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RESEARCH PAPER

A New Approach In the Network DEA Models for Measurement of Productivity of Decision-Making Units Using Multi-Objective Programming Method

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ABSTRACT
So far, numerous studies have been developed to evaluate the performance of "Decision-Making Units (DMUs)" through "Data Envelopment Analysis (DEA)" and "Network Data Envelopment Analysis (NDEA)" models in different places, but most of these studies have measured the performance of DMUs by efficiency criteria. The productivity is considered as a key factor in the success and development of DMUs and its evaluation is more comprehensive than efficiency evaluation. Recently, studies have been developed to evaluate the productivity of DMUs through the mentioned models but firstly, the number of these studies especially in NDEA models is scarce, and secondly, productivity in these studies is often evaluated through the "productivity indexes". These indexes require at least two time periods and also the two important elements of efficiency and effectiveness in these studies are not significantly evident. So, the purpose of this study is to develop a new approach in the NDEA models using "Multi-Objective Programming (MOP)" method in order to measure productivity of DMUs through efficiency and effectiveness "simultaneously, in one stage, in a period, and interdependently". "Simultaneous and single-stage" study provides the advantage of sensitivity analysis in the model. One case study demonstrates application of the proposed approach in the branches of a Bank. Using proposed approach revealed that it is possible for a branch to be efficient by considering its subdivisions separately but not be efficient by considering the conjunction between its subdivisions. In addition, a branch may be efficient by considering the conjunction between its subdivisions but not be productive. Efficient branches are not necessarily productive, but productive branches are also efficient.

KEYWORDS: *Productivity; Effectiveness; Efficiency; Productivity indexes; Network DEA; Multi-objective programming.*

1. Introduction

The performance assessment of industrial and economical units plays important role in achieving their managerial success and continuous progress [1]. Various criteria have been proposed as performance evaluation criteria of organizations that "efficiency, effectiveness and productivity" are the most important of these criteria [2]. Because, productivity is a combination of efficiency and effectiveness simultaneously, therefore, its evaluation will be more complete than the evaluation of effectiveness and efficiency separately [3]. The productivity is a subject of interest to many economists and policymakers, and it is crucial for economic growth and survival [4]. Productivity is also considered as an important element for the operations of the organization and its increase creates a competitive advantage for organization and is a vital issue for management. "Making a profit, reducing costs, and growing an organization" in the long-term need to improve productivity [5].

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The Data Envelopment Analysis (DEA) is one of the main techniques for analyzing the efficiency of organizations and it is considered as a "Well-Known, popular and standard" method for measuring the efficiency of manufacturing and service organizations [6-8]. According to many "experts, researchers and users of operations research", the advantages of DEA technique outweigh its disadvantages [9].

However, from the point of view of "Decision-Making", the performance of a "Decision-Making Unit (DMU)" should be evaluated by considering the internal interactions between its subdivisions. The conventional DEA methods need to reflect the internal interactions between divisions in a DMU under such circumstances [10]. In other words, it is necessary to use a systemic approach in evaluating a DMU. Thus, one of the drawbacks of these models is the neglect of internal activities. The developed approach of DEA technique is called "Network DEA (NDEA)", which considers the internal interactions of the subdivisions of a DMU [11].

Nevertheless, most studies on DEA and NDEA techniques have focused on evaluating the efficiency of "Decision-Making Units (DMUs)". Recently, there are studies that evaluate the productivity of DMUs through the DEA and NDEA techniques. These studies are divided into the following two categories:

