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A Network Data Envelopment Analysis Approach for Efficiency Measurement of Poultry Industry Production Chains

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Abstract

In this paper, models of data envelopment analysis (DEA) were investigated with the aim of measuring the efficiency of production chains in Iran's poultry industry. DEA tool can determine the efficiency frontier and the reference production chain to improve the performance of the poultry industry. Statistical data were collected for 28 active production chains and 8 variables including: Material cost, human resource cost, equipment and facilities cost, transport cost, number of poultry, poultry price, profit, and cost of slaughter. Then, the relative efficiency of each chain was measured using traditional and network DEA. Finally, cross efficiency method was used to rank efficient chains. Traditional DEA results showed 25% of production chains to be efficient. Meanwhile, this percentage was equal to 10.7% in the proposed model of the paper (two-stage DEA). Therefore, the scientific accuracy of the reference production chain will be higher in the network model. The rest of the results and their details were presented and discussed. The results of this paper can be useful in the decision-making and policies of poultry industry managers and also improve the performance of production chains in this industry.

Keywords: Poultry industry, Production chain, Traditional DEA, Network DEA, Efficiency, Performance.

1.Introduction

According to FAO (Food and Agriculture Organization of the United Nations) statistics, Iran's poultry industry ranks seventh in poultry production in the world (FAO, 2020). Despite the spread of production units in the country and its importance in people's food basket, this industry faces two basic categories of problems that affect the fluctuation and increase of the final price of poultry (Afshari et al., 2023; Nazari et al., 2023; Hosseini et al., 2015):

Poor management of poultry farms and unwillingness to train traditional managers; A long period of poultry breeding; Inactivity or semi-activity of many production units; Lack of single and integrated management in the production chain; Fluctuation of production in day-old chicken; The independence of production units and the absence of a contract system.

High cost of production due to the high conversion rate of chicken breeding; old equipment; high energy consumption; Fluctuation in the price of feed inputs and lack of full use of pellet feed.

In Iran, despite the efforts of government and private institutions in supporting the poultry industry, the production of this industry is not enough to meet the domestic demand, and a part of the demand needs to be imported from other countries. Iran's poultry industry can be prioritized for the allocation of government and private facilities compared to other livestock industries for several reasons. Among these reasons are the high growth rate of poultry in a short time compared to other livestock, low food conversion ratio, the possibility of production in all weather conditions, and the need for low capital compared to other animal husbandry industries. In general, the broiler industry includes three sectors: primary breeding, production and distribution. The primary breeding section includes the stages of line chickens and ancestor chickens, the production section includes the stages of mother, hatching, poultry feed and processing (slaughterhouse and cutting), and the distribution section includes the chicken distribution network to sales centers (Delangizan & Jashn Porovakani, 2017).

Now we will explain the concept of the production chain and the final part of the poultry industry, which is distribution in the chain. In general, the production chain includes all the activities required to provide a service or product to the end customer (Zhao et al., 2022; Sarrafha et al., 2014). In other words, a production chain includes all the stages that are directly or indirectly involved in meeting the customer's needs (Liberatore, 2021). Distribution is considered the last link of the production chain, which procures the products produced by the manufacturing plant without intermediaries and,

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according to the planned logistics system, transfers the products to its warehouses and supplies them to the consumer market (Khalili & Alinezhad, 2018; Hosseini & Sheikhi, 2012).

According to the stated definitions and the study case of the present research, the importance of managing a production chain in the poultry industry, especially in the distribution sector, became clearer. It is obvious that examining the performance of production chains in this industry can cause competition between the chains and, as a result, the growth of the poultry industry in the country and the reduction of imports in this area. This is the research problem that this paper focuses on. The main purpose of working on the research problem is to examine the performance of 28 production chains in the country's poultry industry and then determine the reference production chain for the development of other chains.

Performance evaluation in any structure and organization requires an index to be able to accurately examine the variables affecting it. The efficiency index can well reflect the performance of an organization or a unit (Alinezhad et al., 2007). Data Envelopment Analysis (DEA) is a powerful mathematical tool that can measure the efficiency of a decision-making unit (DMU) (production chain in the research case study) and reflect its performance (Emrouznejad et al., 2022; Kiani Mavi et al., 2010). Therefore, in this research, to evaluate the performance of poultry production chains, their efficiency has been measured using DEA. The DEA mathematical tool is a non-parametric method that is sensitive and dependent on the initial values (inputs-outputs); So that the selection of inappropriate variables can lead to incorrect and unrealistic results. In this method, variables are usually selected through consultation with experts in the field under investigation (Hosseinzadeh Lotfi et al., 2023; Amini et al., 2016). In this study, after reviewing the research of the poultry industry and consulting with the experts and managers of this industry, input variables (including the materials cost, human resources cost, equipment and facilities cost, transport cost), intermediate variables (including the number and price of poultry), and output variables (including profit and slaughter cost) were selected to form a two-stage DEA mathematical model. According to the mentioned contents, the main contributions of the paper are:

Aggregating price and cost variables and creating a link between them in order to scientifically reflect the performance of poultry production chains (case study perspective).

