8277-3589) (ORCID: 0000-0003-1875-3302)

Keywords: AHP, Conductive yarn, Electronic Textiles, Multi-criteria decision-making.

Abstract
Conductive yarns are one of the most preferred products that are used for electronic textile products. Although conductive yarns have a wide range of application areas, it is also important to choose the most appropriate yarn according to the intended use. In this study, it was aimed at selecting the most appropriate conductive yarn for a textile factory that makes production using conductive yarn. Within this scope, 8 criteria and 3 conductive yarn alternatives are determined, and a form that includes criteria was sent to 7 experts via e-mail and they were asked to evaluate the criteria for steel, graphene, and silver-plated yarns according to the AHP fundamental scale table. The matrices obtained from the forms filled out by the experts were evaluated with the help of the AHP method. As a result, it has been determined that graphene yarn is the most appropriate yarn for a textile factory among the alternatives according to the specified criteria.

1. Introduction

The rapid increase in technological developments after the Industrial Revolution and the fact that researchers turn to interdisciplinary studies enable innovative products to emerge. One of the most important technological developments that emerged as a result of interdisciplinary studies is wearable technologies [1]. "Wearable technology" concept is defined as the technology which is incorporated into the wearable accessories directly worn on the body [2].

Another concept developed from the concept of wearable technology is the concept of electronic textiles [3]. Electronic textiles are the technical and functional products that result from the combination of materials, design tools and production methods from the two major industries of textile and electronics industries that continue to develop [4].

Nowadays, the increasing importance of studies on electronic textiles and wearable electronics and the increase in commercial products developed and released in this category have led to the production of conductive yarn from sample size to commercial size. Conductive yarns are one of the most preferred conductive textile products that are used both to produce textile surfaces or textures and connection paths. Wearable products manufactured with conductive yarns are frequently encountered in fields such as healthcare, sports, the military, home textiles, and leisure-time products. Although conductive yarns have such a wide range of application areas, it is also important to choose the most appropriate yarn according to the intended use and the process to be applied. Metal ratio, conductivity, flexibility, biocompatibility, mechanical strength, washability, usability in the machine for production, and price are the most important criteria for conductive yarns [5]. In addition

*Corresponding author: *duygu.erdem@selcuk.edu.tr*
Received: 09.08.2023, Accepted: 08.12.2023

to these criteria, there are many different types of conductive yarns, too. The situation becomes more difficult in systems where there are multiple criteria affecting decision-making. In cases where there is a single criterion in decision-making processes, the problem can be easily solved; however, this becomes more difficult as the criteria increase [6].

The decision-making actions of companies are much more complicated and important than people's decision-making actions in daily life. The main reason for this is that every decision taken affects all other units of the company and has a much greater impact on the profitability of the company than expected. Today, different Multi-Criteria Decision-Making Methods (MCDMM) are available for the solution of decision-making problems that contain multiple evaluation criteria, both for companies and our daily lives. Multi-criteria decision-making techniques frequently encountered in literature are DEMATEL (The Decision-Making Trial and Evaluation Laboratory), AHP (Analytical Hierarchy Process), ANP (Analytic Network Process), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), MOORA (Ratios Analysis and Reference Point Approach) and ELECTRE (Elimination and Choice Translating Reality English) [6]-[9].

The choice of multi-criteria decision-making method to be used in the evaluation varies according to the level of knowledge required for each factor, and each method works with a different solution logic. In this paper, the Analytical Hierarchy Process (AHP) method, which is one of the multi-criteria decision-making methods, was chosen and applied. The AHP method decomposes the problem into subcomponents, and the basis of the AHP method is based on both criteria and binary comparisons between alternatives. These binary comparisons include a comparison of the importance of criteria or alternatives according to each other. The calculations for selection or grading are then performed on these binary comparison matrices [6], [10], [11].

In this study, it was aimed at selecting the most appropriate conductive yarn for a textile factory that makes production using conductive yarn. To construct a hierarchical structure, the alternatives are first determined as steel, graphene, and silver-plated yarns. Then, 8 criteria (metal ratio, conductivity, flexibility, biocompatibility, mechanical strength, washability, usability of the machine for production, and price) are determined. After generating the hierarchical structure, binary comparison matrices were established, and the alternatives were listed from the best to the worst.

2. Material and Method

Within the scope of this study, firstly, 8 criteria that are effective in the purchase of conductive yarn were determined. These criteria are metal ratio (C1), conductivity (C2), flexibility (C3), biocompatibility (C4), mechanical strength (C5), washability (C6), usability of the machine for production (C7), and price (C8). Then, 3 conductive yarn alternatives were determined. These alternatives are steel (A1), graphene (A2), and silver-plated (A3) yarns (Table 1).