I) productivity evaluation through productivity indicators: the productivity is measured through indicators such as "Malmquist productivity index and Luenberger productivity index" in this type of evaluation. These indicators are methods for analyzing efficiency changes over a period of time. [12, 13]. In other words, these indicators show changes in the efficiency of DMUs over a period of time [13]. Far (1994) first proposed the "DEA-Malmquist Productivity Index" to measure the growth of productivity and technical progress of DMUs [14]. The Malmquist productivity index is an indicator which shows the "total factor productivity" growth of a DMU, and it can analyzes the changes of the efficiency between two time periods under the multiple inputs and outputs [15]. The Malmquist productivity index is a non-parametric function of evaluating the productivity with the ratio of the distance function and it has a ratio structure, while the Luenberger productivity index has an additive structure [16]. The Malmquist productivity index generally uses "Russell measure" or "enhanced Russell measure" of inefficiency, in which multiplication is used, but the Luenberger productivity index uses "slack-based measure" of efficiency, in which the addition is used [17].

However, these indicators do not show all factors in a system [18]. These indexes also require at least two time periods to evaluate the productivity of DMUs and also the two important elements of efficiency and effectiveness in these studies are not significantly evident. Another weakness of these models is the inability to analyze sensitivity.

II) The productivity evaluation through efficiency and effectiveness: the DEA and NDEA techniques are mostly used to evaluate the efficiency of DMUs [10] and the effectiveness is not considered in them, while effectiveness is as important as efficiency for evaluating DMUs [3].

Many studies have developed organizational effectiveness models, but they have not used a suitable analytical tool to evaluate effectiveness [19]. There exist few researches to measure productivity through efficiency and effectiveness especially in NDEA models [5] that this few researches also measures efficiency and effectiveness in two stages. Efficiency and effectiveness are complementary and they are not independent of each other but they have a different meaning [18]. Therefore, they must be measured in one stage, simultaneously and interdependently. These models also have difficulty in sensitivity analysis.

The publications related to DEA and NDEA can be divided into two groups: The first group uses these techniques to evaluate the performance of different organizations and the second group develops the original model theoretically [20] that the present study is from the second one. According to the above information, the aim and innovation of the present study is to propose a new approach of the NDEA technique that can measure the productivity of DMUs through efficiency and effectiveness using "Multi-Objective Programming (MOP)" method in one stage, interdependently and simultaneously. Using the proposed model, we can easily measure the productivity of DMUs by considering the conjunction between its subdivisions through effectiveness and efficiency in one stage and we can also do sensitivity analysis in the model. This proposed model has all the advantages of the original DEA technique and in addition, can evaluate the effectiveness of DMUs along with efficiency. For a case study in this study, the productivity of Maskan bank branches in Gilan province was evaluated through efficiency and effectiveness, but it can be used in all organizations that have similar inputs and outputs and they also have similar internal interactions. After measuring the productivity of the branches along with considering the interactions between their internal divisions, it became clear that efficient branches are not necessarily productive, but productive branches are also efficient.

2. Literature Review

In this section, first the keywords of the research will be described and then previous studies related to the research topic will be presented. Finally, the gap between previous studies and the current study will be explained.

1.2. Efficiency, effectiveness and productivity

The performance improvement is recognized as one of the key goals of organizations because it has benefits such as "increasing employee motivation, decision support, improvement in organizational learning and continuous improvement" [21]. The various criteria have been proposed to evaluate the performance of organizations that "efficiency, effectiveness and productivity" are the most important of these criteria [1].

The efficiency is defined in various terms such as increasing output, reducing costs, increasing profits and "doing things right" [22]. This term is also defined as [5]

$$\text{efficiency}=\frac{\text{actual consumption}}{\text{expected consumption}}=\frac{\text{produced output}}{\text{consumed input}}=\frac{\text{output}}{\text{input}}$$

The effectiveness is defined as choosing activities in the right way, being able to achieve predetermined goals and "doing the right thing" [5]. According to Lee and Johnson [18], the effectiveness is determined by the distance between observed outputs and a set of desired goals. Azadi et al. [3] also defined the effectiveness of a DMU as $\text{effectiveness}=\frac{\text{output}}{\text{goal}}$

Roghanian et al. [5] define productivity as a combination of efficiency and effectiveness as $\text{productivity}=\frac{\text{output}}{\text{input}}+\frac{\text{output}}{\text{goal}}$

Moreover, Asia Productivity Organization (APO) defines the productivity as "Productivity = Efficiency + Effectiveness =Doing things right + Doing the right things" [5].

