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Research Article

Using Multi-Objective DEA to Assess the Overall and Partial Performance of Hierarchical Resource Utilization

Abdorrahman Haeri, Kamran Rezaie and Mohsen-Sadegh Amalnick
Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

Abstract: Heterogeneous resources transform into other resource forms through business processes and activities in organizations. This basic concept is called "resource transformation" in the literature. Resource transformation assumes that resources receive value from other resources and deliver value to the same resources. In this study, it is assumed that each resource acts as a Decision Making Unit (DMU) that converts input factors from other resources to the output factors that are resources themselves. Multi-Objective Data Envelopment Analysis (MODEA) is applied to attain overall and partial efficiency scores of resources to evaluate the performance of resources in utilizing different types of resources. The results show whether resources utilize other resources weakly or efficiently and provide the ability to compare the performance of different types of resource transformation. The findings help decision makers identify the weaknesses and strengths of resource performance in organizations.

Keywords: Hierarchical resource classification, multi-objective data envelopment analysis, overall efficiency score, partial efficiency score, resource transformation

INTRODUCTION

Organizations use heterogeneous resources to perform their business processes and daily activities. The resources should be hierarchically categorized to enable managers and consultants to investigate and assess their performance. Shapiro (1999) categorized organizational resources as physical (including plants, distribution centers, inventories, etc.), human (including operators, managers, scientists, etc.), financial (including cash flow, debt capacity, equity availability, etc.), information technology (including inventory management system, communication network, etc.), marketing (including market share, brand, etc.), organizational (training system, corporate culture, etc.) and legal (including patents, contracts, etc.). Grant (1991) stated that 3-level classification contains tangible (including plant, equipment, raw material inventory, …), intangible (including reputation, technology, know-how) and personal-based (including culture, training, commitment, loyalty, …) resources. Saltmarshe (2002) classified resources as material, human, natural, social and cultural. Cruz-Ros (2009) paid attention to managerial (including problem solving, managerial leadership, etc.) and organizational resources (including commitment culture, stakeholder cooperation, etc.). Fahy (2002) presented a 3-level classification: Country Specific Resources (CSR) (including a country's location, climate, natural deposit, etc.) or Firm Specific Resources (FSR) (including knowledge, information and brand names). Fernandez *et al*. (2009) categorized competencies of human resources into knowledge, skills and abilities. Roos *et al*. (2005) presented 3-level classification of resources that included tangible and intangible resources at the first level. At the second level, tangible resources are subdivided to monetary and physical and intangible resources include relational, organizational and human. More details about this taxonomy are shown in Table 1. This classification is considered the basic taxonomy approach in this research.

After the literature review about hierarchical resource classification approaches, it is necessary to focus on resource utilization, which is the ability of an organization to efficiently utilize its heterogeneous resources and plays a critical role in the success of the company. Majumdar (1998) applied Data Envelopment Analysis (DEA) to obtain resource utilization measures of companies in the telecommunication industry. He used DEA models to investigate the ability of companies to utilize physical resources to generate calls and create revenue. Giménez-García *et al*. (2007) presented a DEA-based approach, including 3 steps to improve resource utilization in a networked organization. The developed approach is applied to 54 branches of a Spanish restaurant chain. Azadeh *et al*. (2010) applied fuzzy DEA to investigate the relationship between some attributes of organizational resources as input factors and safety behavior as an output factor in Iranian steel companies. "Resource

Corresponding Author: Abdorrahman Haeri, Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran, Tel.: +98 21 82084182; Fax: +98 21 82084182

Table 1: Classification of resources in 3 levels for an advisory organization

Resources in first level	Resources in second level	Resources in third level
Tangible	Monetary	Cash, bonds and stocks, guarantee
	Physical	Office & facility, IT facility, text processing machine
Intangible	Relational	Customers, suppliers, partners, research, financial network
	Organizational	IT system, brand, organizational culture, accumulated data, know-how
	Human	Knowledge, problem solving, human skill, attitude, self-development

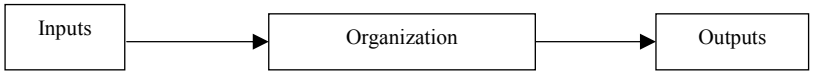

Fig. 1: Broad resource performance measurement (past study)

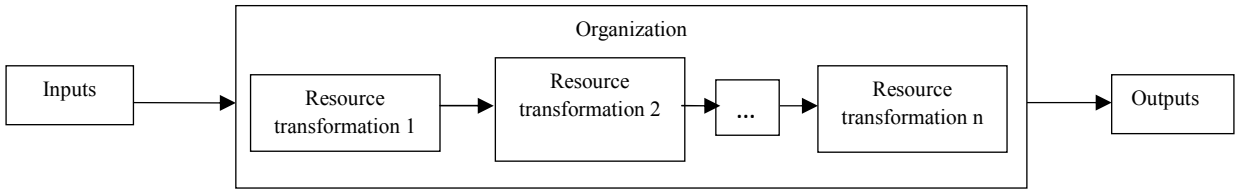

Fig. 2: Detailed resource performance measurement (current study)

allocation" is related to resource utilization. For example, Kao (2000) considered resource allocation in a non-profit organization and applied DEA to allocate the budget, which is one type of financial resource, to subdivisions of a forest district. The applied framework proposed more flexibility in budget allocation to attain better Efficiency Scores (ESs). Also Mahmoudi *et al*. (2012) applied DEA to measure the overall efficiency of used resources and specify the amount of inefficiencies. Tsai *et al*. (2008) investigated four strategies for resource allocation in a GPRS network. They developed analytical models to attain performance measures of the considered strategies. The results show that these strategies can outperform previous strategies to present better performance measures. Some researchers such as Kase and Zupan (2009) consider ways which employee as an important resource is valuable.

In past research, resource utilization was studied at the broad level of the organization so that resources were inputs of a company and some performance measures, such as revenue, quality, sales, etc., were considered outputs of the company. In these approaches, a company is seen as a large convertor that transforms resources (as inputs) into performance measures (as outputs). It is necessary to perform various activities to utilize inputs, create outputs of different processes and finally develop desired outputs. In this study, a framework is presented to enable decision makers to acquire detailed information about the efficiency of resource transformations that occur during processes in an organization. Figure 1 and 2 shows the approaches of past and current research, respectively.