Two-stage mathematical modelling based on network DEA theory to measure the efficiency of production chains and determine the efficient reference (technical perspective).

The rest of the paper is organized as follows: Section 2 reviews the research literature. The research methodology is presented and explained in section 3. Section 4 includes computational results and discussion. Finally, in section 5, conclusions, future research directions and suggestions are given.

2. Literature Review

In recent years, research in the field of decision science has accelerated and expanded greatly (Alinezhad et al., 2023; Alinezhad & Taherinezhad, 2020). DEA is one of the important tools of decision science that has been widely used in various fields (Taherinezhad & Alinezhad, 2023; Taherinezhad & Alinezhad 2022). In current study, if we look at DEA from a technical point of view, the poultry industry will be placed next to it as a case study. Based on this, a comprehensive approach that simultaneously includes DEA and the poultry industry was used to review the literature. We limited the search for relevant articles to the last 7 years to examine novel innovations and contributions. In the following, the found studies are described in detail.

Today, the growth of the livestock production sector has caused significant impacts on the environment. Focusing on this problem, Payandeh et al., (2017) evaluated 90 broiler farms in Isfahan province from the point of view of environmental impacts. Their purpose of this research was to reduce environmental impacts of the studied farms based on the DEA method. After determining the efficiency values, the inefficient farms were improved to reach the efficient level by reducing energy and resource consumption. The results of this research showed that improving energy consumption causes 12-57% reduction in environmental impacts. Following previous research, Sadiq and Singh (2017) identified wasteful uses of energy in order to optimize broiler production. This was done by DEA non-parametric method. Furthermore, the effect of energy optimization on greenhouse gas (GHG) emission was investigated and comparative results of GHG emissions revealed that the amount of CO2 emissions in efficient units was less than inefficient farms. Improving production efficiency in the poultry industry is significant and important. Based on this, Baradaran and Ghodsi (2018) evaluated the efficiency of Iran's provinces in poultry production between 2000-2015. They used K-Means technique to cluster similar provinces. In addition, to overcome the problem of large data dimensions, Exploratory Factor Analysis (EFA) was used. Finally, using DEA models (including BCC and super-efficiency), the efficiency of the provinces of each cluster was calculated. The results of this research showed that Tehran province is leading and efficient in poultry productions. Considering the importance of energy as one of the effective inputs in the poultry industry, Rezaee and

Esmaielzadeh (2018) conducted a study with the aim of measuring broiler production units in Mako free zone. In this research, 5 energy inputs including chicks, seeds, fuel, electricity, labor and 2 outputs like chicken and manure were selected as the initial values of DEA (constant and variable return to scale (CRS-VRS) model). Their results showed that the highest and the lowest fuel consumption were for gasoline (66.2%) and labors (0.07%). Purwaningsih et al., (2019) considered inefficiency in the use of resources and operational distribution system as one of the main problems of the poultry industry, which causes the price of poultry to increase for the final customer. Based on this, they conducted research with the aim of measuring the relative efficiency of intermediary trader in poultry products using DEA and formulating recommendations based on its results. In another study, Hosseinzad and Faraji (2019) evaluated the financial efficiency of poultry farms in Tabriz city. The statistical population of this research was the broiler units, which was investigated in the form of a census. In this research, financial ratios were used as inputs-outputs of DEA. The results of the BCC model in this research showed that the average financial efficiency of poultry farms is equal to 63.66%, which has a gap of about 36% until achieving full financial efficiency. Chen et al., (2019) measured the operational efficiency of listed poultry enterprises in China between 2010-2018 using the BCC-DEA model. They showed that the overall efficiency of poultry listed enterprises had a downward trend in these years. On the other hand, Mardani Najafabadi et al., (2019) evaluated the efficiency of broiler chicken breeding units in Khuzestan province based on fuzzy and robust DEA models. In addition, their secondary purpose was to estimate the optimal use of inputs in inefficient units. The results of their research showed that industrial poultry units are less efficient in using inputs than semi-industrial units. Following the previous research, Mardani Najafabadi et al. (2020) evaluated the efficiency of broiler chicken units in Sistan region. In this work, they used the interval DEA method and the Mont Carlo simulation approach. Piran et al., (2021) conducted a study based on an internal benchmark analysis of a broiler production system with a focus on cost efficiency. The results show that the broiler production system could reduce 32% of the total cost per unit of production if the balance of inputs suggested by the DEA evaluation was used. In another study, Parlakay and Çimrin (2021) measured the technical efficiency of 19 active broiler farms of Hatay Province in Turkey, based on CRS-DEA and VRS-DEA models. Vahedi et al., (2022), Ilham et al., (2022), and Khan et al., (2022) were also other researches that used DEA to measure the efficiency of poultry units in Iran, Indonesia, and Pakistan, respectively. On the other hand, Mansouri and Nemati (2023) used the Malmquist index to evaluate the performance of 30 active poultry farms in Zanjan province of Iran. In this study, the amount of initial hatching, feed consumption, energy costs, personnel costs and healthcare costs were selected as input variables and final slaughter weight and fertilizer weight were selected as output variables. The results of this study showed that the Malmquist index and its components are suitable criteria for evaluating the efficiency of poultry production units. Nandy et al., (2023) is another research in this field that can be mentioned. In this research, the efficiency of 80 women poultry farmers in Sub-Himalayan North Bengal has been calculated and predicted through DEA and machine learning.

