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The Data Envelopment Analytic Hierarchy Process (DEAHP) Approach in the Evaluation of Commercial Credit Applications

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Abstract
In this study, four companies operating in the same sector that had applied for commercial credit from one of the largest private capital banks of Turkey were compared in terms of their performance and the company with the credit application most likely to be satisfied was determined. The Data Envelopment Analytic Hierarchy Process, created by the joint (hybrid) use of the Data Envelopment Analysis and Analytic Hierarchy Process was used in this study. Overall weights were obtained by summing the local weights obtained by Data Envelopment Analysis. Criteria, sub-criteria and weights regarding the alternatives in the hierarchy were calculated according to the Analytic Hierarchy Process and The Data Envelopment Analytic Hierarchy Process methods and the results were similar. According to the findings obtained with both approaches, company ethics and intelligence were determined to be the most important criteria, whereas the company's sales and marketing structure and sectoral structure were determined to be the least important criteria. On the other hand, according to both the Analytic Hierarchy Process and Data Envelopment Analytic Hierarchy Process approaches, Company 2 was determined to be the most appropriate company whose credit application would be satisfied.
Keywords: Commercial credit application; Credit application evaluation model; Multi Criteria Decision Making; Data Envelopment Analytic Hierarchy Process.

1. Introduction

One of the most important components of the economies of developing countries is the existence of an effective financial system. Effective financial systems enable the proper implementation of many government policies. Banks, the cornerstones of financial systems, have an important influence on the stability of the economy and overall financial welfare. Problems that may be encountered in this sector can lead countries into financial crises. Because one of the most important financial risks banks may encounter is credit risk, bankers should be able to make the required predictions on time and effectively to reduce credit risks to a minimum. For this purpose, banks should determine the criteria they can use in the evaluation of both individual and commercial credit applications and make the decision whether to approve a credit application according to these criteria.

The credit evaluation processes of banks include activities that are conducted to determine the repayment of the credits to be granted and to calculate credit risk. The basic purpose of these activities is to minimize credit risk by determining the credit repayment capacity of the credit applicant, a natural or legal person and to enable accurate credit need determination and grant credit of an appropriate amount and term in accordance with this need. In general, such credit evaluation processes are of a subjective nature. Credit evaluation is an activity that should be conducted by well-trained executives working in the related departments of banks. However, currently, as in every other sector, rapidly developing technology and increasing customer expectations have forced banks to take prompt action. Therefore, banks should improve their credit evaluation processes and provide prompt responses to their customers' credit applications. In this respect, the most accurate approach for evaluating credit applications is to create a credit evaluation model that reveals inter-factor relations and that will affect credit-granting decisions and the weights of these factors. Thus, during the evaluation process, the decision regarding whether to grant credit can be made and credit risk will be reduced by considering the results obtained from the model. At the same time, credit-granting processes will become more efficient and the rate of efficiency will increase; consequently, the ability to meet the needs of credit seekers will increase and it will be possible to evaluate more companies within much less time.

The criteria that are considered by banks during credit evaluation processes are important in terms of making accurate and efficient decisions and reducing credit risk. The evaluation of credit applications sets forth a complicated and multi-criteria decision problem that requires the simultaneous consideration of many qualitative and quantitative criteria. This study attempted to develop a credit evaluation model by the use of Analytic Hierarchy Process (AHP), which enables faster and more efficient management of the decision-making process by using many primary qualitative and quantitative criteria. During the second stage of the study, to increase the efficiency of the results obtained from this model, the Data Envelopment Analytic Hierarchy Process (DEAHP) approach, which was developed by combining two different methods, was used.

Although methods and econometric analyses such as multi-variable statistical methods, discriminant analysis, regression analysis, logistic regression analysis and the probit model (Frame et al. 2001; Lee et al. 2002; Bodur & Teker 2005; Abdou et al. 2007; Huang et al. 2007 etc.) have been used in the literature on credit evaluation decision making, particularly on credit risk calculation, studies on the existence of non-financial information - namely, quantitatively non-calculable factors other than financial information –have favored multi-criteria decision-making methods such as AHP, Data Envelopment Analysis (DEA) and PROMETHEE (Cheng et al. 2007; Babic & Plazibat 1998; Chen & Chiou 1999; Yurdakul & İç 2000, 2004; Xu & Zhang 2009; Atan et al. 2004; Sekreter et al. 2004; Albayrak & Erkut 2005; Atan & Maden 2005; Girginer 2008; Akkaya & Demireli, 2010 etc.). Thus, this literature review draws attention to the fact that the use of AHP is limited compared with other methods.

In one study, Girginer 2008 determined the criteria that would be considered in the evaluation of commercial credit applications of private and public banks and the weights of those criteria. In the study, the hierarchical model, which includes four main criteria (financial, managerial, sectoral and intelligence), was evaluated by AHP as two different models, namely, public banks and private banks and the results obtained from both models were compared. According to the results obtained from AHP, it was determined that the public bank attached particular importance to the financial structure of the company, whereas the private bank attached particular importance to the managerial structure and the intelligence obtained in the evaluation of credit applications.

Xu & Zhang (2009) developed a new credit evaluation method based on the AHP and the set pair analysis (SPA) was presented to determine the credibility of the electronic commerce participants. By combining the identity discrepancy contrary analytical thinking of SPA with AHP and applying to the online credit evaluation, they built a dynamic model, taking into account the uncertainty interference and roundly treating qualitative indicators and quantitative indicators. According to their findings, their model which they get could better explain the current credit evaluation scores and the information of potential scores so as to get a true credit evaluation.

Akkaya & Demireli (2010) developed a model regarding the weights credit institutions use in the evaluation of companies' financial ratios as basic performance indicators during the credit-granting period with AHP. They concluded that credit institutions seriously consider activity turnover ratios during the credit-granting period, whereas financial structure ratios are the criteria with the least importance.

As seen in the literature review, there are numerous studies in the literature in which both individual and commercial credit applications of banks have been evaluated. However, no study was found in which credit applications of banks were evaluated with the DEAHP method, which can be usedto increase the possibility of making appropriate and efficient decisions by supporting the results obtained by decision makers in their real-life decision-making process (using AHP) with a different approach.

Furthermore, when the studies in which the DEAHP method was used are examined, a remarkably limited number of studies can be found (Eroğlu & Lorcu 2007; Sevkli et al. 2007; Gemici 2009; Wang et al. 2009; Kamvysi et al. 2010; Mirhedayatian & Saen 2011; Wang & Luo 2012; Zhang et al. 2012).

