Integrated AHP and network DEA for assessing the efficiency of Iranian handmade carpet industry

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C H R O N I C L E	A B S T R A C T
	Data envelopment analysis (DEA) is a method for measuring the efficiency of peer decision making units (DMUs). Traditional DEA models deal with measurements of relative efficiency of DMUs regarding multiple-inputs vs. multiple-outputs. One of the drawbacks of these models is the neglect of intermediate products or linking activities. Recently, DEA has been extended to examine the efficiency of network structures, where there are lots of sub-processes that are linked with intermediate parameters. These intermediate parameters can be considered as the outputs of the first stage and simultaneously as the inputs for the second stage. In contrast to the traditional DEA analysis, network DEA analysis aims to measure different sub-processes' efficiencies in addition to the total efficiency. Lots of network DEA technique has been used recently, but none of them uses Analytic Hierarchy Process (AHP) in network DEA for assessing a network's efficiency. In this paper, AHP methodology is used for considering the importance of each sub-process and network DEA is used for measuring total and partial efficiencies based on the importance of each department measured from AHP methodology. In this regard, the case of Iranian Handmade Carpet Industry (IHCI) is used.

1. Introduction

Data envelopment analysis (DEA) is a method for measuring relative efficiency of peer decision making units (DMUs) with multiple inputs and outputs (Charnes et al., 1978). Although DEA has been applied in many different fields, DMUs have traditionally considered as black boxes with its inputs and outputs and without any consideration of what is happening inside the DMUs (Liu et al., 2013). Castelli et al. (2010) classified the contributions of DEA literature by evaluating DMUs whose internal structure is known. Traditional DEA models fail to measure the efforts of different processes and sub processes within the organization (Moreno & Lozano, 2012). To overcome this, Kao (2008) introduced a linear formulation of the two-level DEA model. This model transforms the nonlinear model into a linear one using a variable substitution technique (Kao 2008). This transformation was required because linear

models are easier to solve than their nonlinear counterparts (Kao, 2009). For network structures with more than two stages, Kao (2009) proposed the relational network DEA model. Liu and Lu (2010) enhanced the network-based approach, which is a novel method to increase discrimination in data envelopment analysis. Next, Hiseh and Lin (2010) utilized relational network DEA to construct a model to analyze the efficiency and effectiveness of international tourist hotel. More valuable research in the field of supply chain efficiency measurement by means of network DEA has been accomplished by Chang et al. (2011) and Vaz et al. (2010).

Cook et al. (2010a) reviewed DEA models and established relationships among various approaches. They showed that all the existing approaches could be categorized by using either Stackelberg (leader-follower), or cooperative game concepts (Cook et al., 2010a). Recently, Li et al. (2012) modeled a two stage structure by assuming the inputs to the second stage including both the outputs from the first stage and additional inputs to the second stage and proposed two new models for evaluating the performance of this general two-stage network structures.

An additive efficiency decomposition method has been proposed lately. Chen et al. (2010) developed a set of DEA models for measuring the performance of two-stage network processes with shared inputs. In addition, in their research additive efficiency decomposition approach for measuring the efficiency of two-stage network process was presented. The models were developed under the assumption of variable returns to scale (VRS), but could be readily applied under the assumption of constant returns to scale (CRS) (Chen et al., 2010). Cook et al. (2010b) represented the overall efficiency of an open multistage process as an additive weighted average of the efficiencies of the individual components or stages that make up that structure. The model therefore allowed one to evaluate not only the overall performance of the network, but also represented how that performance could be decomposed into measures for the individual components of the network (Cook et al., 2010b). Amirteimoori (2013) used the same approach for modeling a two-stage decision process with the existence of perfect and imperfect outputs for the case of Iranian car representatives. In addition, Kao and Liu (2014) developed a multi-period efficiency measurement in DEA to calculate overall and period efficiencies of a DMU at the same time. In their methodology, the overall efficiency is a weighted average of the period efficiencies. In all of these illustrations, the importance of each sub process is based on the amount of relative inputs entered to each one.