By reviewing the studies found from the perspective of case study, we find that their focus is on measuring the efficiency of poultry production units and they do not consider poultry production chains. This means that previous studies do not cover the interactions and communications between production units with units outside of it and the chain is not formed. For this reason, the selected variables in related research only reflect the internal performance of each production unit and not the production chain. In addition, from a technical point of view, the models used in previous researches are not network-based and are single-stage. The present research shows its contribution and participation in this field by focusing on the two mentioned gaps and covering them. Therefore, the innovations and novelties of the research are clearly as follows:

- Identifying the production chains of Iran's poultry industry and measuring their efficiency.

- Using the network DEA model for the scientific reflection of chains performance.

3. Materials and Methods

3.1. Research Method Outline

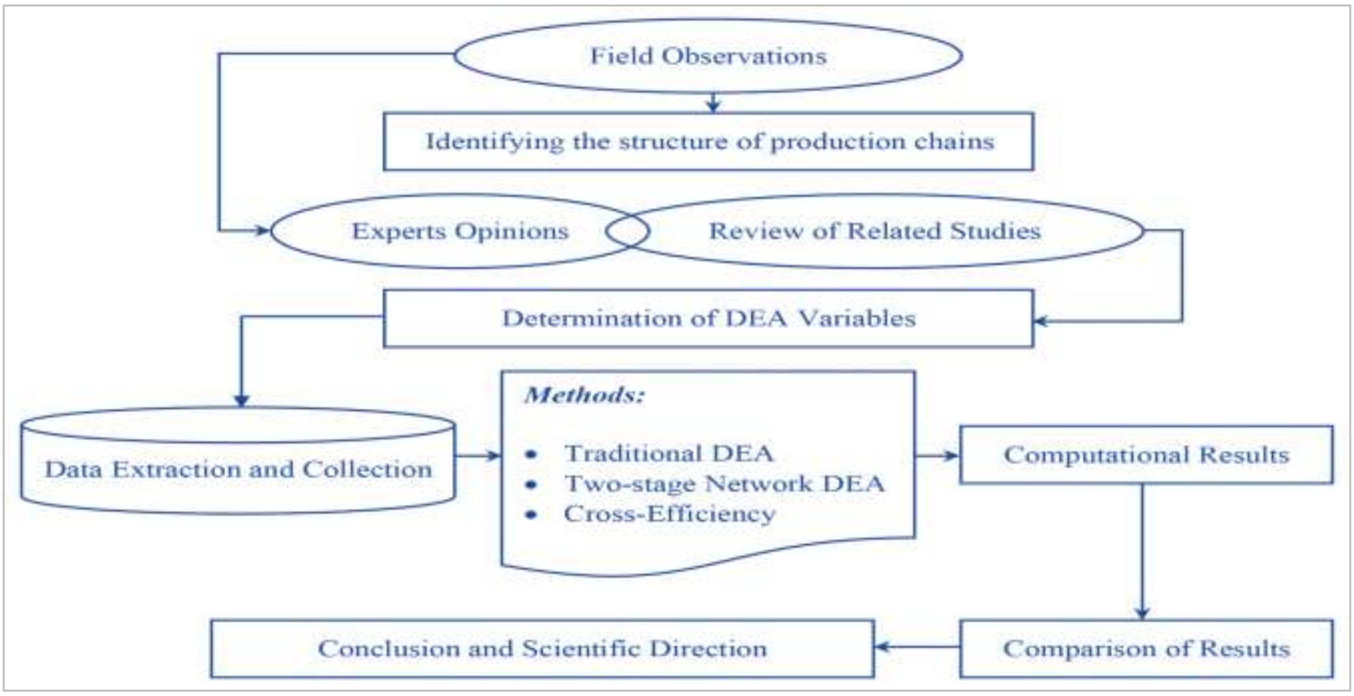

Fig. 1. The architecture of research framework

First, we will discuss the framework of the research method and the details of its process. As seen in Figure 1, in the first stage, the structure of the production chains of the poultry industry has been identified via field observations. Where each production chain is known as a DMU. Determining DEA variables is of great importance and the final results are highly sensitive to them. For this step, a combination of opinions of poultry industry experts and reviews of previous articles have been used. After data extraction and collection, computational results have been obtained and compared via traditional DEA, network two-stage DEA and cross-efficiency methods. Finally, this research determines conclusion and scientific direction.