In this study, motivated by this gap in the literature, DEAHP, which is another multi-criteria decision-making method, was used jointly with AHP to examine the commercial credit-granting decisions of banks. The purpose of the study was to determine the criteria that are considered in commercial credit applications of companies and that must be evaluated together as well as the prioritization of those criteria, according to both the AHP and DEAHP methods. This process will enable the selection of the most appropriate company according to both approaches, thus setting forth the similarities and differences between the two methods. This study and its results may help the parties of the subject when such selection decisions must be made.

2. Material and Method

The existence of numerous qualitative and quantitative criteria considered by banks regarding the problem of evaluating credit applications turns this problem into a multi-criteria decision problem. This study discusses the DEAHP created by the joint use (hybrid) of DEA and AHP, which can be used by banks in their commercial credit-granting decision making to test and support the results obtained by AHP or to approach their decisions from a different perspective.

DEAHP facilitates more appropriate and efficient decision making in cases where the selection by AHP becomes more difficult due to the increase in hierarchy levels. The important advantages of this method include obtaining

more reliable and realistic results regarding real-life problems, being able to overcome the problem of qualitative data analysis, which is sometimes very difficult or impossible to conduct by DEA, providing solutions to problems created by the independence of irrelevant alternatives and ranking changes. DEAHP supports the results obtained by decision makers regarding their real-life decisions, made using AHP, by providing a different numerical support tool and a different approach.

Data Envelopment Analytic Hierarchy Process (DEAHP)

The Data Envelopment Analytic Hierarchy Process was first introduced by Ramanathan in 2006. In his study[1], Ramanathan focused on obtaining the weights attained as a result of AHP through DEA models instead of the classical method. In the study, based on the incorporation of the DEA method into AHP, the DEA method was used to obtain local weights from a given judgment matrix and the overall weights were obtained by adding the local weights obtained. Thus, the DEAHP method was created as a result of obtaining weights through the DEA and AHP methods.

Regarding weight calculation in pair-wise comparison matrices that comprise the basis of the AHP method, DEAHP is an approach that uses DEA models and determines the most appropriate decision based on these weights (Ramanathan 2006). Each row and column of the pair-wise matrix is assumed to be a Decision Making Unit (DMU) and an output, respectively. Because efficiency calculations of each DMU cannot be made entirely with outputs and require at least one input, a dummy input that has a value of 1 for all DMUs is employed. In the DEAHP method, the efficiency scores are calculated using the DEA method and can be interpreted as the local weights of the DMUs. A comparison of a crisp AHP view and the DEAHP view of a judgment matrix is shown in figure 1 (Sevkli et al. 2007).

Crisp AHP View

	Criterion 1	Criterion 2	Criterion 3	…	Criterion m
Alternative 1	1	a_{12}	a_{13}	…	a_{1m}
Alternative 2	$1/a_{12}$	1	a_{23}	…	a_{2m}
Alternative 3	$1/a_{13}$	$1/a_{23}$	1	…	a_{3m}
…	…	…	…	…	…
Alternative n	$1/a_{n1}$	$1/a_{n2}$	$1/a_{n3}$	…	1

DEAHP View

	Output 1	Output 2	Output 3	…	Output m	Dummy Input
DMU 1	1	a_{12}	a_{13}	…	a_{1m}	1
DMU 2	$1/a_{12}$	1	a_{23}	…	a_{2m}	1
DMU 3	$1/a_{13}$	$1/a_{23}$	1	…	a_{3m}	1
…	…	…	…	…	…	…
DMU n	$1/a_{n1}$	$1/a_{n2}$	$1/a_{n3}$	…	1	1

Figure 1. AHP and DEAHP comparison matrices

Ramanathan 2006 proves that DEA correctly calculates the true weights for a consistent judgment matrix. Normally, when local weights are aggregated to overall weights, the importance measures of criteria (local weights of criteria in this case) are also used. For example, the aggregation rule is a weighted arithmetic aggregation incorporating the local weights of each level. However, DEA does not normally require the local criteria weights for aggregation. To obtain the weights of elements in a pair-wise comparison matrix, their previous local weights are used as constraints to calculate the new local weights (Sevkli et al. 2007).

In DEAHP, the weights of alternatives (i.e., the efficiency scores) are calculated separately for each alternative using a separate linear programming model. This can be contrasted from the eigenvector method where weights of all the alternatives are derived simultaneously. In addition, while traditional AHP uses arithmetic normalization, no such normalization is done in the DEAHP. Further, the DEAHP weights are calculated relative to the weight of the best rated alternative. For the discussion below, efficient alternatives are interpreted as relevant alternatives because they play an important role in the rank ordering of all the alternatives. In a general DEA formulation (which is applicable for DEAHP also), if the alternative being eliminated is not an efficient one (i.e., if the alternative being eliminated is an irrelevant alternative), then the new ranking calculated will again be relative to the highest ranked one and the ordering of alternatives will not change (Ramanathan 2006).

The strengths of DEAHP that was created by supporting the weaknesses of the AHP and DEA methods, with the

[1]Ramanathan, R., 2006: Data Envelopment Analysis for weight derivation and aggregation in the Analytic Hierarchy Process, *Computers & Operations Research,* 33, pp. 1289-1307.

aim of acquiring a method that has less restrictions, are as follows: increasing the possibility for more appropriate and efficient decision making in the case of an increase in hierarchy levels, obtaining more reliable and realistic results regarding real-life problems, achieving the ability to overcome the problem of qualitative data analysis (which is sometimes very hard or impossible to conduct by DEA) and providing solutions to problems of the independence of irrelevant alternatives and ranking changes (Ramanathan 2006).

3. Calculation

To perform commercial credit evaluation by DEAHP, a bank manager and a commercial credit department executive working at one of the largest private capital banks in Turkey were consulted. Considering the fact that the judgments of the two experts would vary in pair-wise comparisons, group decision making by two bankers, who are experts in their fields, was preferred to the use of a single decision maker. At the end of the team interviews, the criteria, sub-criteria and alternatives that should be considered when evaluating commercial credit applications were determined. Four companies that operate in the same sector and that had applied for commercial credit at the aforementioned bank were the alternatives of the problem. Members of the team were also included as participants in the AHP with group decision making to determine the pair-wise comparison judgments in the hierarchical structure that was developed for the problem. The geometric means of the participants' judgments were calculated as ultimate importance values. The hierarchical structure of the problem of evaluating commercial credit applications was determined in line with the opinion of the team members and with studies in the literature regarding the subject, as indicated in Figure 2. Five basic criteria (financial structure, partners and managerial structure, sales and marketing structure, sectoral structure and company ethics and intelligence), each of which included sub-criteria, were considered in the construction of the hierarchical structure.