Table 1. The properties of conductive yarn alternatives

Steel yarn	Graphene yarn	Silver-plated yarn
Bekinox® stainless steel yarns	RESISTEX® GRAPHENE	Shieldex silver-plated yarns
		
These stainless steel yarns are flexible and durable electrically conductive yarns. These yarns are used in a wide range of applications related to Anti-static (ESD), intelligent textiles, signal and power transfer, heat-resistant sewing yarn, and thermal conductivity. The yarns can be easily knit, sewn, or woven to produce any type of textile.	It has a higher tenacity and abrasion resistance than normal polyester or polyamide yarns. The electrical conductivity of this yarn can range from 10^3 Ω to 10^6 Ω, placing it in the range of both antistatic and conductive yarns.	This yarn has <600 Ω/m electrical resistance. Due to its higher silver content, it is highly conductive. With their antistatic and antibacterial properties and high electrical and thermal conductivity, these conductive yarns can be used in a wide range of applications. The full silver-plated polyamide yarns can be twisted, knitted, embroidered, woven, and spun like uncoated yarns.

After the determination of the criteria and alternatives, two forms (Appendix 1 and Appendix 2), which include criteria, were sent to 7 experts who are actively working in the textile sector and effective in the decision to purchase conductive yarn, and they were asked to evaluate the criteria for steel, graphene, and silver-plated yarns according to the AHP fundamental scale table. The matrices obtained from the forms filled out by the experts were evaluated with the help of the AHP method, priority vectors were determined, and the alternatives were listed according to their importance weight. Therefore, it has been determined which yarn is the most appropriate for a textile factory to choose among the alternatives according to the specified criteria.

In the study, Adobe Acrobat Pro DC was used to create the fillable forms, and Microsoft® Excel version 16.16.14 was used to make the calculations.

2.1. Analytical Hierarchy Process

There are many methods known as Multi-Criteria Decision Analysis (MCDA) for solving problems [11].

The Analytical Hierarchy Process (AHP) is a decision-making technique that measures all objective and subjective criteria by pairwise comparison and allows them to be quantitatively evaluated by determining their order of importance. Analytical Hierarchy Process (AHP), one of the multi-criteria decision-making methods, was introduced by Myers and Alpert in 1968, and it was developed by Thomas L. Saaty as a model [13].

This method can be applied easily, even to very complex problems, because it takes into account both quantitative and qualitative factors, is applicable to individuals or groups, is easy to use, and does not require special expertise [13], [14].

In this study, the Analytical Hierarchy Process was chosen because it is a widely used tool that enables decision-makers to make decisions, allowing all important criteria to be taken into account and arranged in a hierarchy.

In the Analytical Hierarchy Process, calculations for the selection problems are made using the simple four arithmetical operations. Criteria (price, quality, distance, etc.) that are considered important for the decision-maker are determined in order to carry out the selection process among the alternatives in the selection problem. Decision-makers should express the importance of each criterion according to themselves. Hence, the fundamental scale, which is recommended by Thomas L. Saaty and contains the determined values for importance, is used (Table 2) [15].

Table 2. The fundamental scale

The intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When comprimise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

The Analytical Hierarchy Process has four different axioms. These are named reciprocal, homogeneity, independence, and expectation axioms. The AHP axioms allow for the derivation of ratio scales of absolute numbers through decision-makers’ responses to pairwise comparisons [16].

1. Reciprocal Axiom: According to the decision-maker in this axiom, if criterion A is m times more important than criterion B, criterion B is 1/m times more important than criterion [12]. To give an example, if one stone is judged to be five times heavier than another, then the other is automatically one fifth as heavy as the first because it participated in making the first judgement [16]. This axiom is used to form the comparison matrices. By means of this axiom, the number of questions to be asked to the decision-maker in order to determine the importance of the criteria has fallen in half.

2. Homogeneity Axiom: This axiom is based on the fact that there is no significant difference between the elements to be compared. If the differences between the elements are high, significant measurement errors will occur. Therefore, homogeneity is important to make meaningful comparisons. Since the elements can't be compared to being infinitely significant ($a_{ij} \neq \infty$), a scale in the range 1-9 from the fundamental scale is used.