Figure 1 illustrates the path from the beginning to the end of the research implementation process. This process reflects both practical implementations and implementations of theory experiments. The beginning of the process includes field observations for census and knowledge of chains in Iran. Also, computational experiments on different models and theories to obtain scientific results with the least error can be seen in Figure 1. These experiments have been carried out on different theories of DEA. Figure 1 acts as a general road map for the research in such a way that if an error occurs in the process, it is clear which step of the research implementation it is related to and there is no confusion.

3.2. DEA Variables Selection and Data Collection

In this research, the considered society (decision-making units) are all active production chains in Iran's poultry industry. The data was collected through field observations, as a result of which it was found that in 2018, there were 28 active production chains based on the structure of Figure 2 in the country.

Based on Figure 2, it is obvious that in the process of broiler production until final consumption, the variables of cost, quantity, price of chicken and profit have a direct relationship with each other and directly affect each other. This important point was also confirmed by experts in this field for determining DEA variables. Therefore, selected variables by the experts for mathematical modeling are as follows, and the descriptive statistics of their data are collected in Table 1:

- *Inputs:* Material cost (*X1*), human resources cost (*X2*), equipment and facilities cost (*X3*), transport cost (*X4*).

- *Intermediate outputs:* Number of poultry (*Y1*), poultry price (*Y2*).

- *Final outputs:* Profit (*Z1*) and slaughter cost (*Z2*).

Table 1
Descriptive statistics of the dataset (The units of variables *Y1* and *Y2* are equal to thousand numbers and thousand tomans, respectively. The unit of the remaining variables is equal to millions of Tomans.)respectively. The unit of the remaining variables is equal to millions of Tomans.)

Variable	N	Mean	StDev	Sum	Min	Q1	Median	Q3	Max
$X1$	28	32.46	5.39	909	22	27.25	33	37.50	41
$X2$	28	14.96	2.81	419	11	13	14	16.75	21
$X3$	28	12.89	2.47	361	8	11	13	15	16
$X4$	28	6.25	1.94	175	3	4.25	6.50	8	9
$Y1$	28	10.18	1.87	285	7	9	10	11	17
$Y2$	28	14.57	1.42	408	11	14	14.50	16	17
$Z1$	28	140.71	17.83	3940	110	126.25	140	155	185
$Z2$	28	15.29	3.32	428	11	12.25	15	17	25

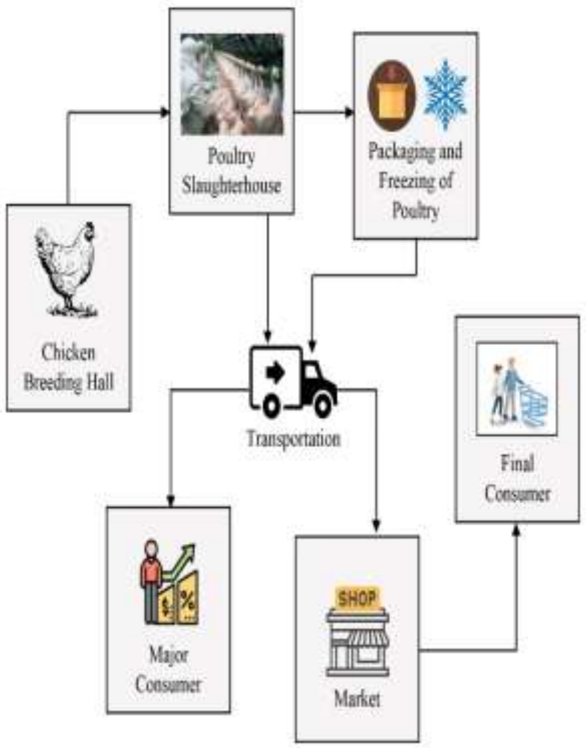

Fig. 2. The structure of active production chains of poultry

Table 1 describes the characteristics of the collected dataset, which can be a representation of the entire statistical population, i.e., production chains. N represents the total number of samples or chains, which is equal to 28 for each variable. This means that data for all variables are available for all 28 chains. Measures of central tendency for each variable, including the mean, median, as well as the first and third quartiles (*Q1*, *Q3*), Summation, Minimum, and Maximum value of variables can be seen in Table 1. In addition, one of the measures of variability, namely the standard deviation (*StDev*), is also included in Table 1 to clearly display the dispersion of each variable.