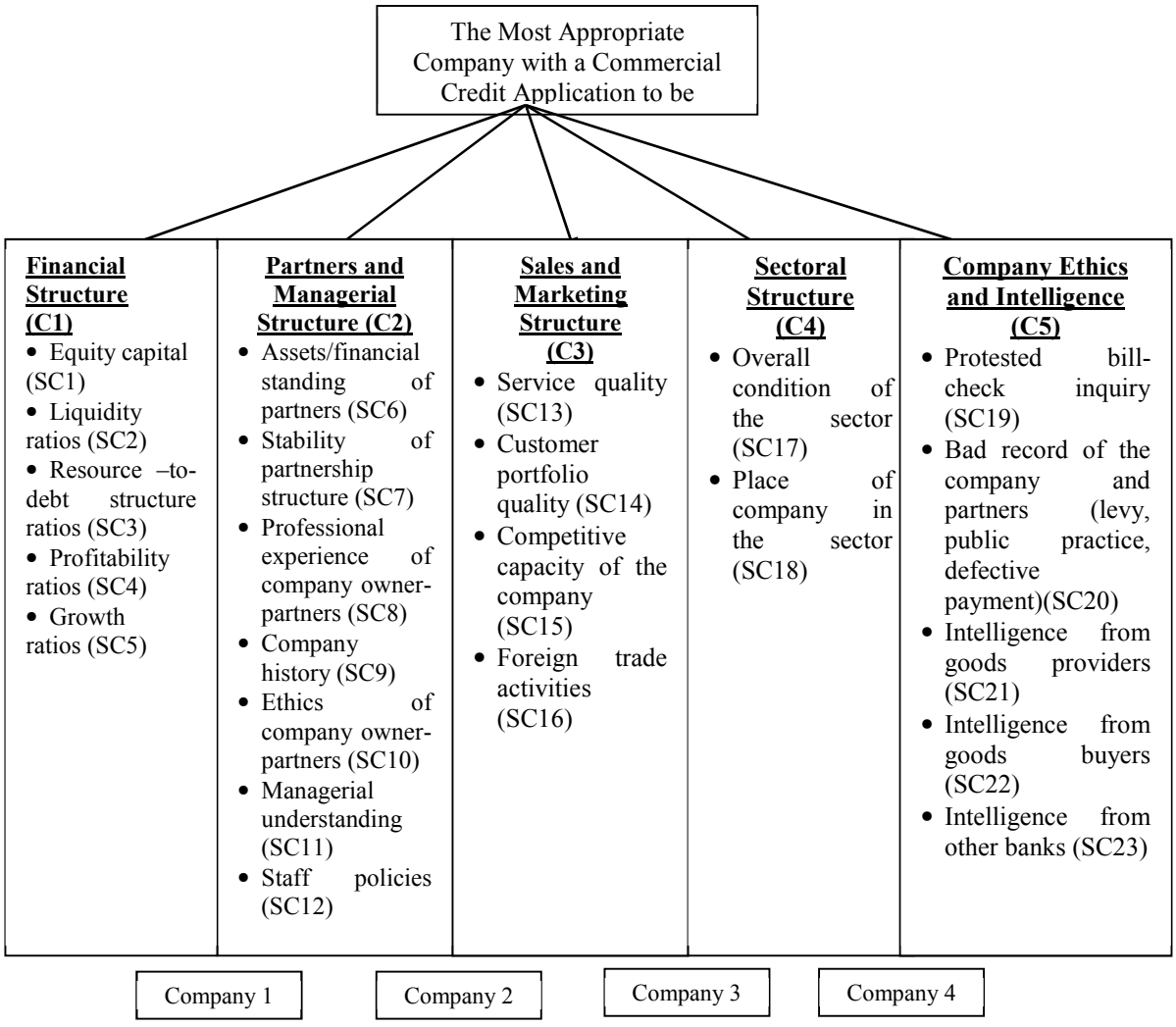

Figure 2. Hierarchical structure of the problem of evaluating credit applications

The model presented in this study utilizes the crisp AHP and DEAHP approaches comparatively. In the DEAHP

model, judgment matrix data are used as output variables to determine the best business firm for the bank. The main steps of the model are listed as follows:

Step 1. Obtaining AHP and DEAHP weights of sub-criteria
(a) The AHP weights of each sub-criterion are obtained by using the pair-wise comparison values of each main criterion in terms of its sub-criteria.
(b) DEA models are constructed for each main criterion by using the pair-wise comparison values of each main criterion in terms of its sub-criteria as parameter values. The DEAHP weights of sub-criteria are obtained by the separate analysis of these models for each sub-criterion.

Step 2. Obtaining AHP and DEAHP weights of the alternatives on a sub-criterion basis
(a) The AHP weights of the alternatives for each sub-criterion are obtained by using the pair-wise comparison values of the alternatives for all sub-criteria.
(b)DEA models are constructed for each sub-criterion by using the pair-wise comparison values of alternatives in terms of all sub-criteria as parameter values. The DEAHP weights of the alternatives are obtained on a sub-criterion basis by solving these models separately for each alternative.

Step 3. Obtaining AHP and DEAHP weights of the alternatives on a main criteria basis
(a) The AHP weights of the alternatives, based on the main criteria, are obtained by using the AHP weights of the alternatives obtained for each sub-criterion in Step 2a.
(b)DEA models are constructed for each main criterion by using the DEAHP weights of the alternatives obtained for each sub-criterion as parameter values in Step 2b. The DEAHP weights of the alternatives are obtained, based on the main criteria, by solving these models separately for each alternative.

Step 4. Obtaining AHP and DEAHP weights of main criteria
(a) The AHP weight of each main criterion is obtained by using of the pair-wise comparisons of the main criteria.
(b)A DEA model is constructed by using pair-wise comparisons of the main criteria as parameter values. DEAHP weights are obtained by solving this model separately for each main criterion.