Resource transformation is another basic concept of this study. Pike *et al*. (2005) stated that organizational resources are interconnected and value is transformed from one resource form to other resource forms during business processes and activities. For example, a marketing department analyzed potential customer data to identify a new target segment of customers. This activity converts an organizational resource (accumulated data) into a relational resource (customer). Afterward, products are sold to the newly identified segment of customers. This activity converts a relational resource (customer) into a monetary resource (money) and so on. Pike *et al*. (2005) treated each resource as a DMU and calculated efficiency scores of DMUs with the ratio of the sum of output values to the sum of input values. Knox (2004) considered an organization as an input-output system that includes some generic processes such as resource transformation. Granstrand (1998) stated that resources are inputs and outputs of the resource transformation processes, such as the production process, in a firm. Rezaie *et al*. (2011) used augmented DEA to calculate efficiency scores of resources based on the resource transformation concept. In this study, based on the resource transformation concept, 2 groups of resource utilization measures are calculated. The first group includes the overall efficiency scores of resource utilization and concerns all input and output resources during resource transformations. The second group contains partial efficiency scores of resource utilization that consider a chosen set of input and output resources.

Table 2: Examples of second-level resource transformations

	Monetary	Physical	Relational	Organizational	Human
Monetary	Buying bonds	Procurement	Investment to create supplier network	Buying data	Buying patents
Physical	Sales	Production	Facilities to increase relationships with partners and customers	Data processing using PCs	Using training facilities
Relational	Selling to loyal customers	Using partner's location	Attracting partner's customers	Experimental exchange meetings	Benchmarking
Organizational	Sales of brand	Energy conservation	Database marketing	Data analysis	E-learning
Human	Selling man-days	Maintenance	Building relationships with partners	Developing IT systems	Training

Table 3: Second-level resource transformation matrix

	Monetary	Physical	Relational	Organizational	Human	Importance (%)
Monetary	2	1	2.40	2.600	2	10
Physical	0	0.88	2.34	4.880	1.900	10
Relational	2.58	0.44	4.85	9.060	3.080	20
Organizational	9.30	1.20	8.97	10.44	10.09	40
Human	3.85	0.23	4.34	6.530	5.060	20

Table 4: Third-level resource transformation matrix

	Cash	Bonds and stocks	Guarantee	Office and facility	IT facility	Text processing machine	Customers	Suppliers	Partners	Research	Financial network
Cash	0.00	0.00	0.00	0.00	0.50	0.50	1.60	0.40	0.40	0.00	0.00
Bonds and stocks	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guarantee	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office and facility	0.00	0.00	0.00	0.00	0.19	0.50	0.38	0.00	0.13	0.00	0.13
IT facility	0.00	0.00	0.00	0.03	0.00	0.07	0.07	0.03	0.03	0.00	0.00
Text processing machine	0.00	0.00	0.00	0.10	0.00	0.00	1.10	0.20	0.30	0.00	0.00
Customers	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.38
Suppliers	0.10	0.00	0.00	0.00	0.00	0.10	0.60	0.00	0.10	0.00	0.00
Partners	0.45	0.00	0.00	0.00	0.30	0.00	3.30	0.15	0.00	0.00	0.08
Research	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
Financial network	0.53	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.00
IT system	0.20	0.00	0.00	0.00	0.20	0.10	0.30	0.05	0.20	0.05	0.00
Brand	1.10	0.00	0.00	0.00	0.00	0.00	1.08	0.19	0.27	0.19	0.09
Organizational Culture	0.20	0.00	0.00	0.00	0.00	0.00	1.00	0.20	0.20	0.00	0.00
Accumulated data	1.80	0.00	0.00	0.00	0.20	0.20	1.20	0.20	0.00	0.50	0.00
Know-how	6.00	0.00	0.00	0.00	0.50	0.00	3.00	0.00	0.00	0.25	0.00
Knowledge	1.00	0.00	0.00	0.00	0.13	0.00	0.88	0.00	0.00	0.31	0.00
Problem solving	1.10	0.00	0.00	0.00	0.10	0.00	0.80	0.05	0.05	0.00	0.00
Human skill	1.00	0.00	0.00	0.00	0.00	0.00	0.80	0.10	0.10	0.00	0.00
Attitude	0.60	0.00	0.00	0.00	0.00	0.00	0.80	0.15	0.15	0.00	0.00
Self-development	0.15	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00

	IT system	Brand	Organizational culture	Accumulated data	Know-how	Knowledge	Problem solving	Human skill	Attitude	Self-development
Cash	0.70	0.70	0.00	0.40	0.80	0.40	0.40	0.40	0.40	0.40
Bonds and stocks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guarantee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office and facility	0.19	1.50	0.13	0.13	0.13	0.25	0.25	0.25	0.63	0.25
IT facility	0.28	0.04	0.00	0.10	0.10	0.12	0.05	0.03	0.05	0.03
Text processing machine	0.00	0.30	0.00	0.60	1.40	0.00	0.00	0.00	0.00	0.00
Customers	0.00	3.25	0.13	0.75	1.00	0.63	0.63	0.63	0.50	0.50
Suppliers	0.00	0.15	0.00	0.05	0.90	0.00	0.00	0.00	0.00	0.00
Partners	0.08	0.60	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00
Research	0.00	0.29	0.03	0.13	0.30	0.15	0.04	0.01	0.00	0.00
Financial network	0.00	0.34	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
IT system	0.00	0.05	0.30	0.40	0.70	0.70	0.20	0.25	0.10	0.20
Brand	0.00	0.00	0.24	0.00	0.05	0.10	0.10	0.10	0.29	0.20
Organizational culture	0.00	0.60	0.00	0.00	0.30	0.30	0.10	0.20	0.60	0.30
Accumulated data	0.00	1.60	0.00	0.00	1.20	0.90	0.20	0.00	0.00	0.00
Know-how	0.25	2.50	1.00	1.25	0.00	1.50	1.75	1.25	0.50	0.25
Knowledge	0.06	0.44	0.25	0.25	1.00	0.00	0.44	0.13	0.06	0.06
Problem solving	0.00	0.40	0.15	0.10	0.60	0.30	0.00	0.20	0.10	0.05
Human skill	0.00	0.30	0.20	0.00	0.60	0.25	0.30	0.00	0.20	0.15
Attitude	0.00	0.50	0.70	0.00	0.30	0.20	0.15	0.15	0.00	0.30
Self-development	0.00	0.08	0.30	0.00	0.30	0.56	0.56	0.41	0.49	0.00