3.3. Traditional DEA

Charnes et al., (1978) developed and presented the first DEA model named CCR to measure the efficiency of DMUs. The CCR model is considered as the basic model for the formation of other models in DEA, which has constant returns to scale. Banker et al., (1984) developed the BCC model with modifications to the basic CCR model. The BCC model is one of the types of DEA models that evaluates the relative efficiency of units with variable return to scale.According to the CCR model, the relative efficiency of each decision-making unit is equal to the ratio of the weighted sum of outputs to the weighted sum of inputs. The calculation of this ratio for the *j*th DMU that has *m* inputs and *s* outputs is obtained from Model 1 Charnes et al., 1978):

$$Maximize\, Z_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

$$Subject\, to:$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$$

$$u_r, v_i \geq 0, \forall r, \forall i, \forall j, Z_0\ free \quad (1)$$

So that x_{ij} is the *i*th input amount of the *j*th unit ($i = 1, ..., m$), y_{rj} is the *r* th output amount of the *j*th unit ($r = 1, ..., s$), u_r is the *r*th output weight, and v_i is the *i*th input weight. The number of investigated units are: $j = 0, ..., n$.

Because the mentioned model is a fractional programming model, it becomes a linear programming model by changing the variable twice. In this model, to increase the efficiency, either the input is assumed to be constant and the output is maximized, or the output is assumed to be constant and the input is minimized. Based on this, data envelopment analysis models are called input-oriented or output-oriented. Therefore, a multiple (initial) model of input-oriented CCR is written as Model 2:

$$
\begin{aligned}
&Maximize\, Z_0 = \sum_{r=1}^{s} u_r y_{r0} \\
&Subject\, to: \\
&\sum_{i=1}^{m} v_i x_{i0} = 1 \\
&\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \\
&u_r, v_i \geq 0, \forall r, \forall i, \forall j, Z_0\, free \qquad (2)
\end{aligned}
$$

In this research, in the first step, based on a strict approach, the Model 2 was used to measure the efficiency of DMUs.

3.4. Network DEA

To evaluate the two-step process of the current research, a network approach was used in the DEA model proposed by Chen and Yan (2011). The key problem in model generation is how to insert the intermediate variables into the DEA model. In the proposed model of Chen and Yan (2011), if j_0 is the evaluated production chain, the efficiency of the chain is calculated according to Model 3:

x_{ij}: The *i* th input value from the *j* th unit
y_{rj}^1: The amount of the *r* th intermediate goods input to M_1
y_{dj}^2: The amount of the *d* th intermediate goods input to M_2
z_{aj}^1: The desirable output value *a* of the producer M_1
$(z_{aj}^{-1})'$: The undesirable output value *a* of the producer M_1
z_{bj}^2: The desirable output value *b* of the producer M_2
$(z_{bj}^{-2})'$: The undesirable output value *b* of the producer M_2
w_i: The weight given to the *i* th initial input
u_r: Intermediate output weight *r* th input to M_1
v_d: Intermediate output weight *d* th input to M_2
μ_a: The desirable output weight *a* of the producer M_1
μ_a': The undesirable output weight *a* of the producer M_1
t_b: The desirable output weight *b* of the producer M_2
t_b': The undesirable output weight *b* of the producer M_2

The mentioned model is converted to the input-oriented multiple CCR form (according to Model 4) with equation $\frac{1}{\sum_{i=1}^{m} \omega_i x_{i0}} = 1$:

$$
Maximize \quad \frac{\sum_{a=1}^{\alpha} \mu_a z_{a0}^1 + \sum_{b=1}^{\beta} t_b z_{b0}^2 + \sum_{a=1}^{\alpha} \mu_a' (z_{a0}^{-1})' + \sum_{b=1}^{\beta} t_b' (z_{b0}^{-2})'}{\sum_{i=1}^{m} w_i x_{i0}}
$$

$$
Subject\, to:
$$

$$
\frac{\sum_{r=1}^{s} u_r y_{rj}^1 + \sum_{d=1}^{e} v_d y_{dj}^2}{\sum_{i=1}^{m} w_i x_{ij}} \leq 1 \;, \quad \frac{\sum_{a=1}^{\alpha} \mu_a z_{aj}^1 + \sum_{a=1}^{\alpha} \mu_a' (z_{aj}^{-1})'}{\sum_{r=1}^{s} u_r y_{rj}^1} \leq 1 \;, \quad \frac{\sum_{b=1}^{\beta} t_b z_{bj}^2 + \sum_{b=1}^{\beta} t_b' (z_{bj}^{-2})'}{\sum_{d=1}^{e} v_d y_{dj}^2} \leq 1 \;,
$$