Analytic Hierarchy Process (AHP) is a multi-criteria decision making approach developed by Saaty (1990). It is a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution (Saaty, 2008). In AHP, a pairwise comparison matrix is constructed using a scale of relative importance (Saaty, 1980, 2008). The AHP determines the consistent weights and evaluates the composite performance score of alternatives to position the rank of an alternative in a hierarchical manner (Rao, 2013). There are numerous examples of AHP applications for key aspects of the operation of enterprises e.g. project management (Martinsuo, 2013), evaluation of technology, buyer decision process (Sumi & Kabir, 2010), integrated manufacturing (Putrus, 1990) and engineering (Triantaphyllou, 1995). AHP is used to arrive at a consensus in situations involving several decision makers with different conflicting objectives and helps to systematically compare and determine the priorities of the criteria and sub-criteria (Tam & Tummala, 2001). The model enables the problem to be structured in a hierarchical manner in terms of criteria and sub-criteria.

Resource allocation is one of the most important issues for companies especially for an enormous industry such as handmade carpet texture. It is important to note that resource limitations is an inseparable issue in each business, so how to allocate budget and resources among different activities is a crucial task for all managers (Yang et al., 2011); if managers allocate the greatest amount of resources to the most efficient activities, productivity and profit of the company will increase too. So due to the shortage of resources, it is so essential to allocate resources to the most efficient products.

Analysis of historical data can also help managers do this duty, successfully. According to the efficiency scores of different DMUs, specialists can make suggestions about which DMU performs better and has priority for more investigation; additionally if a DMU's performance is poor, partial efficiency scores of sub processes can help managers realize which sub process needs to be strengthening in order to maximize the overall performance.

In handmade carpet industry there are different categories of carpets in terms of design, color, size, raw material and the proficiency of weavers; Carpet specialists classified these different types of carpet to some particular categories which is mostly named as the geographic region in which carpets are weaved. Production costs of these categories are different based on various weavers' wages depend on gender and geographic region, in addition different kinds of raw material with various prices are used such as wool, silk, fluff, lint and etc.

From a managerial point of view, the carpet industry's performance is the aggregated efforts of different departments, involving both the production and the sales department. Sales department consists of two major markets: internal market and external market which are working jointly to maximize the productivity of the company. Besides, there is a changeable demand for distinct kinds of carpet in the internal and external markets; some are sold better in the local markets although some are better to be exported. Hence it is necessary to perceive which category is more efficient in production and marketing.

Therefore, if we assume each category of handmade carpets as a DMU, it is so crucial for decision makers to know which DMU works, efficiently. It can help managers allocate more budgets to this category for the next year. In addition, partial efficiency can benefit managers a lot. If managers may reach to the partial efficiency score of various departments they will be able to understand which component is inefficient, so specialists will focus on this department and by empowering it, the overall efficiency of the DMU will increase too. By the knowledge of author, there is no research done yet in the field of measuring the performance of handmade carpet texture industry.

For ease of notation, Section 2 begins with introducing new approach to modeling multi-stage system of Iranian Handmade Carpet Industry (IHCI), then in Section 3, the methodology used for assessing the efficiency of this multi-stage network in introduced. Section 4 summarizes experimental data and the results of solving the model. Conclusions are given in the last section.

2. Methodology

In this investigation DMUs are not treated as a black-box, instead the proposed modeling considers internal structure of Iranian Handmade Carpet Industry, so the overall performance and the effectiveness of IHCI's sub processes will be measured.

2.1. Model construction

Our model disentangles the major Iranian Handmade Carpet Industry's activities and places them into network DEA model. Through the modeling, we consider IHCI as a box that can be broken into two main stages, the first one is the production stage and the second is the marketing stage. The marketing stage is divided into two parallel sub processes named as internal and external markets which use the desired output of the first stage as their own inputs that divided proportionally between these two sub processes. The production department uses raw material, weavers' wages and some other expenses such as designing costs and transportation expenses as its inputs and produce carpets (measured by area) as an output. Since the human body's error is an unavoidably factor in the handmade carpet industry, there are some carpets which are not acceptable for carpet company. Thus, the carpets, which are perfect called as desired outputs which enter the second stage as inputs and some others, which are imperfect