3. Independence Axiom: This axiom is also named the synthesis axiom. In this axiom, when binary comparisons are made between the alternatives in the selection problem and the criteria used to solve the problem, each alternative and criterion is assumed to be independent of each other. This means that the priorities of the higher-level criteria will not change when a new alternative is added or removed [14], [18], [19]. This axiom plays an active role in the generation of the hierarchical structure.

4. Expectation Axiom: This axiom states that all criteria and alternatives affecting the decision should be included in the hierarchical structure. Decision-makers want to make certain that all their ideas are adequately represented in a hierarchical structure, as they have reasons for their decisions. The hierarchical structure established should meet the expectations of the decision-makers and should include all the elements (objective/target, criteria, sub-criteria, and alternatives) related to the decision problem. Otherwise, the decision-maker will not use all criteria or alternatives, and the decision will be inadequate [19], [20].

2.1.1. Application Steps of Analytical Hierarchy Process

The Analytical Hierarchy Process consists of 7 steps in total.

Step 1: Defining the Problem and Constructing the Appropriate Hierarchical Structure

The first step of the AHP method is to identify the problem clearly after it is determined. After defining the problem, all the criteria required in the solution process and all the alternatives to be evaluated should be determined completely. Thereafter, the hierarchical structure is generated with the aim or target at the top, the criteria sets (criteria and sub-criteria) of the problem at the second level, and the alternatives to be evaluated in the problem at the bottom, as seen in Figure 1 [6].

The purpose of the hierarchical structure is to determine the effect of upper-level elements on lower-level elements or the contribution of lower-level elements to the importance or completion of upper-level elements [14].

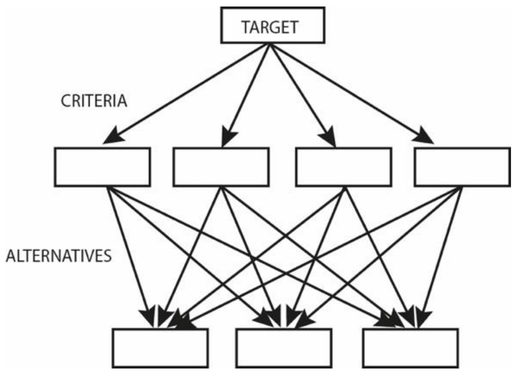


Figure 1. Analytical hierarchy structure

Step 2: Defining Priorities/Importance and Generating the Binary Comparison Matrices

After the problem is expressed in a hierarchical structure, it is necessary to calculate its importance relative to each other by comparing the elements that compose that level. For this purpose, binary comparison matrices are generated. The values in the fundamental scale proposed by Saaty are used to generate these matrices.

$$A = [a_{11} a_{12} \dots\ a_{1n} a_{21} a_{22} \dots\ a_{2n} \vdots\vdots \cdots \vdots\ a_{n2} \cdots a_{nn}]$$

A: Binary comparison matrix, a_{ij}: the importance of element "i" when compared to element "j" (i, j= 1, 2, 3, …., n)

Binary comparisons are performed for only one side of the principal diagonal of the comparison matrix based on the reciprocal axiom. The values at the bottom of the diagonal are determined according to the reciprocal axiom, and the values at the top of the diagonal are inverted according to the multiplication, and filled into the cells in the symmetry of the principal diagonal. In other words, when the weight of property i is expressed as wi and the weight of property j is expressed as wj; it can be said that $a_{ij} = w_i / w_j$ [14].

$$A = \left[\frac{W_1}{W_1}\frac{W_1}{W_2}\cdots\frac{W_1}{W_n}\frac{W_2}{W_1}\frac{W_2}{W_2}\cdots\frac{W_2}{W_n}\vdots\vdots\cdots\vdots\frac{W_n}{W_1}\frac{W_n}{W_2}\cdots\frac{W_n}{W_n}\right]$$

$$= [1 a_{12} \cdots a_{1n} \frac{1}{a_{12}} 1 \cdots a_{2n} \vdots\vdots \cdots \vdots \frac{1}{a_{n1}}\frac{1}{a_{n2}} \cdots 1]$$

Since each criterion does not dominate over itself, the values on the principal diagonal are filled to be equally important (to take the value of 1) [6].

The binary comparison matrix is a n x n-sized square matrix. The values in the cells of this matrix indicate how much more important the element in each row is than the element in each column. The equation in which the number of comparisons to be used to form the binary comparison matrix can be calculated is as follows:

$$Number\ of\ comparison = \frac{(n)x(n-1)}{2} \tag{1}$$

n= Number of criteria to be evaluated

If the decision given for the solution of the problem will affect many people, binary comparison matrices form by combining the judgements of different individuals. In this combining process, geometric averages of the judgements of different individuals are generally taken to obtain consistent binary comparison matrices [14].