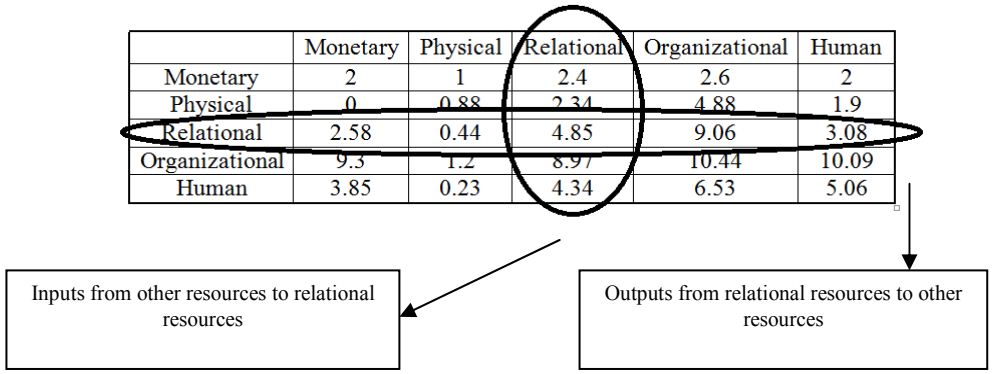

Fig. 3: Input and output resources of relational resources

This study will propose a framework to assess resource utilization from both general and partial viewpoints. No research to date has investigated overall and partial efficiency scores in resource transformation. Therefore, the objectives and main contributions of this study are as follows:

- To provide a basis for resource evaluation from a resource transformation viewpoint
- To assess resources in different levels of a hierarchical taxonomy
- To calculate overall and partial efficiency scores to evaluate resources by considering different criteria
- To rank resources according to the values of the number of efficient or weak cases
- To identify relative efficient or weak resources in utilizing other heterogeneous resources

Specifically the main objective of this research is providing the possibility to assess resource performance during resource transformations from different viewpoints. Initially, calculation of overall efficiency scores is considered to enable managers to gain a general view about performance of resources. At next step, partial efficiency scores are attained to present resource performance measures from tangible/intangible viewpoint. Finally partial efficiency scores in third level are calculated to attain specific performance measures from monetary, physical, relational, organizational and human viewpoints.

METHODOLOGY

Hierarchical resource classification: As stated in the introduction, a 3-level taxonomy derived from Roos *et al*. (2005), is the basic classification in this study. A full description of this classification is shown in Table 1.

Resource transformation: Each case of resource transformation is related to business processes and activities. Table 2 contains examples of processes and activities connected to different cases of second-level transformations.

Roos *et al*. (2005) presented the second-level resource transformation matrix for an advisory organization that is shown in Table 3. Values in this table display how much each transformation contributes to creating value. For example, Table 3 shows that transformation from physical to relational contributes 2.34% of value creation for the considered organization. The sum of the values in each row of the transformation matrix is equal to the importance of the related resource. For example, the importance of the monetary resource (10%) equals the sum of 2, 1, 2.4, 2.6 and 2. Like other values in the resource transformation matrix, the importance of each resource is stated as a percentage.

Roos *et al*. (2005) also presented a resource transformation matrix in the third-level for the considered advisory organization, which is shown in Table 4.

Overall efficiency score of resources: Resource transformation assumes that each resource receives value from all resources and delivers value to all resources. For example, relational resources receive value from monetary, physical, relational, organizational and human resources and deliver value to monetary, physical, relational, organizational and human resources. This concept is shown in Fig. 3.

Based on the stated concept in Fig. 3, the input and output resources of second-level resources are shown in Table 5. In addition, input and output resources for third-level resources are stated in Table 6 and 7, respectively. Each row of Table 5, 6 and 7 is related to one resource, which is considered a Decision Making Unit (DMU). Each column of Table 5, 6 and 7 is related to one input/output resource, which is considered an input/output factor. Therefore, DEA method can be used to calculate the efficiency scores of resources in different levels.

Table 5: Input and output resources of second-level resources

Second-level resources	Input resources					Output resources				
Resources	Monetary	Physical	Relational	Organizational	Human	Monetary	Physical	Relational	Organizational	Human
Monetary	2	0	2.58	9.300	3.85	2	1	2.40	2.600	2
Physical	1	0.88	0.44	1.200	0.23	0	0.88	2.34	4.880	1.900
Relational	2.4	2.34	4.85	8.970	4.34	2.58	0.44	4.85	9.060	3.080
Organizational	2.6	4.88	9.06	10.44	6.53	9.30	1.20	8.97	10.44	10.09
Human	2	1.9	3.08	10.09	5.06	3.85	0.23	4.34	6.530	5.060