are called as undesired outputs which are sent out of the system as wastage. The part of these desired outputs enter as inputs to the external sales department and the rest enter to the internal sales department. The profit earned from each market is the output of these sub processes. Additionally, external sales department has its own inputs which are independent from the first stage that relates to expenses for customs clearance and transportation, so it is considered as an independent input to the external sales sub process. Since the internal sales expenses are much less than customs and transportation costs it can be ignored in the modeling. Fig. 1 presents the divisions and components of handmade carpet industry. This study aims to evaluate efficiency of the overall organization and effectiveness of major departments' operations.
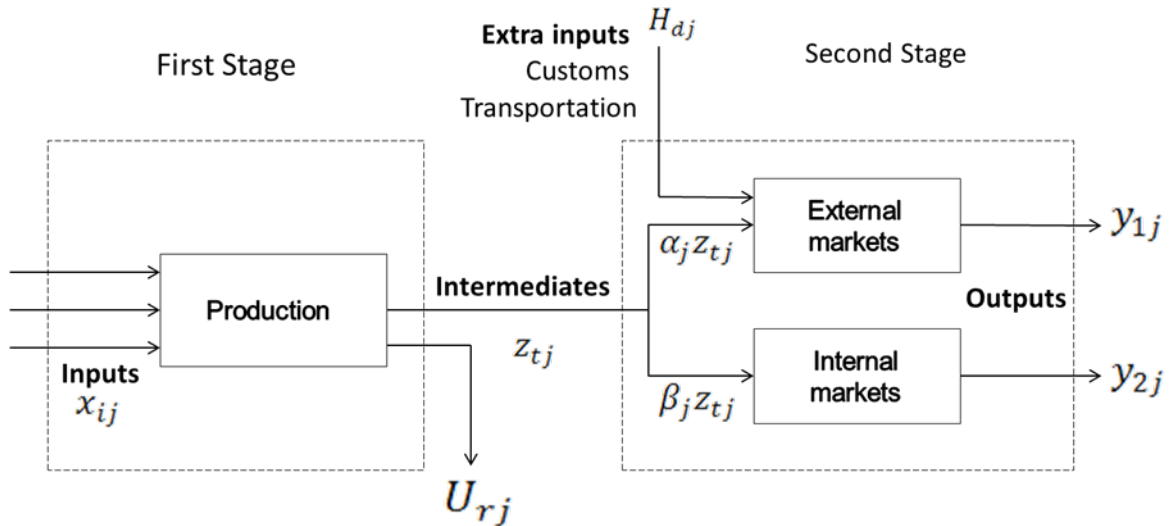

Fig. 1. Multistage structure of Iranian Handmade Carpet Industry (IHCI)

Consider that there are k DMUs where each DMU_j ($j=1,…,k$) consists of two main stages named as production stage and sales stage as shown in Fig 1. Suppose that each DMU_j ($j=1,…,k$) has m inputs denoted by x_{ij} ($i=1,…,m$) to the whole process as well as n desired outputs denoted by z_{tj} ($t=1,…,n$) from the first stage, which then become inputs to the second stage and are referred to intermediate measures. Additionally, suppose that each DMU_j ($j=1,…,k$) has l undesired outputs denoted by U_{rj} ($r=1,…,l$) from the first stage, which get out of the system as losses. The desired outputs from the first stage (z_{tj}) shared as inputs between two sub processes of the second stage, the proportion of these inputs measured by α_j is dedicated to the first sub process while the remaining measured by β_j is associated with the second one, so $\alpha_j + \beta_j = 1$. Furthermore, we assume that the first sub process of second stage has extra inputs from outside of the system denoted by H_{dj} ($d=1,…,p$). Eventually, y_{sj} is the outputs of sth sub process of second stage. These parameters are also illustrated in Fig 1. Consistent with two-stage frameworks commonly used in the existing literatures, the overall organization efficiency can be calculated as follows (Liang et al., 2008; Kao, 2008):

$$maxE_K = max \frac{\sum_s u_{sj}y_{sj} - \sum_r u_{rj}U_{rj}}{\sum_i v_{ij}x_{ij} + \sum_d h_{dj}H_{dj}} \tag{1}$$