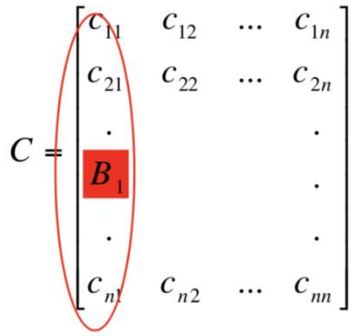
Step 3: Normalization Process and Generating of Priority Vector of Criteria

Once the binary comparison matrix is generated, the comparison matrix is first normalized to calculate the priority of weight vectors. The value in each cell of the binary comparison matrix is divided by the sum of the values in the column individually for the normalization process. The matrix obtained as a result of this process will be the normalization matrix (C). If this process is formulated, first of all, a B column vector is generated with n size and n components using the following formula:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

$$B_i = [b_{11} b_{21} \vdots b_{n1}]$$

These matrix vectors are collocated and C matrix is obtained.



Then, priority/weight vector (W) or percentage importance distributions that show the importance of the factors relative to each other can be obtained using the normalized matrix (C). The elements of the column vector, called the priority vector, are obtained by calculating arithmetic mean of the row elements of the matrix C using the following formula wi.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{3}$$

$$W = [w_1 w_2 \vdots w_n]$$

The results obtained from this formula represent the importance weights of the criteria if they were performed for the criteria and the weight vector of the alternatives for that criterion if they were performed for the alternatives [13], [14].

Step 4: Calculation of Consistency Ratio

It should be tested whether the decision-maker is consistent when performing binary comparisons between criteria. A consistency ratio (CR) must be found for each matrix to test its consistency. The consistency ratio is a ratio recommended by Saaty and used to determine the level of human error that can be made in binary comparison matrices. It is calculated by dividing the consistency index (CI) by the random consistency index (RI).

$$CR = \frac{CI}{RI} \tag{4}$$

Random consistency index (RI) is a predetermined index by Saaty based on the number of criteria, ie matrix size. RI values corresponding to the matrix size are shown in Table 3 [10].

Table 3. Random consistency index

n (matrix size)	1	2	3	4	5	6	7	8	9	10
Random consistency index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Consistency index is calculated using the following formula:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (5)$$

In this formula, λ_{max} represents the greatest eigenvalue. In order to calculate this value, firstly the column vector D is obtained by multiplying the binary comparison matrix (A) with the priority vector (W).

$$D = AxW = [a_{11}a_{12} \cdots a_{1n}a_{21}a_{22} \cdots a_{2n} \vdots\vdots \cdots \vdots$$
$$a_{n1}a_{n2} \cdots a_{nn}]x[w_1 w_2 \vdots w_n] \quad (6)$$

Then, a new column vector is obtained from the division of the reciprocal elements of column vector D and column vector W, which contains the fundamental values (E) for each evaluation factor. The largest eigenvalue (λmax) of the matrix is found by taking the arithmetic mean of the fundamental values in this vector [14], [21], [22].

$$E_i = \frac{d_i}{w_i}(i = 1,2,\cdots,n) \quad (7)$$

$$\lambda\text{max} = \frac{\sum_{i=1}^{n} E_i}{n} \quad (8)$$

For a matrix obtained as a result of binary comparisons to be consistent, the largest eigenvalue (λmax) of the matrix must be equal to the size (n) of the matrix [24]. The largest eigenvalue obtained from these processes is placed in the formulas CI and CR, and CI and CR are calculated using the formulas, respectively. The consistency ratio is expected to be less than 0.1 at the end of the test. Results can be used if the test result is consistent. However, if it is inconsistent, comparisons should be repeated, or subjects that may be wrong should be reviewed.

Step 5: Calculation of Priority Vectors of Alternatives for Each Criteria

This step consists of 4 steps in itself.
Step 1: Binary comparison matrices are obtained by comparing alternatives for each criterion.
Step 2: The normalization of the binary comparison matrices is performed.
Step 3: From the normalization matrices obtained for each criterion, the process of generating priority vectors (column vectors of size mx1) is performed using formula (3).

$$S_i = [S_{11}S_{21} \vdots S_{m1}]$$

Step 4: λ_{max}, CI and CR values are calculated for each criterion separately, and consistency control is performed. If the matrices created for each criterion as a result of step 4 are consistent, it means that the results obtained through these matrices are usable. In other words, priority vectors obtained by binary comparison of alternatives for each criterion can be used in problem-solving when constructing a decision matrix [6].