According to the information in this section, we find that the sum of efficiency and effectiveness is the productivity and the formula of efficiency and effectiveness can also be extracted from this section. So, $\text{productivity}=\frac{\text{output}}{\text{input}}+\frac{\text{output}}{\text{goal}}$

2.2. Relationships between efficiency, effectiveness and productivity

The efficiency is "doing the things right" according to definition; the effectiveness is defined as "doing the right things" in the same way, and productivity is referred to the sum of efficiency and effectiveness, and includes both of them [1]. Many studies have described the relationship between these three concepts in various figures. Azar et al. [23], Lee and Johnson [18] and Roghanian et al. [5] drew Figure (1, 2 and 3) respectively. We find that all three figures are composed of Two-Dimensional matrices, and the titles in the matrix cells are only different from each other. In other words, each of these studies looked at the relationship between efficiency and effectiveness from different perspectives. The fourth cell of each matrix indicates the high efficiency and effectiveness (productivity) in an organization, and the other cells indicate that the organization is low in one or both of them (unproductively). The relationship between efficiency and effectiveness is "Profit-Oriented" in the Figure (1). The fourth cell of this matrix indicates that high efficiency and effectiveness lead to long-term and sustainable profitability. The rest of the matrix cells are weak in profitability. The relationship between efficiency and effectiveness is "Strategic-Oriented" in Figure (2), meaning that the organization has a specific strategy for each of the matrix cells. The fourth cell of this matrix shows that the organization is a leader in the strategy of developing new markets and innovation due to its high efficiency and effectiveness. In other words, the organization is optimal in choosing its production and sales strategies, which leads to competitive advantage. The organization is weak in terms of production or sales strategies in the rest of the matrix cells. The relationship mentioned is "Customer-Oriented" in Figure (3), meaning that the organization is moving toward customer satisfaction. In the fourth cell of this matrix, the organization with the minimum resources brings the maximum satisfaction to customers. The organization performs poorly in the rest of the matrix cells in terms of customer service or resource consumption. According to the presented figures, we can set the relationship between efficiency and effectiveness and productivity as Figure (4).

If we analyze the information in this section, we find that efficiency and effectiveness are interdependent and therefore should be evaluated in one step and simultaneously. Also, efficiency and effectiveness are two integral components of productivity. Therefore, it is better that we use these two elements to evaluate productivity.

3.2. DEA

Farrell [24] introduced the nonparametric methods for estimating efficiency. There was an input and an output in his case to measure efficiency. Charles et al. [25] developed the Farrell view, and they provided a fractional and nonlinear mathematical programming model to measure efficiency with multiple inputs and outputs. This model was called the DEA model, and the model was named “Charnese, Coopere and Rhodes (CCR)” model due to the first letter of the developers’ name. Banker et al. [26] presented a new model named “Bankere, Charnese and Cooper (BCC)” model, with a little change in the CCR model. Accordingly, the DEA is a “boundary-based nonparametric” evaluation model which is used to measure the relative efficiency and performance of a set of comparable entities [27]. The efficiency of a DMU is calculated by the best efficiency observed in the set of DMUs. This linear programming model determines the optimal weights for input and output of DMUs to maximize efficiency [28]. The basic DEA models are faced with two assumptions of “Constant Return to Scale (CRS)” and “Variable Return to Scale (VRS)”. The CRS assumption is called the CCR model and the VRS assumption is called the BBC model [29]. The CCR model measures the technical efficiency of DMUS [30] and it is used when the units operate at their optimal size [29]. The BCC model calculates the pure technical efficiency [30] and is used when the units do not operate under optimal size conditions [29].