$$
\frac{\sum_{a=1}^{\alpha} \mu_a z_{aj}^1 + \sum_{a=1}^{\alpha} \mu_a' (z_{aj}^{-1})' + \sum_{b=1}^{\beta} t_b z_{bj}^2 + \sum_{b=1}^{\beta} t_b' (z_{bj}^{-2})'}{\sum_{i=1}^{m} w_i x_{ij}} \leq 1
$$

$$
w_i, u_r, v_d, \mu_a, t_b, \mu_a', t_b' \geq 0 \qquad (3)
$$

$$
\begin{aligned}
&Maximize \sum_{a=1}^{\alpha} \mu_a z_{a0}^1 + \sum_{b=1}^{\beta} t_b z_{b0}^2 + \sum_{a=1}^{\alpha} \mu_a' (z_{a0}^{-1})' \\
&\qquad + \sum_{b=1}^{\beta} t_b' (z_{b0}^{-2})' \\
&Subject\, to: \\
&\sum_{i=1}^{m} w_i x_{i0} = 1 \\
&\sum_{r=1}^{s} u_r y_{rj}^1 + \sum_{d=1}^{e} v_d y_{dj}^2 - \sum_{i=1}^{m} w_i x_{ij} \le 0 \\
&\sum_{a=1}^{\alpha} \mu_a z_{aj}^1 + \sum_{a=1}^{\alpha} \mu_a' (z_{aj}^{-1})' - \sum_{r=1}^{s} u_r y_{rj}^1 \le 0 \\
&\sum_{b=1}^{\beta} t_b z_{bj}^2 + \sum_{b=1}^{\beta} t_b' (z_{bj}^{-2})' - \sum_{d=1}^{e} v_d y_{dj}^2 \le 0 \\
&\sum_{a=1}^{\alpha} \mu_a z_{aj}^1 + \sum_{a=1}^{\alpha} \mu_a' (z_{aj}^{-1})' + \sum_{b=1}^{\beta} t_b z_{bj}^2 + \sum_{b=1}^{\beta} t_b' (z_{bj}^{-2})' \\
&-\sum_{i=1}^{m} w_i x_{ij} \le 0 \\
&w_i, u_r, v_d, \mu_a, t_b, \mu_a', t_b' \ge 0 \qquad (4)
\end{aligned}
$$

In Model 4, which is comprehensively written, the objective function includes all desirable and undesirable final output variables produced by DMU_0. Accordingly, we seek to maximize the final outputs produced by poultry production chains. It is important to mention that Model 4 is an input-oriented model, which means that DMUs have control over changing inputs, thereby optimizing outputs and increasing efficiency. How to control inputs to produce intermediate and final outputs is included in Model 4 limitations. Suppose (Θ_0) is equal to the objective function of Model 4 and represents efficiency value. In this case, the efficiency of DMU_0 is obtained by solving Model 4. Therefore, to obtain efficiency values for all poultry production chains, Model 4 must be solved for the all of chains (28 iteration). So that the data associated with each chain in the model is replaced each time.

3.5. Cross Efficiency Method

Sexton et al., (1986) presented the concept of cross-efficiency and cross-efficiency matrix in their effort to distinguish between efficient units. Consider *N* DMUs evaluated in terms of *m* inputs and *s* outputs. Where x_{ij} and y_{rj} be their input and output values for $i = 1, ..., m$ and $r = 1, ..., s$ and $j = 1, ..., n$. The efficiency of DMUs is measured using the CCR model as Model 5.

Where v_{ik} and u_{rk} for $i = 1, ..., m$ and $r = 1, ..., s$ are input and output weights. In fact, the CCR model searches for a set of input and output weights that are most favorable for DMU_k. Using Charnes and Cooper transformations, Model 5 can be transformed into linear Model 6, which is written as follows:

$$
\begin{aligned}
&Maximize\, \theta_{kk} = \frac{\sum_{r=1}^{s} u_{rk} y_{rko}}{\sum_{i=1}^{m} v_{ik} x_{iko}} \\
&Subject\ to: \\
&\frac{\sum_{r=1}^{s} u_{rk} y_{rk}}{\sum_{i=1}^{m} v_{ik} x_{ik}} \le 1, j = 1, \dots, N \\
&u_{rk} \ge 0, r = 1, \dots, s \\
&v_{ik} \ge 0, i = 1, \dots, m \qquad (5)
\end{aligned}
$$

$$
\begin{aligned}
&Maximize\, \theta_{kk} = \sum_{r=1}^{s} u_{rk} y_{rko} \\
&Subject\, to: \\
&\sum_{i=1}^{m} v_{ik} x_{iko} = 1 \\
&\sum_{r=1}^{s} u_{rk} y_{rk} - \sum_{i=1}^{m} v_{ik} x_{ik} \le 0, \ \ j = 1, \dots, N \\
&u_{rk} \ge 0, r = 1, \dots, s \\
&v_{ik} \ge 0, i = 1, \dots, m \qquad (6)
\end{aligned}
$$

Model 6 is solved for each DMU in order, and as a result, there will be *N* sets of input and output weights for DMUs, and each DMU will have (*N-1*) cross efficiency and one CCR efficiency. These efficiencies are shown as a cross-efficiency matrix in Table 2.