Step 6: Generating the Decision Matrix with Aggregation Procedure

At this stage, the decision matrix (K) is generated by combining the priority vectors (Si, column vectors) obtained in the 5th step of the AHP application.

$$K = [S_{11}S_{12} \cdots S_{1n}S_{21}S_{22} \cdots S_{2n} \vdots \cdots \cdots \vdots S_{m1}S_{m2} \cdots S_{mn}]$$

The values in the obtained decision matrix represent the priority weights of the alternatives for each criterion [6].

Step 7: Sensitivity Analysis by Calculating Ultimate Priority Vectors

It should be determined that the model established depends on which criteria or criterion to what extent by sensitivity analysis [18]. For that purpose, column vector L with m elements is obtained by multiplying the priority vector (W, column vector) and the decision matrix (K) obtained in the 6th step.

$$L = KxW = [S_{11}S_{12} \cdots S_{1n}S_{21}S_{22} \cdots S_{2n} \vdots \cdots \cdots \vdots$$
$$S_{m1}S_{m2} \cdots S_{mn}]x[w_1 w_2 \vdots w_n] = [l_{11}l_{21} \vdots l_{m1}] \quad (9)$$

Each element of the obtained column vector (L) shows the percentage distribution/importance order of the decision alternatives. Consequently, the sum of these elements will be 1. The alternative with the largest value/importance in the column vector L is the most suitable alternative [13], [23], [24].

3. Results and Discussion

The problem of this study is "the selection of the most appropriate conductive yarn for a textile factory that uses conductive yarn in its production line." To construct a hierarchical structure, first of all, the alternatives should be determined in this selection problem. For this purpose, three commonly used conductive yarn types have been identified. Secondly, in order to solve this problem with the analytical hierarchy process and construct a hierarchical structure, the criteria should be determined for the evaluation of conductive yarn selection. Therefore, studies in the literature have been examined, and it has been found that 8 of the criteria affecting the selection of conductive yarn have come into prominence.
The results obtained should be included in this section and supported by figures and tables if necessary. The findings can be compared with the relevant literature if required. Results should be clear and concise. In the discussion section, the important results of the study should be highlighted, and excessive citation and literature discussion should be avoided.

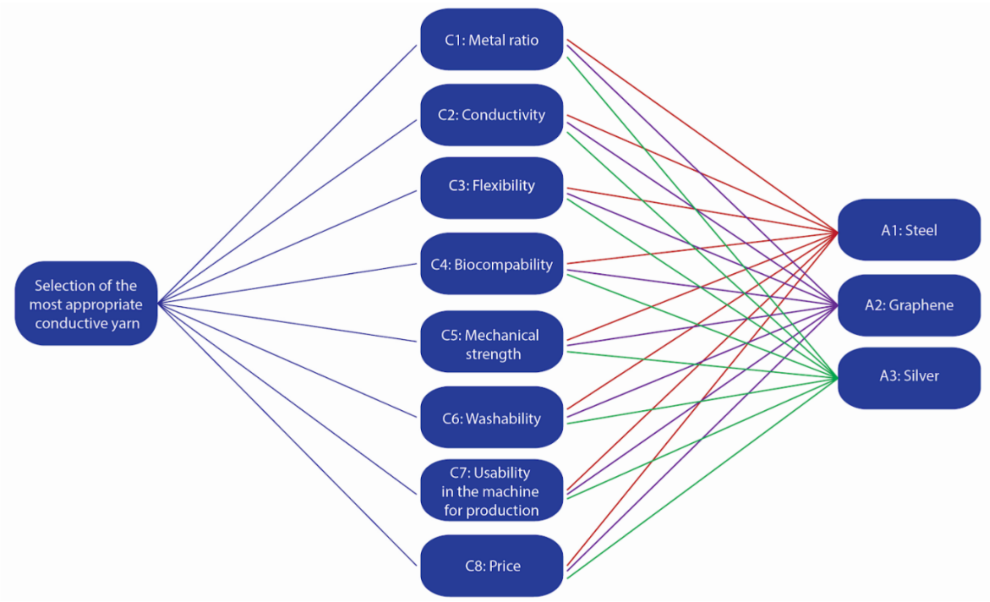


Figure 2. Hierarchical structure of appropriate conductive yarn selection problem

After constructing the hierarchical structure (Figure 2), a questionnaire was conducted to evaluate the alternatives according to the criteria. The questionnaire was applied online to 7 experts who were effective in their conductive yarn purchasing decisions. Using the data collected through questionnaires, a binary comparison matrix (A) containing the geometric mean of the judgments of 7 people was formed (Table 4).