Step 5. Obtaining ultimate AHP and DEAHP weights of the alternatives
(a) The ultimate AHP weight of each alternative is obtained by using the AHP weights of the alternatives obtained for each main criterion in Step 3a.
(b)A DEA model is constructed by using the DEAHP weights of the alternatives obtained for each main criterion in Step 3b as parameter values. The ultimate DEAHP weights of the alternatives are obtained by solving this model separately for each alternative.

After the hierarchical structure of the commercial credit evaluation has been identified based on the evaluations of the bankers, they also indicated their degree of preference between and within the criteria at each level of the hierarchy in a pair-wise form using Saaty's scales (Saaty 1980) ranging from 1 to 9. Next step involves the weight calculation of each level to obtain the overall score of each business firm with respect to all sub-criteria and pair-wise comparisons of the main selection criteria.

Step 1
Pair-wise comparisons of the financial structure criterion in terms of its sub-criteria are given in Table 1. The values of the AHP and DEAHP weights are given in the last two columns of Table 1. The local weights (priority vector) of the related sub-criteria are obtained by AHP by using the pair-wise matrix in Table 1.
Table 1. Pair-wise comparisons for the financial structure main criterion, AHP and DEAHP weights

							Weights	
	SC1	SC2	SC3	SC4	SC5	Input	AHP	DEAHP
SC1	1.000	1.000	0.450	1.000	3.000	1.000	0.194	1.000
SC2	1.000	1.000	1.000	1.000	3.000	1.000	0.227	1.000
SC3	2.220	1.000	1.000	1.730	3.000	1.000	0.303	1.000
SC4	1.000	1.000	0.580	1.000	3.000	1.000	0.201	1.000
SC5	0.330	0.330	0.330	0.330	1.000	1.000	0.076	0.333
CR			0.020					

To obtain local weights through the DEAHP approach, Table 1 is converted into a decision-making unit, output

and input as shown in Figure 1. Dummy input column that each of them have the value of 1 are added to the pair-wise comparison matrix. The DEA model constructed for a system with N number of decision-making units (number of sub-criteria), one input (each of the value 1 inputs) and N number of outputs (number of sub-criteria) is shown below, in Model 1. The purpose function of the model constructed for the financial structure is set forth by using the first line of the judgment matrix, whereas restrictions are set forth by using the overall matrix.

Model 1

$\text{Max } z = 1y_{11}+1y_{12}+0.45y_{13}+1y_{14}+3y_{15}$

st

$x_{11}=1$

$1y_{11}+1y_{12}+0.45y_{13}+1y_{14}+3y_{15}-x_{11} \leq 0$

$1y_{11}+1y_{12}+1y_{13}+1y_{14}+3y_{15}-x_{12} \leq 0$

$2.22y_{11}+1y_{12}+1y_{13}+1.73y_{14}+3y_{15}-x_{13} \leq 0$

$1y_{11}+1y_{12}+0.58y_{13}+1y_{14}+3y_{15}-x_{14} \leq 0$

$0.33y_{11}+0.33y_{12}+0.33y_{13}+0.33y_{14}+1y_{15}-x_{15} \leq 0$

$y_{11}, y_{12}, y_{13}, y_{14}, y_{15}, x_{11,} x_{12}, x_{13}, x_{14}, x_{15} \geq 0$

Here,

x_{ij}: Observed value of input i for decision-making unit j

y_{ij}: Observed value of output i for decision-making unit j

a_{ij}: Weight attached to inputs and outputs of decision-making unit j

are described as above.

Model 1 was solved separately for each sub-criterion by using the Lingo program and the results are shown in the DEAHP column in Table 1. When this optimization model is solved by Lingo, the local weight of equity capital (SC1) is obtained (1.000). To obtain the local weight of other categories, similar models were used by changing the objective function. The resulting local weights of liquidity rates (SC2), resource-to-debt structure ratios and their structures (SC3), profitability ratios (SC4) and growth ratios (SC5) are given in Table 1 (1.000, 1.000, 1.000, 0.333). These weights obtained by DEAHP are considered to be the local weights (priority vector) of the sub-criteria of the related criterion.

In Table 1, after normalization of the DEAHP values, the DEAHP value was found 0.231 when the AHP value was 0.194 for the equity capital; the DEAHP value was found 0.231 when the AHP value was 0.227 for the liquidity ratios, for the resource-to-debt structure ratios DEAHP and AHP values were respectively found 0.231 and 0.303, for the profitability ratios 0.231 and 0.201 and for the growth ratios both of them were found 0.0.76. Analyses were conducted on the overall main criteria by constructing similar models and the results are shown in Table 2.

Table 2. AHP and DEAHP weights for other main criteria

Main-Criteria	Sub-Criteria	AHP	DEAHP	CR
Partners and Managerial Structure	SC6	0.089	0.333	0.030
	SC7	0.149	0.430	
	SC8	0.137	0.577	
	SC9	0.084	0.380	
	SC10	0.441	1.000	
	SC11	0.055	0.250	
	SC12	0.047	0.250	
Sales and Marketing Structure	SC13	0.125	0.282	0.020
	SC14	0.118	0.335	
	SC15	0.268	0.680	
	SC16	0.489	1.000	
Sectoral Structure	SC17	0.500	1.000	0.000
	SC18	0.500	1.000	
Company Morality and Intelligence	SC19	0.216	0.883	0.020
	SC20	0.400	1.000	
	SC21	0.097	0.333	
	SC22	0.097	0.333	
	SC23	0.191	0.747	

When the weight values in Table 2 are examined, it is remarkable that the most efficient sub-criteria are the

ethics of the company owner and partners among the sub-criteria of the partners and managerial structure main criterion, foreign trade activities among the sub-criteria of the sales and managerial structure main criterion and bad record criteria such as levies and defective payments among the sub-criteria of the company ethics and intelligence main criterion. The weights of the sub-criteria of the overall condition of the sector and of the place of the company in the sector under the sectoral structure main criterion are of equal weight. Moreover, the contradiction ratio (CR) is below 0.10.