Besides, E_{K1} and E_{K2} are the efficiencies of production stage and sales stage, respectively. Based on the constant return to scale (CRS) model (Charnes et al. 1978), the CRS efficiency score for DMU_j in the first and second stages can be calculated, respectively by the following two equations:

$$E_{K1} = max \frac{\sum_t w_{tj} z_{tj} - \sum_r u_{rj} U_{rj}}{\sum_i v_{ij} x_{ij}} \qquad (2)$$

$$E_{K2} = max \frac{\sum_s u_{sj} y_{sj}}{\sum_t w_{tj} z_{tj} + \sum_d h_{dj} H_{dj}} \qquad (3)$$

As can be clearly seen, efficiency of each stage is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs. The rationale for the negative sign of the second term in the numerator of first stage's efficiency is that the outputs U_{rj} are undesirable and try to be minimized so it should be decreased in the production process. Therefore, the model can be illustrated as follows:

subject to

$$\frac{\sum_s u_{sj} y_{sj} - \sum_r e_{rj} U_{rj}}{\sum_i v_{ij} x_{ij} + \sum_d h_{dj} H_{dj}} \leq 1 \qquad (5)$$

$$\frac{\sum_t w_{tj} z_{tj} - \sum_r e_{rj} U_{rj}}{\sum_i v_{ij} x_{ij}} \leq 1 \qquad (6)$$

$$\frac{\sum_s u_{sj} y_{sj}}{\sum_t w_{tj} z_{tj} + \sum_d h_{dj} H_{dj}} \leq 1 \qquad (7)$$

$$\frac{u_{1j} y_{1j}}{\alpha_j w_{1j} z_{1j} + h_j H_j} \leq 1 \qquad (8)$$

$$\frac{u_{2j} y_{2j}}{\beta_j w_{2j} z_{2j}} \leq 1 \qquad (9)$$

For a specific DMU$_j$, constraint 5 considers the system as a whole and represents that the weighted summation of outputs of the whole process is smaller or equal to its inputs. As it is mentioned before, since U_{rj} is undesired outputs, it should be decreased and that is why it has negative sign in this constraint. Similarly, constraint 6 corresponds to the same constraint as 5 with the difference that it considers the first stage as a box. Constraint 7 represents the whole second stage's efficiency which is smaller or equal to one. Constraint 8 and 9 represent the relative efficiencies of each sub processes of the second stage to be smaller or equal to one. Based on relational model (Kao, 2008), we assume that the same factor has the same multiplier, no matter how it is used. It means that we assume $w_{tj} = w_{1j} = w_{2j}$, therefore α_j and β_j coefficients represent the difference between amounts of inputs enter to each sub process of second stage. We also assume $z_{tj} = z_{1j} = z_{2j} = z_j$.

The purpose of this issue is to determine the optimal value of the variables $w_{tj}, e_{rj}, u_{sj}, v_{ij}$ and h_{dj} for each DMU$_j$ ($j=1,...,k$) such that the overall efficiency of the whole system is maximized. It is blindingly evident that this modeling results to a multi-objective program which cannot be solved with standard linear programming approaches and needs some changes to transform into one objective function. In the following, a new procedure is introduced to alter this multi-objective program. In this paper, integrated AHP approach with network DEA is used for transforming this multi-objective problem.

2.2. Sub-processes' importance by AHP

For measuring the efficiency ratio of a multistage structure such as Iranian Handmade Carpet Industry, we assume that the efficiency ratio for an overall process can be expressed as the weighted average of the efficiencies of the individual components. The efficiency of any given component is the ratio of

weighted total outputs to the total inputs corresponding to that component. Note that the weights are intended to represent the relative importance or contribution of the performances of individual stages. An alternative approach for measuring the efficiency of the multistage process is to view them from a centralized perspective, and determine a set of optimal weights that maximize the aggregate efficiency score to achieve maximum profit. One reasonable choice for weights is to use AHP technique. The AHP is a multi-criteria decision making approach that was developed by Saaty (1990).