Table 4. Binary comparison matrix (A)

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	0.11	0.8	0.47	1	2.05	0.12	0.98
C2	9	1	3.63	2.42	1.25	6.71	0.53	4.61
C3	1.25	0.28	1	0.3	1.26	3.39	0.6	2.62
C4	2.12	0.41	3.32	1	1.07	2.82	0.49	4
C5	1	0.8	0.79	0.93	1	4.11	0.75	2.12
C6	0.49	0.15	0.3	0.35	0.24	1	0.13	0.28
C7	8.16	1.89	1.67	2.04	1.33	7.5	1	3.42
C8	1.02	0.22	0.38	0.25	0.47	3.63	0.29	1
Total	24.04	4.86	11.89	7.76	7.62	31.21	3.91	19.03

The values in the binary comparison matrix indicate the importance of row elements relative to column elements. Using the formula (2), B column vectors were obtained. Then, these column vectors were placed side by side to form a normalization matrix (C) (Table 5).

Table 5. Binary comparison matrix (A)

	C1	C2	C3	C4	C5	C6	C7	C8	W
C1	0.0416	0.0226	0.0673	0.0606	0.1312	0.0657	0.0307	0.0515	0.0589
C2	0.3744	0.2058	0.3053	0.3119	0.1640	0.2150	0.1355	0.2422	0.2443
C3	0.0520	0.0576	0.0841	0.0387	0.1654	0.1086	0.1535	0.1377	0.0997
C4	0.0882	0.0844	0.2792	0.1289	0.1404	0.0904	0.1253	0.2102	0.1434
C5	0.0416	0.1646	0.0664	0.1198	0.1312	0.1317	0.1918	0.1114	0.1198
C6	0.0204	0.0309	0.0252	0.0451	0.0315	0.0320	0.0332	0.0147	0.0291
C7	0.3394	0.3889	0.1405	0.2629	0.1745	0.2403	0.2558	0.1797	0.2477
C8	0.0424	0.0453	0.0320	0.0322	0.0617	0.1163	0.0742	0.0525	0.0571
Column vectors	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	

The priority vector (W), which is seen in Table 5, was generated by calculating the arithmetic mean of the row elements of the normalization matrix (C). The priority vector (W) shows the importance weights of the criteria.

After this stage, it is necessary to test the consistency. For this purpose, firstly, the column vector D was generated using formula (6). A new column vector containing the fundamental values (E) for each evaluation factor was obtained by the formula (7). Afterwards, λmax was calculated using formula (8). The consistency index (CI) was calculated by substituting λmax in formula (5). Finally, the consistency ratio (CR) was calculated using the random consistency index (RI)=1.41, which corresponds to n=8 in the random consistency table, and the consistency index (CI) was calculated by means of formula (4) (Table 6).

Table 6. Consistency calculations

D	W	E
0.4981	0.0589	8.4562
2.2229	0.2443	9.0989
0.8326	0.0997	8.3507
1.2595	0.1434	8.7828
1.0127	0.1198	8.4532
0.2516	0.0291	8.6477
2.222	0.2477	8.9703
0.4784	0.0571	8.3788
	λ_{max}	8.6423
	CI	0.0918
	CR	0.0651

The consistency ratio (CR) should be less than 0.1 for the test result to be consistent. In this study, the consistency ratio (CR) is calculated as 0.0651, and it can be said that our test result is consistent. As the test result is consistent, the priority vector W, which shows the importance weights of the appropriate conductive yarn selection problem criteria given in Table 5, can be used to solve the problem. Binary comparison matrices were established by comparing alternatives for each criterion. The 8 matrices obtained were normalized. Then, their consistency was tested by calculating the priority vectors (Si), λmax, CI, and CR values of these matrices. The results of these calculations can be seen in Table 7.