Step 2

In the following level of the analysis, as described in Step 2a, the AHP weights of all companies were first obtained for each sub-criterion by using the pair-wise comparison values of the companies for all sub-criteria. Thus, the level of the properties defined in the sub-criteria that the companies are required to have is determined. Then, as required by Step 2b, the DEA models were constructed for each sub-criterion by using the pair-wise comparison values of the companies in terms of all sub-criteria and the weights to be acquired by the companies in terms of sub-criteria were obtained by DEAHP by solving these models separately for each company. For example, equity (a_1), liquidity ratios (a_2), resource-to-debt structure ratios (a_3), profitability ratios (a_4) and growth ratios (a_5), which are the sub-criteria of the financial structure main criterion, were compared with regard to Firm 1, Firm 2, Firm 3 and Firm 4 and local weights were obtained by DEAHP. The results are shown in Tables 3, 4, 5, 6 and 7. The model constructed for the equity sub-criteria is shown in Model 2 as an example.

Model 2

$$\text{Max } z=1y_{11}+0.111y_{12}+0.169y_{13}+1y_{14}$$

st

$$x_{11}=1$$

$$1y_{11}+0.111y_{12}+0.169y_{13}+1y_{14}-x_{11}<=0$$

$$9y_{11}+1y_{12}+1y_{13}+7.937y_{14}-x_{12}<=0$$

$$5.916y_{11}+1y_{12}+1y_{13}+4.583y_{14}-x_{13}<=0$$

$$1y_{11}+0.126y_{12}+0.218y_{13}+1y_{14}-x_{14}<=0$$

$$y_{11}, y_{12}, y_{13}, y_{14}, x_{11,} x_{12}, x_{13}, x_{14}, x_{15} \geq 0$$

Here,

x_{ij}: Observed value of input i for decision-making unit j

y_{ij}: Observed value of output i for decision-making unit j

a_{ij}: Weight attached to inputs and outputs of decision-making unit j

are defined as above.

Table 3. Comparison matrix of equity sub-criterion for companies

	Company 1	Company 2	Company 3	Company 4	Input	AHP	DEAHP
Company 1	1.000	0.111	0.169	1.000	1.000	0.062	0.169
Company 2	9.000	1.000	1.000	7.937	1.000	0.487	1.000
Company 3	5.916	1.000	1.000	4.583	1.000	0.383	1.000
Company 4	1.000	0.126	0.218	1.000	1.000	0.068	0.218
			CR=0.010				

Table 4. Comparison matrix of liquidity ratio sub-criterion for companies

	Company 1	Company 2	Company 3	Company 4	Input	AHP	DEAHP
Company 1	1.000	0.111	0.378	0.333	1.000	0.054	0.111
Company 2	9.000	1.000	5.196	7.937	1.000	0.682	1.000
Company 3	2.646	0.192	1.000	2.236	1.000	0.161	0.294
Company 4	3.000	0.126	0.447	1.000	1.000	0.102	0.333
			CR=0.050				

Table 5. Comparison matrix of resource-to-debt structure ratios sub-criterion for companies

	Company 1	Company 2	Company 3	Company 4	Input	AHP	DEAHP
Company 1	1.000	9.000	7.000	5.000	1.000	0.667	1.000
Company 2	0.111	1.000	0.258	0.258	1.000	0.047	0.111
Company 3	0.143	3.873	1.000	0.577	1.000	0.119	0.430
Company 4	0.200	3.873	1.733	1.000	1.000	0.167	0.430
			CR=0.050				

Table 6. Comparison matrix of profitability sub-criterion for companies

	Company 1	Company 2	Company 3	Company 4	Input	AHP	DEAHP
Company 1	1.000	0.111	0.169	0.192	1.000	0.044	0.111
Company 2	9.000	1.000	3.873	2.236	1.000	0.538	1.000
Company 3	5.917	0.258	1.000	1.000	1.000	0.200	0.657
Company 4	5.196	0.447	1.000	1.000	1.000	0.217	0.577
			CR=0.050				

Table 7. Comparison matrix for growth ratio sub-criterion for companies

	Company 1	Company 2	Company 3	Company 4	Input	AHP	DEAHP
Company 1	1.000	0.192	0.333	0.378	1.000	0.076	0.192
Company 2	5.196	1.000	3.873	3.873	1.000	0.572	1.000
Company 3	3.000	0.258	1.000	1.000	1.000	0.179	0.577
Company 4	2.646	0.258	1.000	1.000	1.000	0.172	0.509
			CR=0.050				

It is remarkable that Company 1 is determined to be the weakest company and Company 2 is the most efficient company in terms of equity, liquidity ratios, profitability ratios and growth ratios; however, Company 2 is the weakest company and Company 1 is the most efficient one in terms of resource-to-debt structure ratios.

The model applied to the sub-criteria of the financial structure main criterion must also be applied to the sub-criteria of the other main criteria. The results of the model applied to the sub-criteria of all main criteria are observed below in Tables 8, 9, 10 and 11.

Table 8. Comparison matrix of partners and management structure sub-criterion for companies

	Company 1		Company 2		Company 3		Company 4	
	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP
SC6	0.045	0.111	0.635	1.000	0.158	0.509	0.162	0.509
SC7	0.039	0.111	0.467	1.000	0.327	1.000	0.166	0.577
SC8	0.049	0.111	0.695	1.000	0.185	0.556	0.071	0.192
SC9	0.044	0.111	0.471	1.000	0.336	0.882	0.150	0.430
SC10	0.036	0.111	0.585	1.000	0.238	1.000	0.141	0.657
SC11	0.045	0.111	0.666	1.000	0.222	0.778	0.066	0.192
SC12	0.110	0.333	0.433	1.000	0.303	1.000	0.154	0.577

Table 9. Comparison matrix of sales and marketing structure sub-criterion for companies

	Company 1		Company 2		Company 3		Company 4	
	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP
SC13	0.127	0.333	0.472	1.000	0.228	0.655	0.173	0.577
SC14	0.048	0.111	0.673	1.000	0.183	0.447	0.095	0.333
SC15	0.045	0.126	0.650	1.000	0.187	0.745	0.118	0.488
SC16	0.250	1.000	0.250	1.000	0.250	1.000	0.250	1.000

Table 10. Comparison matrix of sectoral structure sub-criterion for companies

	Company 1		Company 2		Company 3		Company 4	
	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP
SC17	0.120	0.333	0.441	1.000	0.257	0.776	0.182	0.577
SC18	0.052	0.111	0.674	1.000	0.176	0.447	0.098	0.333

Table 11. Comparison matrix of company ethics and intelligence sub-criterion for companies

	Company 1		Company 2		Company 3		Company 4	
	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP	AHP	DEAHP
SC19	0.250	1.000	0.250	1.000	0.250	1.000	0.250	1.000
SC20	0.112	0.333	0.471	1.000	0.208	0.745	0.208	0.745
SC21	0.114	0.333	0.463	1.000	0.259	0.882	0.164	0.577
SC22	0.109	0.333	0.412	1.000	0.284	0.882	0.195	0.745
SC23	0.046	0.111	0.574	1.000	0.247	0.657	0.134	0.430

According to Table 8 – Table 11, Company 2 is the most efficient company and Company 1 is the weakest company with regard to all other sub-criteria of all the main criteria, whereas all companies are of equal importance according to the foreign trade activities sub-criterion under the sales and marketing structure main criterion and according to the protested bills sub-criterion under the company ethics and intelligence sub-criterion.