Table 6: Input resources of third-level resources

	Input resources									
Third level resources	Cash	Bonds and stocks	Guarantee	Office and facility	IT facility	Text processing machine	Customers	Suppliers	Partners	Research	Financial network
Cash	0.00	1.00	1.00	0.00	0.00	0.00	1.50	0.10	0.45	0.00	0.53
Bonds and stocks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guarantee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office and facility	0.00	0.00	0.00	0.00	0.03	0.10	0.00	0.00	0.00	0.00	0.00
IT facility	0.50	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.30	0.00	0.00
Text processing machine	0.50	0.00	0.00	0.50	0.07	0.00	0.00	0.10	0.00	0.00	0.04
Customers	1.60	0.00	0.00	0.38	0.07	1.10	0.00	0.60	3.30	0.06	0.06
Suppliers	0.40	0.00	0.00	0.00	0.03	0.20	0.00	0.00	0.15	0.00	0.00
Partners	0.40	0.00	0.00	0.13	0.03	0.30	0.13	0.10	0.00	0.00	0.00
Research	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Financial network	0.00	0.00	0.00	0.13	0.00	0.00	0.38	0.00	0.08	0.00	0.00
IT system	0.70	0.00	0.00	0.19	0.28	0.00	0.00	0.00	0.08	0.00	0.00
Brand	0.70	0.00	0.00	1.50	0.04	0.30	3.25	0.15	0.60	0.29	0.34
Organizational culture	0.00	0.00	0.00	0.13	0.00	0.00	0.13	0.00	0.00	0.03	0.00
Accumulated data	0.40	0.00	0.00	0.13	0.10	0.60	0.75	0.05	0.00	0.13	0.00
Know-how	0.80	0.00	0.00	0.13	0.10	1.40	1.00	0.90	1.05	0.30	0.04
Knowledge	0.40	0.00	0.00	0.25	0.12	0.00	0.63	0.00	0.00	0.15	0.00
Problem Solving	0.40	0.00	0.00	0.25	0.05	0.00	0.63	0.00	0.00	0.04	0.00
Human skill	0.40	0.00	0.00	0.25	0.03	0.00	0.63	0.00	0.00	0.01	0.00
Attitude	0.40	0.00	0.00	0.63	0.05	0.00	0.50	0.00	0.00	0.00	0.00
Self-development	0.40	0.00	0.00	0.25	0.03	0.00	0.50	0.00	0.00	0.00	0.00

	Input resources									
Third level resources	IT system	Brand	Organizational culture	Accumulated data	Know-how	Knowledge	Problem solving	Human skill	Attitude	Self-development
Cash	0.20	1.10	0.20	1.80	6.00	1.00	1.10	1.00	0.60	0.15
Bonds and stocks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guarantee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office and facility	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IT facility	0.20	0.00	0.00	0.20	0.50	0.13	0.10	0.00	0.00	0.00
Text processing machine	0.10	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Customers	0.30	1.08	1.00	1.20	3.00	0.88	0.80	0.80	0.80	0.15
Suppliers	0.05	0.19	0.20	0.20	0.00	0.00	0.05	0.10	0.15	0.00
Partners	0.20	0.27	0.20	0.00	0.00	0.00	0.05	0.10	0.15	0.00
Research	0.05	0.19	0.00	0.50	0.25	0.31	0.00	0.00	0.00	0.00
Financial network	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IT system	0.00	0.00	0.00	0.00	0.25	0.06	0.00	0.00	0.00	0.00
Brand	0.05	0.00	0.60	1.60	2.50	0.44	0.40	0.30	0.50	0.08
Organizational culture	0.30	0.24	0.00	0.00	1.00	0.25	0.15	0.20	0.70	0.30
Accumulated data	0.40	0.00	0.00	0.00	1.25	0.25	0.10	0.00	0.00	0.00
Know-how	0.70	0.05	0.30	1.20	0.00	1.00	0.60	0.60	0.30	0.30
Knowledge	0.70	0.10	0.30	0.90	1.50	0.00	0.30	0.25	0.20	0.56
Problem solving	0.20	0.10	0.10	0.20	1.75	0.44	0.00	0.30	0.15	0.56
Human skill	0.25	0.10	0.20	0.00	1.25	0.13	0.20	0.00	0.15	0.41
Attitude	0.10	0.29	0.60	0.00	0.50	0.06	0.10	0.20	0.00	0.49
Self-development	0.20	0.20	0.30	0.00	0.25	0.06	0.05	0.15	0.30	0.00

Partial efficiency score of resources: Resources have attributes or features that are usually related to their hierarchical resource classification. Monetary and physical resources are tangible; therefore, they have

Table 7: Output resources of third-level resources

Third-level resources	Output resources: Cash	Bonds and stocks	Guarantee	Office and facility	IT facility	Text processing machine	Customers	Suppliers	Partners	Research	Financial network
Cash	0.00	0.00	0.00	0.00	0.50	0.50	1.60	0.40	0.40	0.00	0.00
Bonds and stocks	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guarantee	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office and facility	0.00	0.00	0.00	0.00	0.19	0.50	0.38	0.00	0.13	0.00	0.13
IT facility	0.00	0.00	0.00	0.03	0.00	0.07	0.07	0.03	0.03	0.00	0.00
Text processing machine	0.00	0.00	0.00	0.10	0.00	0.00	1.10	0.20	0.30	0.00	0.00
Customers	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.38
Suppliers	0.10	0.00	0.00	0.00	0.00	0.10	0.60	0.00	0.10	0.00	0.00
Partners	0.45	0.00	0.00	0.00	0.30	0.00	3.30	0.15	0.00	0.00	0.08
Research	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
Financial network	0.53	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.00
IT system	0.20	0.00	0.00	0.00	0.20	0.10	0.30	0.05	0.20	0.05	0.00
Brand	1.10	0.00	0.00	0.00	0.00	0.00	1.08	0.19	0.27	0.19	0.09
Organizational culture	0.20	0.00	0.00	0.00	0.00	0.00	1.00	0.20	0.20	0.00	0.00
Accumulated data	1.80	0.00	0.00	0.00	0.20	0.20	1.20	0.20	0.00	0.50	0.00
Know-how	6.00	0.00	0.00	0.00	0.50	0.00	3.00	0.00	0.00	0.25	0.00
Knowledge	1.00	0.00	0.00	0.00	0.13	0.00	0.88	0.00	0.00	0.31	0.00
Problem solving	1.10	0.00	0.00	0.00	0.10	0.00	0.80	0.05	0.05	0.00	0.00
Human skill	1.00	0.00	0.00	0.00	0.00	0.00	0.80	0.10	0.10	0.00	0.00
Attitude	0.60	0.00	0.00	0.00	0.00	0.00	0.80	0.15	0.15	0.00	0.00
Self-development	0.15	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00