For assessing the relative importance of criteria, Saaty (1980, 2008) suggested a quantified on the linguistic "one to nine" measurement scale in where $a_{ij} = 1$ signifies that criteria i and j are equally important, 2= i weakly or slightly more important than j, 3= moderately, 4= moderately plus, 5= strongly, 6= strongly plus, 7= very strongly or demonstrated, 8= very, very strongly, 9= extremely. A value of $a_{ij}=1/5$ indicates that criterion j is strongly more important than i and $a_{ij}=1/9$ indicates that criterion j is extremely more important than i.

For measuring the relative importance of each sub-process, expand interviews are accomplished with IHCI's experts and chief managers in order to collect their insights. In this regard, some personal meetings for discussion were held with field experts. Therefore, expert's views have been collected based on the nine point Likert scale and then to check the internal consistence of collected data, reliability analysis has been performed using SPSS 16 software, through calculating the Cronbach's alpha coefficient, which comes as 0.781, under the recommended range: $0.7<\alpha<0.95$. In Table 1, the results of relative importance of criterion are summarized based on consultants accomplished by IHCI's experts.
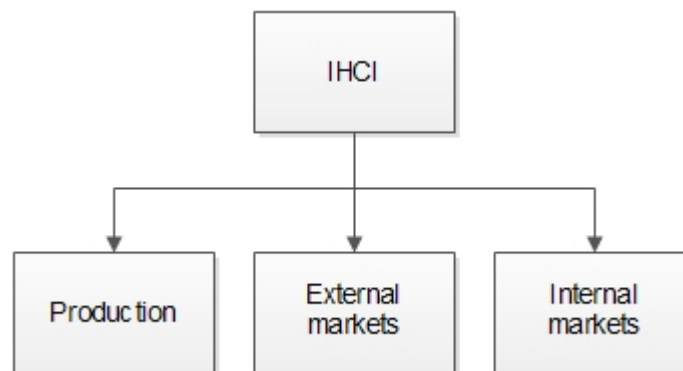

Fig. 2. Relative importance of departments by AHP

Table 1
Relative importance of IHCI's sub-processes in one to nine Likert scale

	Production	Internal markets	External markets
Production	1	1/3	1/5
Internal markets	3	1	1/4
External markets	5	4	1

Based on the data collected in Table 1, the relative importance of each sub-process can be calculated by Expert Choice software as follows:

Table 2
Relative importance of IHCI's sub-processes calculated by AHP methodology

	Production	Internal markets	External markets
Relative importance	0.101	0.226	0.674

So total efficiency score for each DMU_j (j=1,…,k) can be calculated from the following equation:

$$E_j = \omega_{pj}E_{Pj} + \omega_{ej}E_{Ej} + \omega_{ij}E_{Ij} \tag{10}$$

We propose to combine three departments in a weighted average of efficiency scores of each department where E_{Pj}, E_{Ej} and E_{Ij} are the efficiency ratios of production, internal and external sales department, respectively. Furthermore, ω_{pj}, ω_{ej} and ω_{ij} illustrate the relative importance of each component from AHP approach such that $\omega_{pj} + \omega_{ej} + \omega_{ij} = 1$. Note that this definition ensures that a DMU is overall efficient if and only if all departments are efficient. Where:

$$E_{Pj} = \frac{\sum_t w_{tj}\, z_{tj} - \sum_r e_{rj}U_{rj}}{\sum_i v_{ij}\, x_{ij}}$$

$$E_{Ej} = \frac{\sum u_{1j}y_{1j}}{\sum \alpha_j w_{1j}z_j + \sum h_j H_j} \tag{11}$$

$$E_{Ij} = \frac{\sum u_{2j}y_{2j}}{\sum \beta_j w_{2j}z_j}$$

We then set out to optimize the overall efficiency E_j of the multistage process, subject to the restrictions that the individual efficiency measures must not exceed unity. These restrictions can be converted to the linear programming format by using the usual Charnes and Cooper (1962) transformation. By applying the Charnes–Cooper transformation, the above fractional program (constraint set 5 to 9) can be converted to the following model:

subject to

$$\sum_s u_{sj}y_{sj} - \sum_r e_{rj}U_{rj} - \sum_i v_{ij}\, x_{ij} - \sum_d h_{dj}H_{dj} \leq 0$$