Step 3

In the first step, the AHP weights of the companies on a main-criteria basis were calculated by using the AHP weights of the companies obtained for each sub-criterion, as shown in Tables 12, 13, 14, 15 and 16.

Table 12. AHP weights of the companies at the financial structure sub-criteria level

	SC1	SC2	SC3	SC4	SC5	AHP
Company 1	0.062	0.054	0.667	0.044	0.076	0.220
Company 2	0.487	0.682	0.047	0.538	0.572	0.425
Company 3	0.383	0.161	0.119	0.200	0.179	0.212
Company 4	0.068	0.102	0.167	0.217	0.172	0.143
Local Weights of the Criteria	0.194	0.227	0.303	0.201	0.076	0.172

Table 13. AHPweights of the companies at the partners and management structure sub-criteria level

	SC6	SC7	SC8	SC9	SC10	SC11	SC12	AHP
Company 1	0.045	0.039	0.049	0.044	0.036	0.045	0.110	0.045
Company 2	0.635	0.467	0.695	0.471	0.585	0.666	0.433	0.563
Company 3	0.158	0.327	0.185	0.336	0.238	0.222	0.303	0.255
Company 4	0.162	0.166	0.071	0.150	0.141	0.066	0.154	0.138
Local Weights of the Criteria	0.089	0.149	0.137	0.084	0.441	0.055	0.047	0.345

Table 14. AHP weights of the companies at the sales and marketing structure sub-criteria level

	SC13	SC14	SC15	SC16	AHP
Company 1	0.127	0.048	0.045	0.250	0.196
Company 2	0.472	0.673	0.650	0.250	0.356
Company 3	0.228	0.183	0.187	0.250	0.235
Company 4	0.173	0.095	0.118	0.250	0.214
Local Weights of the Criteria	0.125	0.118	0.268	0.489	0.051

Table 15. AHP weights of the companies at the sectoral structure sub-criteria level

	SC17	SC18	AHP
Company 1	0.120	0.052	0.093
Company 2	0.441	0.674	0.533
Company 3	0.257	0.176	0.225
Company 4	0.182	0.098	0.149
Local Weights of the Criteria	0.500	0.500	0.039

Table 16. AHP weights of the companies at the company ethics and intelligence structure sub-criteria level

	SC19	SC20	SC21	SC22	SC23	AHP
Company 1	0.250	0.112	0.114	0.109	0.046	0.151
Company 2	0.250	0.471	0.463	0.412	0.574	0.402
Company 3	0.250	0.208	0.259	0.284	0.247	0.239
Company 4	0.250	0.208	0.164	0.195	0.134	0.208
Local Weights of the Criteria	0.216	0.400	0.097	0.097	0.191	0.394

According to Table 12 – Table 16, Company 2 stands out as the most successful company with regard to the sub-criteria of all of the main criteria. Company 4 has the least weight with regard to the financial structure main criterion, whereas Company 1 has the least weight with regard to all other main criteria. The weights of Companies 1 and 3 are very close to each other with regard to financial structure, whereas Company 3 is the second most successful company, following Company 2, with regard to all other criteria.

To obtain similar weights by DEAHP, the process described in Step 3b was followed. DEA Model 3 was constructed by the addition of the DEAHP values of each sub-criterion obtained by using their company-wise comparison and the DEAHP values of the criterion obtained by its sub-criterion-wise comparison to restrictions; then, the model was solved for each company. The results are shown in the DEAHP column in Table 17. The aggregations in DEAHP and additional constraints were appended to calculate the second level of each alternative. For example, the linear programming model was used to obtain the weights of Firm 1 at the second level.

Model 3

Max $z = 0.169y_{11}+0.111y_{12}+1y_{13}+0.111y_{14}+0.192y_{15}$

st

$x_{11}=1$

$0.169y_{11}+0.111y_{12}+1y_{13}+0.111y_{14}+0.192y_{15}-x_{11} \leq 0$

$1y_{11}+1y_{12}+0.111y_{13}+1y_{14}+1y_{15}-x_{12} \leq 0$

$1y_{11}+0.294y_{12}+0.430y_{13}+0.657y_{14}+0.577y_{15}-x_{13} \leq 0$

$0.218y_{11}+0.333y_{12}+0.430y_{13}+0.577y_{14}+0.509y_{15}-x_{14} \leq 0$

$y_{11}=y_{12}=y_{13}=y_{14}=3y_{15}$(additional constraints)

$y_{11}, y_{12}, y_{13}, y_{14}, y_{15}, x_{11}, x_{12}, x_{13}, x_{14} \geq 0$

When this optimization model was solved, the local weight (0.422) of Firm 1 was obtained. The local weights of other firms were obtained by using a similar model; the objective function and the additional constraints were changed. In this model, the additional constraints were obtained from column DEAHP of Table 1, which are 1.000, 1.000, 1.000, 1.000 and 0.333 denoting that al sub-criterion of financial structure are three times more important than growth ratios. Hence, this information was added as a constraint in order to calculate the local weights of the next level.

Similarly, each firm's local weight was calculated using the same model for the other categories in liquidity ratios, resource-to-debt structure ratios and their structures, profitability ratios and growth ratios. These results are shown in Table 18 – Table 21.

Table 17. DEAHP weights of the companies at the sub-criteria level of the financial structure

	SC1	SC2	SC3	SC4	SC5	Input	DEAHP
Company 1	0.169	0.111	1.000	0.111	0.192	1.000	0.422
Company 2	1.000	1.000	0.111	1.000	1.000	1.000	1.000
Company 3	1.000	0.294	0.430	0.657	0.577	1.000	0.747
Company 4	0.218	0.333	0.430	0.577	0.509	1.000	0.502
Restrictions	$y_{11}=y_{12}=y_{13}=y_{14}=3y_{15}$						

The same priority ranking obtained as a result of AHP was also valid for DEAHP and Company 2 became prominent as the most successful company at the financial structure sub-criteria level. Considering financial structure, the AHP values of Companies 1 and 3 were very close to each other, whereas considering the DEAHP values, Company 3 was far more successful than Company 1. However, it is known that adding an additional restriction to the restrictions changes the value of the results, blocks two criteria that might have the same value and provides more accurate results.