Third-level resources	Output resources: IT system	Brand	Organizational culture	Accumulated data	Know-how	Knowledge	Problem solving	Human skill	Attitude	Self-development
Cash	0.70	0.70	0.00	0.40	0.80	0.40	0.40	0.40	0.40	0.40
Bonds and stocks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guarantee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office and facility	0.19	1.50	0.13	0.13	0.13	0.25	0.25	0.25	0.63	0.25
IT facility	0.28	0.04	0.00	0.10	0.10	0.12	0.05	0.03	0.05	0.03
Text processing machine	0.00	0.30	0.00	0.60	1.40	0.00	0.00	0.00	0.00	0.00
Customers	0.00	3.25	0.13	0.75	1.00	0.63	0.63	0.63	0.50	0.50
Suppliers	0.00	0.15	0.00	0.05	0.90	0.00	0.00	0.00	0.00	0.00
Partners	0.08	0.60	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00
Research	0.00	0.29	0.03	0.13	0.30	0.15	0.04	0.01	0.00	0.00
Financial network	0.00	0.34	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
IT system	0.00	0.05	0.30	0.40	0.70	0.70	0.20	0.25	0.10	0.20
Brand	0.00	0.00	0.24	0.00	0.05	0.10	0.10	0.10	0.29	0.20
Organizational culture	0.00	0.60	0.00	0.00	0.30	0.30	0.10	0.20	0.60	0.30
Accumulated data	0.00	1.60	0.00	0.00	1.20	0.90	0.20	0.00	0.00	0.00
Know-how	0.25	2.50	1.00	1.25	0.00	1.50	1.75	1.25	0.50	0.25
Knowledge	0.06	0.44	0.25	0.25	1.00	0.00	0.44	0.13	0.06	0.06
Problem solving	0.00	0.40	0.15	0.10	0.60	0.30	0.00	0.20	0.10	0.05
Human skill	0.00	0.30	0.20	0.00	0.60	0.25	0.30	0.00	0.20	0.15
Attitude	0.00	0.50	0.70	0.00	0.30	0.20	0.15	0.15	0.00	0.30
Self-development	0.00	0.08	0.30	0.00	0.30	0.56	0.56	0.41	0.49	0.00

Table 8: Input and output factors of “Tangible to Intangible” transformation

Resources (DMUs)	Input factors: Monetary	Physical	Output factors: Relational	Organizational	Human
Monetary	2	0	2.40	2.600	2
Physical	1	0.88	2.34	4.880	1.900
Relational	2.4	2.34	4.85	9.060	3.080
Organizational	2.6	4.88	8.97	10.44	10.09
Human	2	1.90	4.34	6.530	5.060

tangible attributes. Relational, organizational and human resources are intangible; therefore, they have intangible attributes. Resources have features that are related to the higher level of classification. For example, monetary resources, which are second-level resources, have intangible (that is, a first-level resource) attributes. Partial efficiency scores consider different resource attributes and are related to a chosen set of input and output factors of resources. Table 8 shows a chosen set of input and output factors of second-level resources so that the input factors are monetary and physical (tangible) resources and the output factors are relational, organizational and human (intangible) resources. The data in this table are the basis for calculating the partial efficiency score of "Tangible to Intangible” (TI) transformation. Other partial efficiency

Table 9: Input and output factors of "human to organizational" transformation

	Input factors					Output factors				
	Knowledge	Problem solving	Human skill	Attitude	Self-development	IT system	Brand	Organizational culture	Accumulated data	Know-how
Cash	1.00	1.10	1.00	0.60	0.15	0.70	0.70	0.00	0.40	0.80
Bonds and stocks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guarantee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office and facility	0.00	0.00	0.00	0.00	0.00	0.19	1.50	0.13	0.13	0.13
IT facility	0.13	0.10	0.00	0.00	0.00	0.28	0.04	0.00	0.10	0.10
Text processing machine	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.60	1.40

scores can be calculated in a similar way.

Similarly, at the second level, it is possible to calculate partial efficiency scores of third-level resources. For example, the data in Table 9 can be used to calculate the "Human to Organizational" (HO) partial efficiency score.

Single and multi-objective data envelopment analysis: The basic DEA model that was developed by Charnes *et al*. (1978) is called the CCR DEA model and assumes that there are *n* DMUs that have *m* inputs and *s* outputs. The parameters and variables of the model are the following:

x_{ij} : The *i*-th input of the *j*-th DMU
y_{rj} : The *r*-th input of the *j*-th DMU
v_i : The weight of the *i*-th input
u_r : The weight of the *r*-th output
es_j : The efficiency score of the *j*-th DMU

The objective function and constraints of the model are as follows:

$$\begin{aligned} & es_j = \max\left(\sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{i=1}^{m} v_i x_{ij}\right) \\ & s.t. \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \\ & u_r, v_i \ge \varepsilon \end{aligned} \tag{1}$$

Model (2) is a linear programming model of model (1):

$$\begin{aligned} & es_j = \max \sum_{r=1}^{s} u_r y_{rj} \\ & s.t. \\ & \sum_{i=1}^{m} v_i x_{ij} = 1 \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \\ & u_r, v_i \ge \varepsilon \end{aligned} \tag{2}$$

The basic DEA model has low discrimination power so that in many cases, obtained efficiency scores for some DMUs equal one. Therefore, in this study, a modified multi-objective DEA is applied to increase the discrimination power and the capability of the resource analysis to correctly identify the weaknesses and strengths of resource utilization. Chen *et al*. (2009) applied a common weight approach on DEA model and used the difference between inputs and outputs instead of an output/input ratio. They used the Chebychev distance to generate common weights. The difference between the sum of the weighted inputs and the sum of the weighted outputs of the *j*-th DMU is shown with g_j, calculated below:

$$g_j = \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \tag{3}$$

Using the above relation, constraint (4) is obtained as follows:

$$g_j = \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \ge 0 \tag{4}$$

The final multi-objective DEA model is presented below:

$$\begin{aligned} & Min\ [\ \max_{1 \le s \le n} \{g_s - z\} + \rho \sum_{i=1}^{n} (g_i - z)] \\ & s.t. \quad \sum_{r=1}^{p} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ik} \le 0 \\ & \quad k = 1,2,...,n \\ & \quad u_r \ge \varepsilon \quad r = 1,2,...,p \\ & \quad v_i \ge \varepsilon \quad i = 1,2,...,m \end{aligned} \tag{5}$$