Table 7. Priority vectors and consistency ratios of alternatives for each criteria

C1	S1	D	E	λ_{max}	CI	CR
	0.1062	0.3197	3.0112	3.0387	0.0194	0.0334
	0.6333	1.9456	3.072			
	0.2605	0.7901	3.033			
C2	S2	D	E	λ_{max}	CI	CR
	0.0567	0.1709	3.0119	3.0813	0.0407	0.0701
	0.6486	2.0432	3.1501			
	0.2946	0.908	3.0819			
C3	S3	D	E	λ_{max}	CI	CR
	0.0567	0.1709	3.0119	3.0813	0.0407	0.0701
	0.6486	2.0432	3.1501			
	0.2946	0.908	3.0819			
C4	S4	D	E	λ_{max}	CI	CR
	0.0667	0.2001	3.0002	3.0002	0.0001	0.0002
	0.4667	1.4001	3.0002			
	0.4667	1.4001	3.0002			
C5	S5	D	E	λ_{max}	CI	CR
	0.1062	0.3196	3.0111	3.0387	0.0193	0.0333
	0.6334	1.9456	3.0719			
	0.2605	0.7901	3.0329			
C6	S6	D	E	λ_{max}	CI	CR
	0.0664	0.1998	3.0101	3.0542	0.0271	0.0467
	0.5706	1.7613	3.0869			
	0.3631	1.1129	3.0654			
C7	S7	D	E	λ_{max}	CI	CR
	0.0567	0.1709	3.0119	3.0813	0.0407	0.0701
	0.6486	2.0432	3.1501			
	0.2946	0.908	3.0819			
C8	S8	D	E	λ_{max}	CI	CR
	0.6334	1.9456	3.0719	3.0387	0.0193	0.0333
	0.2605	0.7901	3.0329			
	0.1062	0.3196	3.0111			

As seen in the table above, all matrices are consistent (CR < 0.1). As the AHP analysis results are consistent, Si priority vectors showing the importance weights of the appropriate conductive yarn selection problem criteria given in Table 6 can be used to solve the problem.

Priority vectors in Table 6 were combined side by side to form a decision matrix (K) which shows the priority weights of alternatives for each criterion (Table 8).

Table 8. Decision matrix (K)

Criteria weights (Wi)	0.0589	0.2443	0.0997	0.1434	0.1198	0.0291	0.2477	0.0571
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
A1	0.1062	0.0567	0.0567	0.0667	0.1062	0.0664	0.0567	0.6334
A2	0.6333	0.6486	0.6486	0.4667	0.6334	0.5706	0.6486	0.2605
A3	0.2605	0.2946	0.2946	0.4667	0.2605	0.3631	0.2946	0.1062

Finally, the ultimate priority vectors were calculated. The formula (9) is used in this calculation.

Table 9. Ultimate priority vector (L) of the alternatives and ranking results

	Ultimate Priority Vector of the Alternatives	**Ranking**
A1	0.1002	3
A2	0.5954	1
A3	0.3044	2

The results in the ultimate priority vector (L) in Table 9 are listed in descending order. As a result of the ranking, the alternative with the biggest value, A2 (Graphene), is the best alternative.

4. Conclusion and Suggestions

In this study, a questionnaire consisting of two parts, which collect general information online and evaluate the conductive yarns they received, was conducted to the experts who are effective in purchasing the conductive yarns of the factories producing textile products.

The matrices obtained from the forms filled out by the experts were evaluated with the help of the AHP method, priority vectors were determined, and the alternatives were listed according to their importance weight. Therefore, it has been determined that graphene yarn is the most appropriate yarn for a textile factory among the alternatives according to the specified criteria.

Graphene is a material that stands out with its high conductivity and flexibility. Graphene yarns can be produced in large quantities, and they are washable, inexpensive, and soluble in nature. Also, graphene is a material that is highly sensitive to changes in the environment, as each atom is in contact with its environment. When the AHP analysis results are taken into consideration in light of this information, it is concluded that graphene is a good choice in many aspects of the production of electronic textiles and wearable products.

Contributions of the authors

All authors have contributed equally.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

References

[1] G. Yetmen, Giyilebilir teknoloji, *Ulakbilge*.Vol.5, no.9, pp.275-289, 2017.

[2] Y. Gao, H. Li, and Y. Luo, An empirical study of wearable technology acceptance in healthcare, *Industrial Management & Data Systems*, Vol.115, pp.1074-1723, 2015.

[3] S. Wagner, E. Bonderover, W. B. Jordan, and J. C. Sturm, Electrotextiles: concepts and challenges, *International Journal of High Speed Electronic Systems*, Vol.12, pp. 391-399, 2002.

[4] E. Ethridge, *Electrotextiles-technology to applications*, *Proc. of the Materials Research Society Conference Symposium, Boston, ABD*, 2002, pp. 1-10.

[5] M. S. Çetin, and D. Erdem, İletken iplik alımında etkili kriterler arasındaki ilişkilerin DEMATEL yöntemi ile belirlenmesi, *Avrupa Bilim ve Teknoloji Dergisi*, Vol.17, pp.152-160, 2019.