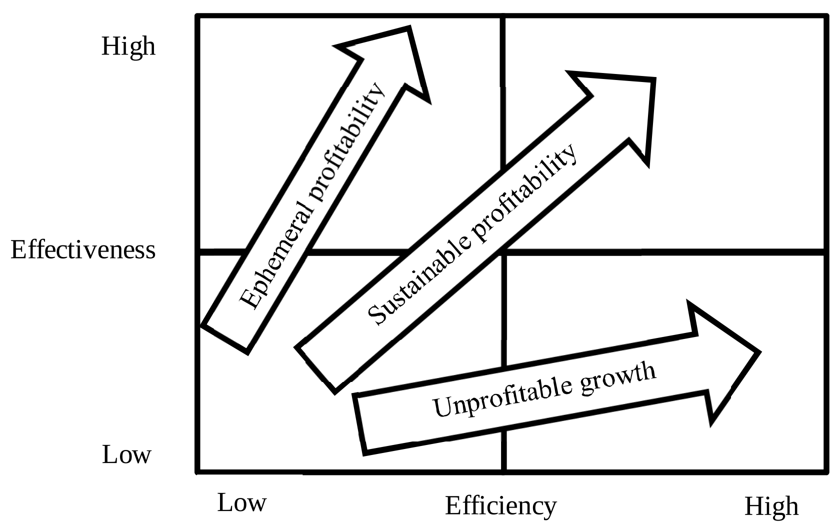

Fig. 1. The effect of different levels of efficiency and effectiveness

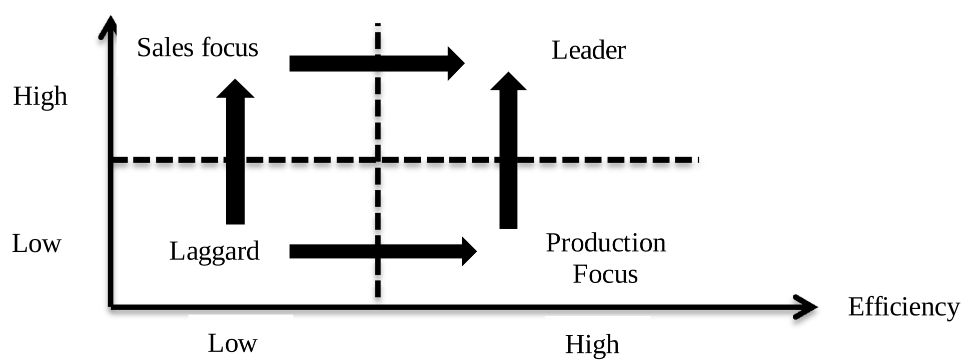

Fig. 2. Two-dimensional strategic position between efficiency and effectiveness

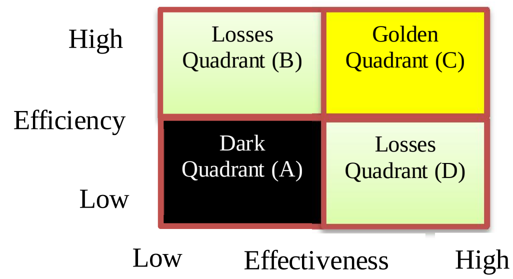

Fig. 3. Efficiency and effectiveness matrix

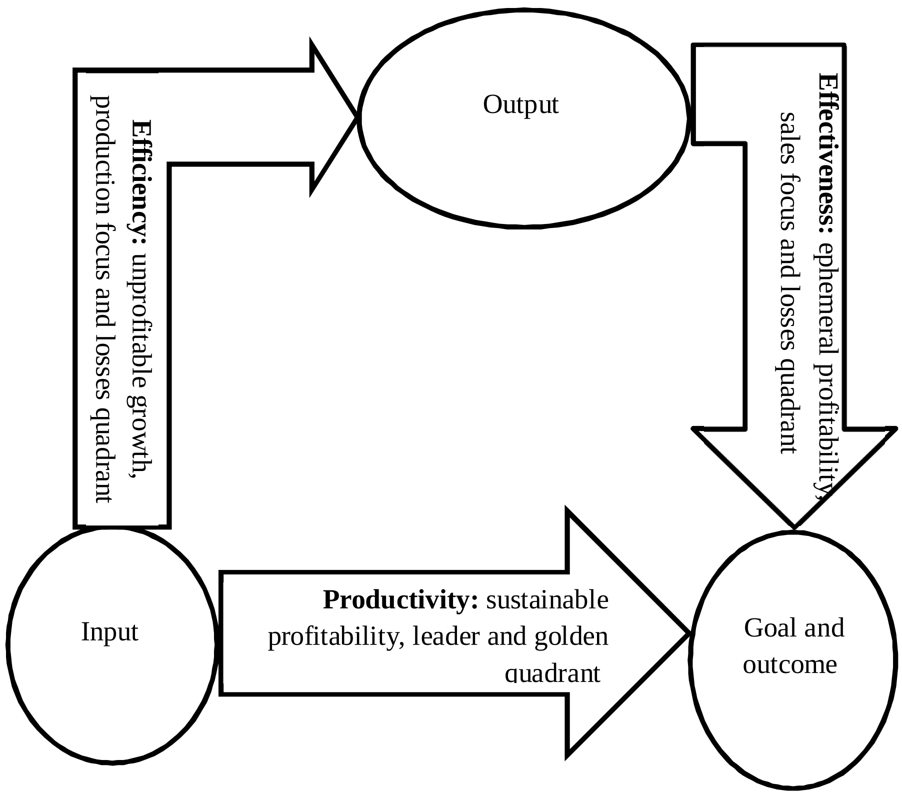

Fig. 4. The relationship between effectiveness, efficiency and productivity

Cadavid et al. [30] describes the relationship between technical efficiency (CCR) and pure technical efficiency (BCC) through the following:

$$\text{Scale efficiency}=\frac{\text{CCR efficiency}}{\text{BCC efficiency}},$$

$$\text{CCR efficiency}=\text{BCC efficiency}\times \text{scale efficiency}$$

In another classification, the “CCR and BCC” models are called radial models, and the non-radial models include “additive model, multiplicative model, Range-Adjusted Measure (RAM), and Slack-Based Measure (SBM)” [31].

Advantages of DEA are as follows:

- It does not need to define the mathematical form of the production function.
- It is useful to discover relationships which are impossible for other methods.
- It can handle multiple inputs and outputs.
- It can be used for any input-output measurement.
- It can identify and analyze inefficient resources in each DMU [32].
- It avoids the influence of subjective factors on the evaluation results [33].
- Inputs and outputs can have different units of measurement such as quantitative and qualitative [34].
- Its application is easy and interpretable [7].

Clermont and Schaefer [9] state that “from the viewpoint of many researchers and users in the field of Operations Research”, the advantages of DEA seem to outweigh the disadvantages.

According to the information in this section, the reasons for using the DEA and NDEA techniques in this study is identified and also "the concepts described in this section" can be used in Section 3.

4.2. NDEA

One of the weaknesses of original DEA models is ignoring the internal connections of divisions of a DMU. If these connections are ignored, it can lead to misleading results. The research literature shows that even if all components of a process are not efficient, the overall system can be efficient [35]. If we break down large operations into small processes, it helps to identify efficient and inefficient resources and the real impact of factors. For this reason, Farr and Grascop (2000) proposed the idea of NDEA model to solve these problems by considering the efficiency of small processes in calculating system performance [36]. The results show that the NDEA model is necessary to produce more accurate and reliable results especially when a DMU has network structure [35]. This technique is an advanced DEA model in which DMUs have a network structure. Recently, many NDEA models have been developed to evaluate and measure DMUs [37].