After the formation of Table 2, the row average of the efficiencies can be used as a ranking criterion. Due to the fact that Model 6 may have multiple optimal solutions, then there will be different rankings. As we can see in Table 2, the number of rows and columns is equal to the number of DMUs in the analysis. Consider the cell or unit *jk* in Table 2. In this case, the cross efficiency of DMU_{jk} will be equal to $\theta_{jk} = \frac{\sum_{r=1}^{s} u_{rk}^* y_{rj}}{\sum_{i=1}^{m} v_{ik}^* x_{ij}}$. In other words, for each cell (*jk*), the efficiency of unit *jk* computed with weights that are optimal to unit *k*. The higher the values in a given column *k*, the more likely it is that the unit *jk* an example of truly efficient operating practices.

Table 2
Cross efficiency matrix

DMU	1	2	…	*k*	Cross-Efficiency
1	θ_{11}	θ_{12}	…	θ_{1k}	$\frac{1}{n}\sum_{k=1}^{n}\theta_{1k}$
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
n	θ_{n1}	θ_{n2}	…	θ_{nk}	$\frac{1}{n}\sum_{k=1}^{n}\theta_{nk}$

4. Computational Results and Discussion

Based on the collected data and by implementing Model 2 in Excel software, traditional DEA calculation results were obtained. These results are compiled in Table 3. The results of solving Model 2 show that units 3, 5, 10, 11, 12, 18, and 26, which constitute 25% of all units under investigation, are efficient. In the next step, Model 4 which is a two-stage DEA model, was implemented in Excel. The results of solving this model are also shown in Table 3, which shows that units 5, 18, and 26, which constitute 10.7% of the total units under investigation, are efficient. Comparing the results of Models 2 and 4 (Figure 3) shows that the two-stage DEA has a stricter approach.

Table 3
Computational results of traditional and two-stage DEA

DMUs	Efficiency Score (Traditional DEA)	Efficiency Score (Two-Stage DEA)	DMUs	Efficiency Score (Traditional DEA)	Efficiency Score (Two-Stage DEA)
1	87	82	15	83	79
2	97	84	16	80	77
3	100	95	17	98	94
4	85	81	18	100	100
5	100	100	19	95	91
6	84	80	20	83	79
7	88	86	21	76	72
8	84	80	22	83	78
9	83	79	23	85	82
10	100	95	24	86	83
11	100	96	25	95	92
12	100	96	26	100	100
13	86	82	27	87	84
14	84	81	28	67	63

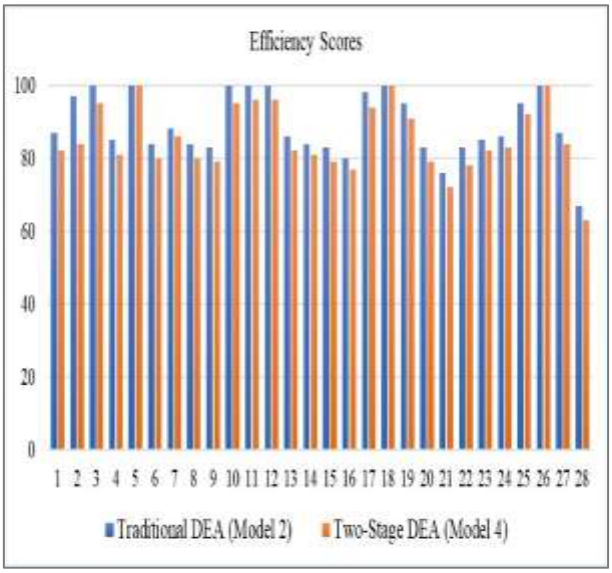

Fig. 3. Comparison of efficiency scores resulting from the solution of traditional and two-stage DEA models (horizontal axis indicates decision-making units and vertical axis indicates efficiency scores (%))