Table 18. DEAHP weights of the companies at the sub-criteria level of the partners and management structure

	SC6	SC7	SC8	SC9	SC10	SC11	SC12	Input	DEAHP
Company 1	0.111	0.111	0.111	0.111	0.111	0.111	0.333	1.000	0.128
Company 2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Company 3	0.509	1.000	0.556	0.882	1.000	0.778	1.000	1.000	0.838
Company 4	0.509	0.577	0.192	0.430	0.657	0.192	0.577	1.000	0.478
Restrictions	$3y_{11}=2.33y_{12}=1.73y_{13}=2.63y_{14}=y_{15}=4y_{16}=4y_{17}$								

Table 19. DEAHP weights of the companies at the sub-criteria level of the sales and marketing structure

	SC13	SC14	SC15	SC16	Input	DEAHP
Company 1	0.333	0.111	0.126	1.000	1.000	0.530
Company 2	1.000	1.000	1.000	1.000	1.000	1.000
Company 3	0.655	0.447	0.745	1.000	1.000	0.802
Company 4	0.577	0.333	0.488	1.000	1.000	0.699
Restrictions	$3.55y_{11}=2.99y_{12}=1.47y_{13}=y_{14}$					

Table 20. DEAHP weights of the companies at the sub-criteria level of the sectoral structure

	SC17	SC18	Input	DEAHP
Company 1	0.333	0.111	1.000	0.222
Company 2	1.000	1.000	1.000	1.000
Company 3	0.776	0.447	1.000	0.612
Company 4	0.577	0.333	1.000	0.455
Restrictions	$y_{11}=y_{12}$			

Table 21. DEAHP weights of the companies at the sub-criteria level of the company ethics and intelligence structure

	SC19	SC20	SC21	SC22	SC23	Input	DEAHP
Company 1	1.000	0.333	0.333	0.333	0.111	1.000	0.462
Company 2	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Company 3	1.000	0.745	0.882	0.882	0.657	1.000	0.821
Company 4	1.000	0.745	0.577	0.745	0.430	1.000	0.725
Restrictions	$1.13y_{11}=y_{12}=3y_{13}=3y_{14}=1.34y_{15}$						

According to Table 18 – Table 21, the ranking obtained from AHP again did not change for all main criteria except financial structure; the ranking from the most successful to least successful companies was determined as follows: Company 2, Company 3, Company 4 and Company 1.

Step 4

Table 22 shows the importance attached by the banks to the properties they consider when evaluating commercial credit applications. As explained in Step 4a, the AHP weights of each main criterion were calculated by making use of the aforementioned pair-wise comparisons of the main criteria. Furthermore, as explained in Step 4b, the DEA model was constructed by using the pair-wise comparisons of the main criteria as parameter values and the DEAHP weights of the main criteria were obtained by solving this model separately for each main criterion.

The weights obtained by DEAHP will comprise the restrictions for the following step. Thus, if the weights of the C2 and C5 main criteria are assumed to be 1, then this weight value will be 1.73 times the weight of the C1 main criterion, 5.21 times the weight of the C3 main criterion and 6.71 times the weight of the C4 main criterion.

Table 22. Weights obtained by the pair-wise comparisons of the main criteria, AHP and DEAHP

	C1	C2	C3	C4	C5	Input	AHP	DEAHP
C1	1.000	0.577	3.000	5.196	0.378	1.000	0.172	0.577
C2	1.732	1.000	9.000	6.708	1.000	1.000	0.345	1.000
C3	0.333	0.111	1.000	1.732	0.111	1.000	0.051	0.192
C4	0.192	0.149	0.577	1.000	0.111	1.000	0.039	0.149
C5	2.646	1.000	9.000	9.000	1.000	1.000	0.394	1.000
	CR=0.020							

Step 5
Tables 23 and 24 indicate the comparison values of each company in terms of the main criteria and sub-criteria and in terms of the weights obtained by AHP and DEAHP, respectively. For each main criterion, the ultimate AHP weight for each alternative was calculated, as shown in Table 23, by using the AHP weights of the companies obtained in Step 3 for each main criterion.

To calculate these weights by DEAHP, a DEA model was constructed, as in Model 3, by using the DEAHP results of the comparisons at one level below as outputs and the DEAHP results of the comparisons at the highest level as restrictions; then, the model was solved for each company. The DEAHP column in Table 22 creates the following constraints: $1.73y_{11}=y_{12}=5.21y_{13}=6.71y_{14}=y_{15}$. The solution results indicate the weights that each company will receive. The overall weights of all four business firms using the DEAHP approach are shown in Table 24, while the overall weights of suppliers based on the crisp AHP method are shown in Table 23.

Table 23. Weights of the companies determined by AHP

	C1	C2	C3	C4	C5	AHP
Company 1	0.220	0.045	0.196	0.093	0.151	0.130
Company 2	0.425	0.563	0.356	0.533	0.402	0.454
Company 3	0.212	0.255	0.235	0.225	0.239	0.239
Company 4	0.143	0.138	0.214	0.149	0.208	0.177
Local Weights of the Criteria	0.172	0.345	0.051	0.039	0.394	

Table 24. Weights of the companies determined by DEAHP

	C1	C2	C3	C4	C5	Input	DEAHP
Company 1	0.422	0.128	0.530	0.222	0.462	1.000	0.332
Company 2	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Company 3	0.747	0.838	0.802	0.612	0.821	1.000	0.800
Company 4	0.502	0.478	0.699	0.455	0.725	1.000	0.581
Restrictions	$1.73y_{11}=y_{12}=5.21y_{13}=6.71y_{14}=y_{15}$						

4. Comparing the DEAHP and AHP Results
When the results of the analyses conducted by AHP and DEAHP are examined in terms of evaluating price performance, Company 2 has the highest performance, with an AHP evaluation result of 0.454 and a DEAHP efficiency of 1, followed by Company 3, Company 4 and Company 1. In Table 25, the AHP and normalized DEAHP values are given together. When the DEAHP weights are normalized from this table, it is observed that values that are very close to the weights obtained by AHP are obtained. Furthermore, it has been stated by Ramanathan 2006 that the difference between AHP and DEAHP values emerges from the assumptions made for DEAHP.