ρ and z are sufficiently small numbers that are set to 10^{-5} and 10^{-4}, similar to Chen *et al*. (2009). Model (5) is a non-linear programming min-max model and is converted to a linear model (6):

$$
\begin{aligned}
&Min \quad \eta \\
&\text{s.t.} \quad g_s - z + \rho \sum_{i=1}^{n} (g_i - z) \le \eta \quad s = 1,2,...,n \\
&\qquad \sum_{r=1}^{p} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ik} \le 0 \quad k = 1,2,...,n \\
&u_r \ge \varepsilon \quad r = 1,2,...,p \\
&v_i \ge \varepsilon \quad i = 1,2,...,m \\
&g_s = \sum_{i=1}^{m} v_i x_{is} - \sum_{r=1}^{p} u_r y_{rs} \quad s = 1,2,...,n
\end{aligned} \tag{6}
$$

After solving model (6), optimum weights of input and output factors are obtained. u_y^* and v_i^* are corresponding weights of the optimal solutions of the model (6). Then, the efficiency scores of DMUs are calculated based on model (7) using optimum common weights:

$$
es_j = \frac{\sum_{r=1}^{p} u_r^* y_{rj}}{\sum_{i=1}^{m} v_i^* x_{ij}} \tag{7}
$$

Amin and Toloo (2004) applied a polynomial algorithm to obtain a relation (8) to calculate suitable Epsilon for DEA models such as model (6):

$$
\begin{aligned}
&M = 1/\max\{1_m X_j : j = 1,...,n\} \\
&N = \min\{(1_m X_j)/(1_s Y_j) : j = 1,...,n\} \\
&Epsilon = \min\{M, MN\}
\end{aligned} \tag{8}
$$

RESULTS AND DISCUSSION

In this section, computational analysis of the performance of resources, results and discussion is presented.

Calculation of the efficiency scores of second-level resources: Multi-objective DEA is applied to the data of Table 5 to calculate the overall efficiency scores of second-level resources (Table 10). It is obvious from Table 10 that in the second level, relational and human resources do not utilize resources efficiently.

Previous studies such as Rezaie *et al*. (2011) used DEA to calculate the overall efficiency of resource transformation. To obtain more insight, it is useful to calculate the partial ESs of resources. Second-level resources can be tangible or intangible. Therefore, four types of resource transformation can be considered to calculate partial efficiency scores: Tangible to Tangible Transformation (TT), Tangible to Intangible transformation (TI), Intangible to Tangible transformation (IT) and Intangible to Intangible Transformation (II). Each of the above cases concerns a chosen set of input and output factors. For example, to calculate the partial efficiency score of Tangible to Tangible (TT) transformation, the input and output factors are tangible resources that are monetary and physical resources in the second level. Partial Efficiency Scores (ESs) of the second-level resources are shown in Table 11.

Both the monetary and organizational resources perform Tangible to Tangible (TT) transformations efficiently. In Tangible to Intangible (TI) and Intangible to Intangible (II) cases, physical resources perform transformations efficiently. Based on the partial efficiency scores, Table 12 shows partial ranks for different types of second-level resources.

The results of Table 13 indicate that the average partial efficiency scores of utilizing tangible resources (0.759) is significantly greater than the average partial efficiency scores of utilizing intangible resources (0.370). Therefore, it is obvious that the organization's ability to utilize tangible resources is much greater than its ability to utilize intangible resources. In each case, resources whose Efficiency Scores (ESs) are lower than the average of the ESs are assumed to be weak resources in the considered case of resource utilization. The corresponding cells of weak resources in Table 13 are highlighted with gray. Descriptions of weakness points of second-level resources are stated in Table 14.

Calculation of the efficiency scores of third-level resources: Multi-objective DEA is applied to the data of Table 6 and 7 to calculate the overall efficiency scores of third-level resources. DEA models assume that for each DMU (Resource), the value of at least one input factor is greater than zero. Table 6 shows that all input factors for 2 types of third-level resources ("Bonds and Stocks" and "Guarantee") equal zero. Therefore, these resources are not considered in the calculation of the overall and partial efficiency scores. The obtained ESs of third-level resources are shown in Table 15. It is obvious from Table 15 that in the third-level, "Office and Facility," "IT Facility," "Financial Network," "Organizational Culture" and "Accumulated Data" utilize resources efficiently.

Like second-level efficiency scores, the partial efficiency scores of third-level resources should be calculated to obtain detailed insight of resource utilization performance in the third-level. Third-

Table 10: Overall efficiency scores of second level resources

Resource (DMU)	Monetary	Physical	Relational	Organizational	Human
Efficiency score	1	1	0.7326150	1	0.9174996

Table 11: Partial efficiency scores of second level resources

	TT	TI	IT	II
Monetary	1	0.5544400	0.252525	0.09832825
Physical	0.327118	1	0.536585	1
Relational	0.446432	0.7512596	0.218524	0.23046120
Organizational	1	0.9224272	0.538462	0.31486780
Human	0.732539	0.8524816	0.309795	0.20254970
Average of efficiency scores	0.701218	0.8161217	0.371178	0.36924139

Table 12: Partial ranks of second-level resources

Resources	TT	TI	IT	II	Importance (%)
Monetary	1	5	4	5	10
Physical	4	1	2	1	10
Relational	3	4	5	3	20
Organizational	1	2	1	2	40
Human	2	3	3	4	20

Table 13: Averages of partial ESs of second-level resources

	Average of partial ESs for tangible to other resource transformations	Average of partial ESs for intangible to other resource transformations
Monetary	0.777	0.175
Physical	0.664	0.768
Relational	0.599	0.224
Organizational	0.961	0.427
Human	0.793	0.256
Average	0.759	0.370

Table 14: Weakness points of second-level resources

Resources	Description of weakness
Monetary	Weak in utilizing intangible resources
Physical	Weak in utilizing tangible resources
Relational	Weak in utilizing both tangible and intangible resources
Organizational	-
Human	Weak in utilizing intangible resources

level resources can have monetary, physical, relational, organizational or human attributes. Abbreviations of the resource names are listed in Table 16.

Resource transformation is shown with the abbreviations as well. For example "Monetary to Monetary" transformation is shown with "MM" and so on. Multi-objective DEA is applied to attain partial efficiency scores of the third-level resources that are shown in Table 17.