$$\sum_t w_{tj}\, z_{tj} - \sum_r e_{rj}U_{rj} - \sum_i v_{ij}\, x_{ij} \leq 0 \tag{12}$$

$$\sum_s u_{sj}y_{sj} - \sum_t w_{tj}z_{tj} - \sum_d h_{dj}H_{dj} \leq 0$$

$$\begin{bmatrix} u_{1j} & 0 \\ 0 & u_{2j} \end{bmatrix} \cdot \begin{bmatrix} y_{1j} \\ y_{2j} \end{bmatrix} - \begin{bmatrix} \alpha_j \\ \beta_j \end{bmatrix} w_j z_j - \begin{bmatrix} h_j & 0 \\ 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} H_j \\ L_j \end{bmatrix} \leq 0$$

In the constraint set above, the summation of weighted outputs is smaller than the summation of weighted inputs. It can be clearly seen that the proposed methodology converts the nonlinear constraint set 5 to 9 into the linear programming format which is summarized in constraint set 12. In addition to the overall efficiency of the system, the relative efficiencies of sub processes can be calculated from Eq. (11) where E_{Pj}, E_{Ej} and E_{Ij} are the efficiency ratio of production, internal and external sales department, respectively.

3. Empirical study

We present an illustrative example with real data of Iranian Handmade Carpet Industry (IHCI) in order to compare the results of two proposed models. When the consultants are completed with carpet specialists we assume 15 DMUs as the main carpet industry's DMUs, which are based on various categories of carpets such as Tabriz carpet, Yazd carpet, Isfahan carpet, etc. For each DMU, we assume three inputs named as raw material expenses(X_{1j}), weavers' wages (X_{2j}) and other expenses related to

plan, design and the equipment needed for weaving a carpet (X_{3j}). The amount of perfect carpets weaved by weavers is measured by area (m^2) which is assumed as desired output of first stage(Z_j) which enters the second stage. Besides, undesired or imperfect carpets are denoted by U_j which is sent to outside of the system. The proportion of the desired outputs denoted by $\alpha_j z_j$ enters to the external markets and the remaining denoted by $\beta_j z_j$ enters to the internal markets. Consider that $\alpha_j \; and \; \beta_j$ are the parameters of the model and $\alpha_j + \beta_j = 1$. In addition, independent inputs to the external markets are denoted by H_j. The profit earned from each market is the outputs of these sub processes denoted by y_{1j} and y_{2j} for external and internal sales sub processes, respectively. The data set for a one year period is summarized in Table 3. The results are reported in Table 4. The first column of Table 4 shows the overall efficiency score. In addition partial efficiency score of all departments are summarized in the rest columns of Table 4.

Table 3
Data set of Iranian Handmade Carpet Company (IHCC's archives, 2013)

| DMU | First stage's inputs | | | Intermediate variables | | | | Second stage's inputs | second stage's outputs | |
	raw material	Wages	Other expenses	Desired output	Undesired output	A	B	Customs and transportation	External markets' earning	Internal markets' profit
Dep1	56	190	41	470	24	0.30	0.70	22	103	28
Dep2	282	298	6.8	1280	75	0.47	0.53	58	579	80
Dep3	38	122	5.8	800	61	0.23	0.77	26	285	317
Dep4	82	262	23	310	19	0.16	0.84	8	86	36
Dep5	18	208	15	610	21	0.18	0.82	5	172	87
Dep6	129	295	30	1120	71	0.34	0.66	53	314	58
Dep7	79	132	29	600	13	0.25	0.75	22	169	66
Dep8	54	128	21	460	12	0.26	0.74	18	128	59
Dep9	63	98	15	710	30	0.31	0.69	32	198	36
Dep10	43	85	13	360	12	0.14	0.86	8	99	26
Dep11	76	129	17	530	19	0.19	0.81	16	148	26
Dep12	68	120	25	860	34	0.17	0.83	19	241	90
Dep13	85	124	2.7	370	28	0.15	0.85	12	103	161
Dep14	95	75	7.9	250	12	0.23	0.77	7	69	20
Dep15	54	55	9.3	320	30	0.13	0.87	5	88	13