Table 25. AHP and normalized DEAHP weights

Companies	**AHP**	**Normalized DEAHP**
Company 1	0.130	0.122
Company 2	0.454	0.369
Company 3	0.239	0.295
Company 4	0.177	0.214

An overall examination reveals that Company 1 is prominent in terms of resource-to-debt structure ratios, foreign trade activities and protested bill-check inquiry. Company 2 is the most successful company for all other sub-criteria except for resource-to-debt structure ratios. Additionally, Company 1 is the most successful company in terms of resource-to-debt structure ratios, followed by Company 3 and Company 4. Company 3 is ahead of all other companies in terms of the equity, stability in partnership structure, ethics of company owner and partners, staff policies, foreign trade activities and protested bill-check inquiry sub-criteria. Although Company 4 is prominent only in terms of foreign trade activities and protested bill-check inquiry, it outranks Company 1, which is successful in terms of overall results with its resource-to-debt structure ratios and foreign trade activities in addition to protested bill-check inquiry and is the third-successful company. This result can be explained by the fact that although Company 1, unlike Company 4, was the only company successful in terms of resource-to-debt structure ratios, it was the least successful company in terms of all other sub-criteria in the model.

Table 22 displays the ranking of all five categories of business firm selection criteria based on the overall weights using both the AHP and DEAHP approaches. It is readily apparent from Table 22 that there is a consistent pattern in the ranking of selection criteria for both approaches. The first three leading broad categories of selection criteria include firm ethics and intelligence, partners and managerial structure and financial structure. The remaining two categories of sales and marketing structure and sectoral structure are the lowest ranked selection criteria. The ranking of individual criteria comprising each category of the first three broad selection criteria as well as the evaluation of business firms based on each criterion are discussed below.

Table 2 shows that from the full set of firm ethics and intelligence criteria, problematic firm and partner records (enforcement, interrupted payment) was the most important criterion in both the AHP and DEAHP methods. From the bank's perspective, Firm 2 was the most suitable firm in terms of problematic firm and partner records, as shown in Table 11. In contrast, Firm 1 was determined to be the most appropriate supplier with respect to all firm ethics and intelligence criteria, while Firm 3 and Firm 4 were not determined to be the most preferred firms in terms of all sub-criteria. When all five criteria were considered together, Firm 2 emerged as the most appropriate firm, as shown in Table 16 (with an AHP weight of 0.402) and in Table 21 (with a DEAHP weight of 1.000).

Table 2 indicates that from the full set of seven criteria constituting partners and managerial structure, the ethics of the company owner and partners' criterion was found to have the highest weight, while the managerial understanding and staff policy criteria had the lowest weight in both the AHP and DEAHP approach. Of the four firms, Firm 2 had the highest weight in terms of the ethics of the company owner and partners' criterion and was considered to be the most suitable firm in the AHP approach, as shown in Table 8. In contrast, Firm 1 and Firm 2 had the highest weights in terms of the ethics of the company owner and partners' criterion and were considered to be the most suitable firms according to the DEAHP results. In contrast, Firm 2 was identified to be the most preferred firm by having the highest weight in terms of all other partners and managerial structure sub-criteria and Firm 3 was the second most suitable firm for all seven selection criteria. However, according to the overall evaluation of the partners and managerial structure, Firm 2 emerged as the most appropriate firm, as shown in Table 13 (with an AHP weight of 0.563) and in Table 18 (with a DEAHP weight of 1.000).

From the whole set of five criteria comprising financial structure, resource-to-debt structure ratio and their structures was found to have the highest ranking criteria, while growth ratios had the lowest ranking criteria based on AHP as shown in Table 1. On the other hand all financial structure criteria were found to have highest ranking criteria other than growth ratios based on DEAHP. NonethelessFirm1 was selected as the most suitable firm with respect to structure-to-debt ratio and their structures in both methods. Table 12 and Table 17 however, indicates that Firm 2 was selected as the most appropriate firm with respect to all five financial structure criteria in both methods.

5. Conclusion

In this study, the utility of the DEAHP approach (created by the joint use of DEA and AHP) in multi-criteria decision-making problems was demonstrated using a performance evaluation of four customers that had submitted commercial credit applications to a bank. In the application, the weights of the main criteria, sub-criteria and alternatives in the hierarchy were calculated by using the AHP and DEAHP methods; the ranking of the results was similar for the two methods.

According to the AHP and DEAHP results, ethics and intelligence are considered to be the most important criteria. The financial structure of the company was determined to be the third most important main criterion. This situation is a reminder of the question of a judge commissioned in the Research Committee of the US Congress directed to the bankers in 1912: "Will banks give credit only to the persons who have money and assets?" J.P. Morgan, whose name was given to the one of the largest financial institutions operating today, gave the following answer: "No, morality is the priority." When the judge asked the same question again in a suspicious manner, J.P. Morgan explained: "A person who I don't trust can never get credit from me." This is not a surprising result, considering that sometimes even some firms that have a good financial status do not reimburse the credit they received. Accordingly, to minimize the risk of credit, banks do not want to give credit to a firm that has poor morality, even if it has good solvency and sufficient assets. According to both approaches, sales and marketing structures and sectoral structures were determined to be the main criteria with the least weight in commercial credit-granting decisions.

The company rankings were the same according to the two approaches. Company 2 was the most appropriate company according to both approaches, followed by Company 3, Company 4 and Company 1. However, this

study cannot be compared to any other study in the literature in terms of DEAHP findings because no other study has used DEAHP to evaluate commercial credit applications.

Even though the most appropriate firms whose commercial credit application and weights of the criteria to be covered were determined within the scope of the established hierarchical model by consulting two experts' opinions, these results do not reflect the opinion of all banking sectors. Although the results of the study are based on the individual considerations of credit evaluation experts from an anonymous private bank that are undisclosed for privacy reasons, the results obtained from the study will be helpful for companies applying for credit by enabling them to determine their strengths and weaknesses. Furthermore, the use of the model recommended by the study based on group decision making and common considerations of credit evaluation experts of several public and private banks may facilitate the ability to reach more general results and repeat the study with different criteria and sub-criteria.

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