Some resources in some transformation cases act efficiently, so their partial efficiency scores equal one. For example, in the "Monetary to Physical" (MP) transformation, "Text Processing Machine" and "Accumulated Data" are efficient resources. Table 18 classifies efficient resources in different cases of transformation and notes the number of transformations in which each resource acts efficiently.

Some resources, such as "IT System," "Partners," "Accumulated Data" and "Know-How," utilize many resources efficiently. They are the strong resources in the considered advisory organization in this study.

For each resource, the averages of the third-level partial efficiency scores in different cases are listed in Table 19. For example, the partial efficiency scores of "Cash" in utilizing monetary resources are 0 (MM transformation), 0.5 (MP transformation), 1 (MR transformation), 1 (MO transformation) and 1 (MH transformation). Therefore the average of the ESs for "Monetary to Other" resource transformations equals 0 + 0.5 + 1 + 1 + 1/5 = 0.7, which is shown in Table 19. Like second-level resources, resources with ESs that are lower than the average of ESs are assumed to be weak resources in the considered case of resource utilization and their related cells are highlighted with gray. The last column of Table 19 is dedicated to the number of weak cases for each type of resource. For example, the number of weak cases for "IT Facility" resource is equals four and Table 19 shows that in four cases of resource utilization (utilizing monetary, physical, relational and organizational), "IT Facility" acts weakly in resource transformations. Some findings of Table 19 are stated as follows:

- The biggest challenge is related to the fact that 13 out of 19 third-level resources utilize

Table 15: Overall efficiency scores of third-level resources

Third-level resources	Cash	Office & facility	IT facility	Text processing machine	Customers	Suppliers	Partners	Research	Financial network	IT system
Efficiency score	0.3071405	1	1	0.8090082	0.3540337	0.2852494	0.6977972	0.7769231	1	0.1841072
Third-level resources	Brand	Organizational culture	Accumulated data	Know-how	Knowledge	Problem solving	Human skill	Attitude	Self-development	
Efficiency score	0.3267005	1	1	0.9510776	0.7162333	0.4974474	0.6287090	0.4528153	0.3971849	

Table 16: Abbreviations of resources

Resource	Monetary	Physical	Relational	Organizational	Human
Abbreviation	M	P	R	O	H

Table 17: Partial efficiency scores of third-level resources

	Monetary to other resources					Physical to other resources					Relational to other resources				
	MM	MP	MR	MO	MH	PM	PP	PR	PO	PH	RM	RP	RR	RO	RH
Cash	0.00	0.50	1.00	1.00	1.00	-	-	-	-	-	0.00	0.22	0.12	0.05	0.08
Office and facility	-	-	-	-	-	0.00	1.00	1.00	1.00	1.00	-	-	-	-	-
IT facility	0.00	0.44	0.07	0.16	0.09	0.00	1.00	0.06	0.40	0.13	0.00	0.10	0.06	0.10	0.05
Text processing machine	0.00	1.00	0.75	0.74	0.00	0.00	0.25	0.18	0.33	0.00	0.00	1.00	0.68	1.00	0.00
Customers	0.13	0.00	0.70	0.49	0.28	0.26	0.00	0.31	0.40	0.32	0.16	0.00	0.01	0.08	0.05
Suppliers	0.03	0.25	0.33	0.40	0.00	0.12	0.11	0.18	0.41	0.00	0.27	0.18	0.62	0.40	0.00
Partners	0.15	0.75	1.00	0.62	0.00	0.26	0.24	0.74	0.41	0.00	1.00	1.00	1.00	1.00	0.00
Research	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Financial network	-	-	-	-	-	1.00	0.31	0.04	0.42	0.00	0.55	0.05	0.01	0.07	0.00
IT system	0.04	0.43	0.36	0.34	0.32	0.16	0.07	0.11	0.10	0.09	1.00	1.00	1.00	1.00	1.00
Brand	0.21	0.00	1.00	0.06	0.17	0.15	0.00	0.35	0.02	0.04	0.12	0.00	0.05	0.00	0.02
Organizational Culture	-	-	-	-	-	0.38	0.00	1.00	1.00	1.00	0.65	0.00	1.00	0.67	1.00
Accumulated data	0.60	1.00	1.00	1.00	0.42	0.61	0.13	1.00	0.30	0.15	1.00	0.30	0.21	0.36	0.13
Know-how	1.00	0.63	0.41	1.00	1.00	1.00	0.10	0.39	0.35	0.66	0.88	0.07	0.08	0.14	0.17
Knowledge	0.33	0.33	0.62	0.76	0.26	0.82	0.06	0.97	0.26	0.08	0.67	0.12	0.17	0.31	0.09
Problem solving	0.37	0.25	0.24	0.46	0.25	1.00	0.10	0.17	0.30	0.12	0.83	0.10	0.15	0.20	0.09
Human skill	0.33	0.00	0.38	0.39	0.34	0.94	0.00	0.24	0.34	0.20	0.78	0.00	0.17	0.17	0.13
Attitude	0.20	0.00	0.51	0.54	0.30	0.23	0.00	0.12	0.22	0.08	0.59	0.00	0.24	0.30	0.14
Self-development	0.05	0.00	0.02	0.24	0.77	0.14	0.00	0.04	0.21	0.46	0.15	0.00	0.03	0.14	0.36
Average of efficiency scores	0.23	0.37	0.56	0.55	0.35	0.42	0.20	0.41	0.38	0.25	0.51	0.24	0.33	0.35	0.19