[6] Y. Çelikbilek, *Çok Kriterli Karar Verme Yöntemleri-Açıklamalı ve Karşılaştırmalı Sağlık Bilimleri Uygulamaları ile*, Nobel Akademik Yayıncılık Eğitim Danışmanlık Tic. Ltd. Şti., Ankara, 2018, pp. 43-51.

[7] M. Velasquez, and P. T. Hester, An analysis of multi-criteria decision making methods, *International Journal of Operations Research*, Vol.10, pp. 56-66, 2013.

[8] N. G. Akın, İşletme Bölümü Öğrencilerinin Meslek Seçimini Etkileyen Faktörlerin Bulanık Dematel yöntemi ile Değerlendirilmesi. *Uluslararası Yönetim İktisat ve İşletme Dergisi,* Vol. 13(4), pp. 873-890, 2017.

[9] B. Paçacı, S. Erol ve K. Çubuk , AHP Application for Logistics Center Location Selection According to Criteria, *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, Vol. 11, no. 4, pp. 943-952, 2022.

[10] R. W. Saaty, The analytic hierarchy process—what it is and how it is used, *Mathematical Modelling*, Vol. 9, pp. 161-176, 1987.

[11]. B. L. Golden, E. A. Wasil, and P. T. Harker, *The Analytic Hierarchy Process. Applications and Studies*, Springer, Berlin, 1989, pp. 37-58.

[12] A. Ishizaka, and P. Nemery, *Multi-Criteria Decision Analysis Methods and Software*, Wiley & Sons, Ltd., West Sussex, 2013, pp. 13-50.

[13] A. Abdulvahitoğlu, *Yeni ürün tasarımında Triz ve Ahp ile en uygun kararın verilmesi*, Master Thesis (Çukurova University, Adana, 2012).

[14] E. G. Türkmen, İ. Güngör, and F. Erinci, Öğretmenlerin tayin yeri seçiminde analitik hiyerarşi proses uygulaması, *Uluslararası Alanya İşletme Fakültesi Dergisi*, Vol.7, pp. 35-49, 2015.

[15] T. L. Saaty, How to make a decision: the analytic hierarchy process, *European Journal of Operational Research*, Vol. 48, pp. 9-26, 1990.

[16] D. A. Regier, and S. Peacock, *Multi-Criteria Decision Analysis to Support Healthcare Decisions*, eds. K. Marsh, M. Goetghbeur, P. Thokala, and R. Baltussen, Springer, Berlin, 2017, pp.19-21.

[17] T. L. Saaty, Axiomatic foundation of the analytic hierarchy process, *Management Science*, Vol. 32, pp. 841-855, 1986.

[18] Ö. F. Ünal, Performans değerlemede analitik hiyerarşi prosesi (AHP) uygulamaları, *Sosyal Bilimler Araştırmaları Dergisi,* Vol. 7, pp. 37-55, 2012.

[19] E. İmren, *Mobilya endüstrisinde analitik hiyerarşi prosesi (AHP) yöntemi ile kuruluş yeri seçimi*, Master Thesis (Bartın University, Bartın, 2011).

[20] G. Kecek, and A. G. E. Yıldırım, Kurumsal kaynak planlama (ERP) sisteminin analitik hiyerarşi süreci (AHP) ile seçimi: otomotiv sektöründe bir uygulama, *Suleyman Demirel University Journal of Faculty of Economics & Administrative Sciences*, Vol. 15, pp. 193-211, 2010.

[21] E. G. Kadak, *Türkiye'de AHP tekniğinin performans değerlendirmedeki yeri ve ilaç dağıtım sektöründe uygulanması*, Master Thesis (Çukurova University, Adana, 2006).

[22] E. Ç. Turgut, *Tedarik zinciri yönetiminde AHP ve bulanık AHP yöntemi kullanılarak tedarikçilerin performansının ölçülmesi, yeni yöntem önerileri ve uygulamaları*, Ph.D. Thesis (Dokuz Eylül University, İzmir, 2015).

[23] T. Eren, M. Hamurcu, and N. İ. Süt, Analitik hiyerarşi süreci kullanılarak ankara-sivas yüksek hızlı tren hat güzergahının değerlendirilmesi, *Harran Üniversitesi Mühendislik Dergisi*, Vol.3, pp. 22-30, 2018.

[24] N. Karakaşoğlu, *Bulanık çok kriterli karar verme yöntemleri ve uygulama*, Master Thesis (Pamukkale University, Denizli, 2008).