As seen in Figure 3, the graph of the results of Model 4 are lower than the graph of the results of Model 2. This means that efficient units in traditional DEA are not necessarily efficient in two-stage DEA, but the opposite is true. In fact, Figure 3 reveals a comparative trend of DEA values based on two different theories. The average efficiency of traditional and two-stage DEA is equal to 89.14% and 85.39% respectively. It can be concluded that when every poultry production chain is considered in two stages and the internal interactions between the stages are defined, the efficiency decreases. This strict approach can be seen not only in the average efficiency but also in the number of efficient units. According to Figure 3, the number of efficient units obtained from Models 2 and 4 is 6 and 3, respectively. Now the question is, considering that DEA results can introduce efficient units as a reference for other units, which DEA model is appropriate? The answer to this question comes back to the policies of the managers of each production chain. But it is obvious that the two-stage approach of DEA is more consistent with the connections and interactions that are defined in a production chain. Based on the results (Table 3 and Figure 3), it was observed that in none of the models, there was one efficient unit and several units were efficient. Now the question that arises is how to rank the efficient units and explain the model or final efficient unit?

4.1. Ranking of Efficient Units using Cross-Efficiency Method

As mentioned in the "Materials and Methods" section, the cross-efficiency method has been used for efficient units ranking. The difference between the cross-efficiency method and the two traditional and two-stage DEA methods is that this method ranks the units whose efficiency score is equal to 1 in the traditional and two-stage models. In other words, by using this method, only efficient units are rated and not all units. In this step, by implementing Model 6 in Excel software, the efficient units obtained from the previous models were ranked (Figure 4). The results show that units 12 and 26 have the highest efficiency in traditional and two-stage models with 98% and 96%.

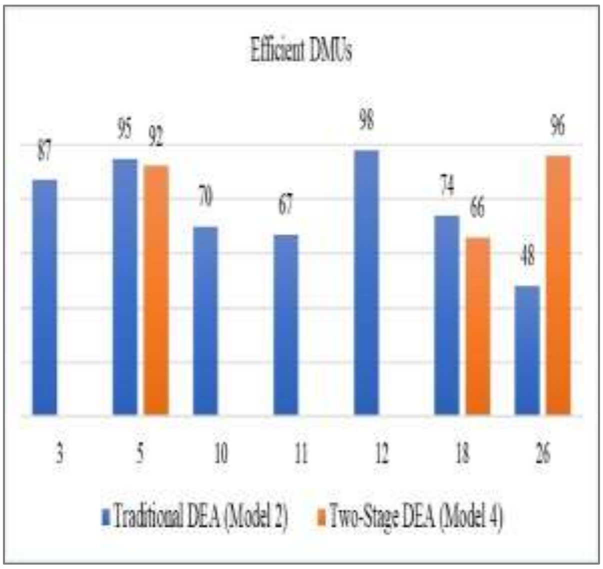

Fig. 4. Ranking results of efficient units. (Horizontal axis indicates decision-making units and vertical axis indicates efficiency scores (%)

Based on Figure 4, we find that unit 26 is a suitable reference for other poultry production chains. Because it has been identified as the most efficient unit by going through the strict two-stage DEA approach and the cross-efficiency method. According to the selected variables for DEA, what has made this unit efficient is the balanced and optimal use of inputs or costs in the chain. Therefore, other inefficient units trying to improve their efficiency should examine how this unit manages the costs of poultry production including material cost, human resources cost, equipment and facilities cost, transport cost, and slaughter cost and achieves the best output with a minimum mode.

5. Conclusion and Future Research Directions

Production chain management is one of the components of competitive strategies. Managers of many industries, including the poultry industry, especially production managers, try to manage the production chain optimally and evaluate its performance from moment to moment. One of the appropriate and efficient tools in the field of evaluating the efficiency and performance of decision-making units is the powerful DEA mathematical tool. This technique has had an upward growth graph due to its successful uses, practical features, as well as researches and case studies published in the last few years. Traditional DEA does not pay attention to dependencies and intermediate values in network systems and usually overstates the efficiency of the system. Since the production chain is a network of members that are connected with each other, therefore, in this research, to calculate the efficiency of active production chains in the poultry industry, the network DEA (two-stage) method was used to determine the relationship between the subsystems in the calculation of efficiency scores. Be considered. The methodology of this research has determined a new frontier for more and more studies and researches in Iran's poultry industry. Researchers are encouraged to pay attention to the following issues in their future research:

- This research is based on quantitative calculations. Since many of the final decisions are made based on the opinions of managers and experts of the poultry industry, it is therefore suggested that in future studies, while considering qualitative variables, the integration of quantitative network DEA model and qualitative models should be used.

- In future research, it is possible to search for the loss of intermediate outputs in the production chain, which is caused by the imbalance between supply and demand in domestic sectors, and provide a comprehensive discussion on resource efficiency for the production chain.

- It is suggested to use the combination of data envelopment analysis models with different modes under conditions of uncertainty (fuzzy, neutrosophic, gray, etc.) to better reflect the performance of chains.

- The evaluation of other elements of the production chain and their selection in the chain network is one of the areas that can be investigated for future research.

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