	Organizational to other resources					Human to other resources				
	OM	OP	OR	OO	OH	HM	HP	HR	HO	HH
Cash	0.00	0.10	0.12	0.44	0.05	0.00	0.13	0.09	0.17	0.07
Office and facility	-	-	-	-	-	-	-	-	-	-
IT facility	0.00	0.16	0.03	1.00	0.07	0.00	1.00	0.09	0.57	0.09
Text processing machine	0.00	1.00	1.00	0.95	0.00	-	-	-	-	-
Customers	0.11	0.00	0.03	0.17	0.13	0.16	0.00	0.02	0.15	0.12
Suppliers	0.05	0.16	0.45	0.47	0.00	0.22	0.33	0.20	0.52	0.00
Partners	0.15	0.45	1.00	0.65	0.00	1.00	1.00	1.00	1.00	0.00
Research	0.00	0.00	0.03	0.19	0.08	0.00	0.00	0.02	0.10	0.03
Financial network	1.00	0.44	0.67	1.00	0.00	-	-	-	-	-
IT system	0.80	1.00	1.00	1.00	1.00	0.49	1.00	1.00	1.00	1.00
Brand	0.22	0.00	0.19	0.02	0.05	0.23	0.00	0.11	0.02	0.07
Organizational culture	0.05	0.00	0.20	0.07	0.20	0.05	0.00	0.07	0.06	0.20
Accumulated data	0.49	0.21	0.22	0.17	0.12	1.00	0.30	0.73	0.46	0.18
Know-how	1.00	0.22	0.28	0.65	1.00	0.67	0.07	0.18	0.21	0.20
Knowledge	0.13	0.03	0.08	0.14	0.05	0.66	0.10	0.21	0.61	0.51
Problem solving	0.29	0.04	0.12	0.08	0.06	0.26	0.03	0.10	0.09	0.06
Human skill	0.28	0.00	0.14	0.08	0.10	0.56	0.00	0.19	0.19	0.23
Attitude	0.18	0.00	0.26	0.22	0.19	0.50	0.00	0.79	0.67	0.36
Self-development	0.05	0.00	0.03	0.10	0.67	0.12	0.00	0.02	0.12	1.00
Average of efficiency scores	0.27	0.21	0.33	0.41	0.21	0.37	0.25	0.30	0.37	0.26

Table 18: Number of efficient cases for third-level resources

No.	Third-level resources	Number of efficient cases
1	IT system	13
2	Partners	10
3	Accumulated data, know-how	6
4	Text processing machine, organizational culture	5
5	Office and facility	4
6	Cash, IT facility, financial network	3
7	Brand, problem solving, self-development	1
8	Customers, suppliers, research, knowledge, human skill, attitude	0

organizational resources weakly. This finding is noteworthy because organizational resources are the most important resource, with a 40% importance measure.

- Overall, monetary resources are used most efficiently, followed by physical, relational, human and organizational resources in the next orders.
- In other words, the ability of resources to utilize relational, organizational and human resources (intangible) are lower than the ability to utilize monetary and physical (tangible) resources. These

Table 19: Average partial ESs of third-level resources

	Average ESs of monetary to other resource transformations	Average ESs of physical to other resource transformations	Average ESs of relational to other resource transformations	Average ESs of organizational to other resource transformations	Average ESs of human to other resource transformations	Number of weak cases
Cash	0.700	-	0.094	0.142	0.092	3
Office and facility	-	0.800	-	-	-	0
IT facility	0.152	0.318	0.062	0.252	0.350	4
Text processing machine	0.498	0.152	0.536	0.590	-	1
Customers	0.320	0.258	0.060	0.088	0.090	5
Suppliers	0.202	0.164	0.294	0.226	0.254	5
Partners	0.504	0.330	0.800	0.450	0.800	1
Research	-	-	-	0.060	0.030	2
Financial network	-	0.354	0.136	0.622	-	1
IT system	0.298	0.106	1	0.960	0.898	2
Brand	0.288	0.112	0.038	0.096	0.086	5
Organizational culture	-	0.676	0.664	0.104	0.076	2
Accumulated data	0.804	0.438	0.400	0.242	0.534	1
Know-how	0.808	0.500	0.268	0.630	0.266	2
Knowledge	0.460	0.438	0.272	0.086	0.418	2
Problem solving	0.314	0.338	0.274	0.118	0.108	4
Human skill	0.288	0.344	0.250	0.120	0.234	4
Attitude	0.310	0.130	0.254	0.170	0.464	4
Self-development	0.216	0.170	0.136	0.170	0.252	5
Average of ESs	0.411	0.331	0.326	0.285	0.310	
Number of weak cases	9	9	12	13	10	53

Table 20: The number of weak cases for third-level resources

No.	Third-level resources	Number of weak cases
1	Customers, suppliers, brand, self-development	5
2	IT facility, problem solving, human skill, attitude	4
3	Cash	3
4	Research, IT system, organizational culture, know-how, knowledge	2
5	Text processing machine, financial Network, accumulated data, partners	1
6	Office & facility	0

findings confirm the results of the second-level analysis that states resources utilize tangible resources more efficiently than intangible resources.

- "Know-How," an organizational resource, utilizes monetary resources best.
- "Office and Facility," a physical resource, utilizes physical resources best.
- "IT System," an organizational resource, utilizes relational resources best.
- "IT System," an organizational resource, utilizes organizational resources best.
- "IT System," an organizational resource, utilizes human resources best.
- Organizational resources such as "IT System" utilize heterogeneous resources best.

As mentioned before, the last column of Table 19 shows the number of weak cases for each resource. Table 20 presents a classification of third-level resources based on the number of weak cases. For each resource group, Table 20 shows how many resources utilize resources efficiently. Table 20 shows that there are five weak cases for "customer," "suppliers," "brand" and "self-development." This finding indicates that the partial efficiency scores of the mentioned resources are lower than the average of the ESs in all cases of resource utilization, including utilizing monetary, physical, relational, organizational and human resources. This group is the first priority in improvement plans.

CONCLUSION

In this study, different aspects of resource transformation are investigated at different levels of hierarchical resource classification. Each resource is considered a DMU that has input and output factors from other resources. Based on this approach, multi-objective DEA is applied to calculate the overall and partial efficiency scores of resources in an advisory organization. Important findings of this research are categorized in 3 main groups. The first group identified resources that are efficient in utilizing heterogeneous resources. The second group showed the resources that utilize resources weakly in different cases of resource transformation. Finally, the third group investigated the

overall and partial efficiency scores of resource transformations in the second and third levels. The findings of this study can assist decision makers and managers in accurately identifying weaknesses in resource utilization. Presenting an improvement plan to increase efficiency scores in resource transformation is a suggestion for future studies. Improvement plans would provide a basis to increase the ability of resources to utilize heterogeneous resources more efficiently.

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