Table 4
Results of efficiency measurement

DMU	Total efficiency	Production efficiency	External sales efficiency	Internal sales efficiency
Dep1	0.317	0.474	0.345	0.165
Dep2	0.487	1.000	0.496	0.229
Dep3	0.820	1.000	0.732	1.000
Dep4	0.634	0.204	0.820	0.269
Dep5	0.851	1.000	1.000	0.338
Dep6	0.353	0.556	0.390	0.152
Dep7	0.525	1.000	0.533	0.285
Dep8	0.506	0.876	0.506	0.337
Dep9	0.420	1.000	0.425	0.143
Dep10	0.751	0.875	0.929	0.163
Dep11	0.582	0.864	0.695	0.118
Dep12	0.681	1.000	0.779	0.245
Dep13	0.895	0.788	0.877	0.995
Dep14	0.481	0.532	0.567	0.202
Dep15	0.776	0.803	1.000	0.091

It is necessary to note that a DMU will be efficient only if all of its departments are efficient. This reasonable result is obtained from the proposed approach. As an illustration consider 5th DMU which is efficient in production and external sales, but the internal sales department of this DMU is not

working properly and has an efficient score of 0.338. Therefore, the consequence is that total efficiency score of this DMU must be less than one because all departments of this DMU is not efficient. The results illustrate the value of 0.851 for total efficiency score of this DMU.

Results summarized in Table 4 can be used to develop beneficial management strategies for future years. For instance, department No. 3, 5 and 13 have higher total efficiency scores among all 15 departments. So, during the production planning and resource allocation in the following year, more resources will be allocated to these special categories of handmade carpet in order to maximize the profit and productivity of the company. In addition, by focusing on partial effectiveness of different departments, most efficient departments can be classified as the following: among production departments, DMUs No. 2, 3, 5, 7, 9 and 12 are efficient DMUs. It means that production department of these DMUs produces the maximum amount of desired output in proportion to their inputs compared with other DMUs. Among external sales departments, DMUs No. 5 and 15 are efficient. These DMUs earn maximum profitability of export. By planning for more investment on these categories, the company will earn more income from export. Among internal sales departments, DMUs No. 3 and 13 have the greatest amounts of efficiency score. Hence, these categories of Iranian carpets are the most profitable kinds of carpets in domestic markets.

4. Conclusion

Standard data envelopment analysis considers just inputs and outputs for measuring the efficiency of DMUs with neglecting the intermediate parameters. On the contrary, network data envelopment analysis focuses on intermediate parameters and aims to measure the efficiency of all sub-processes in addition to the whole efficiency of DMUs. Therefore, the conventional problem in data envelopment analysis converts to a multi-objective problem where the efficiency of each sub-process can be measured as one objective. One approach for solving this multi-objective approach is the usage of weighting approach while the weights of each sub-process can be measured from AHP methodology. In this regard, this study focuses on measuring the efficiency of Iranian Handmade Carpet Industry (IHCI) by means of integrated AHP and network data envelopment analysis.

The main objective of this paper is to assess the performance of handmade carpet industry for the first time. To achieve this goal, this study measures the efficiency and effectiveness of Iranian Handmade Carpet Industry (IHCI) which is a multi-stage system with extra inputs, undesired outputs and shared variables. Because of network structure of the system, the main problem convert to a multi-objective problem which aims to maximize partial efficiency the same as the total efficiency. In order to solve this multi-objective problem, integrated AHP and network data envelopment analysis have been used. This approach converts the multi-objective problem into a one objective function which is the summation of partial efficiency of each sub process multiplied by optimal weights. Optimal weights are obtained from solving an AHP problem that consider experts' insights.

Results calculated from empirical data of IHCI illustrate that this methodology could assess total and partial efficiency of a multi-stage network at the same time and also it could distinguish the most efficient departments. Further researches will shed light on the exploration of using other multi-objective programming methodology in order to solve network DEA models for measuring the performance of more complex multi-stage networks with undesired outputs and in variable return to scale mode. In addition, based on the importance of carpet industry, more investigations in this area are needed.

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