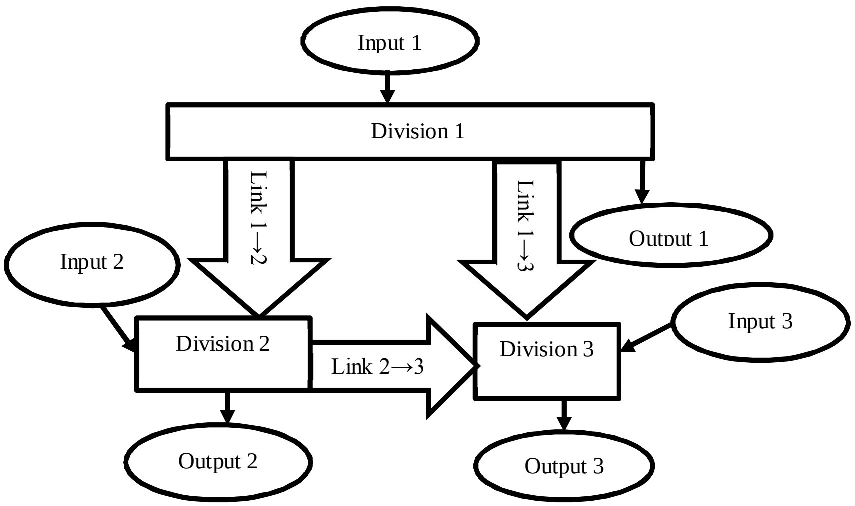

Fig. 5. Company with three linked divisions

For further explanation, we consider an example in Figure (5). Many companies are made up of several divisions. In fig.5, the DMU has three divisions. Each division has its own inputs and outputs, but there are also connection activities between divisions, which are shown as "1-2 link, link 1-3 and link 2-3" [11].

In traditional DEA models, there are at least two approaches to evaluating the performance of multi-divisions DMUs:

I) Black box: In this approach, to integrate the three divisions in Figure (5), the DMU uses "inputs 1, 2, and 3" to produce "outputs 1, 2, and 3", which can be seen in Figure (6). Using this approach, we ignore internal connection activities and therefore we cannot assess the impact of inefficiency of a division on the overall performance of the company [11]. These models do not pay any attention to the internal structure of the DMUs [38]. Black box approach has the lowest resolution between performance scores and the NDEA approach has the highest resolution between performance scores. In this approach, the effect of inefficiencies of a particular division on the overall efficiency of the DMU cannot be evaluated [35].

II) Separation: The second approach is to evaluate the performance of each division separately, as shown in Figure (7). In this approach we can evaluate the performance of each division of the DMU among the set of DMUs and therefore we can find the criteria for each division. However, this approach ignores the connections and continuity of communication between divisions [11].

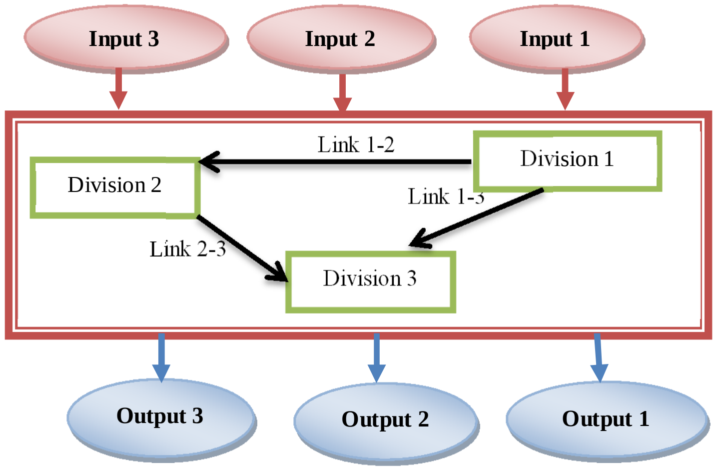

Fig. 6. Black box

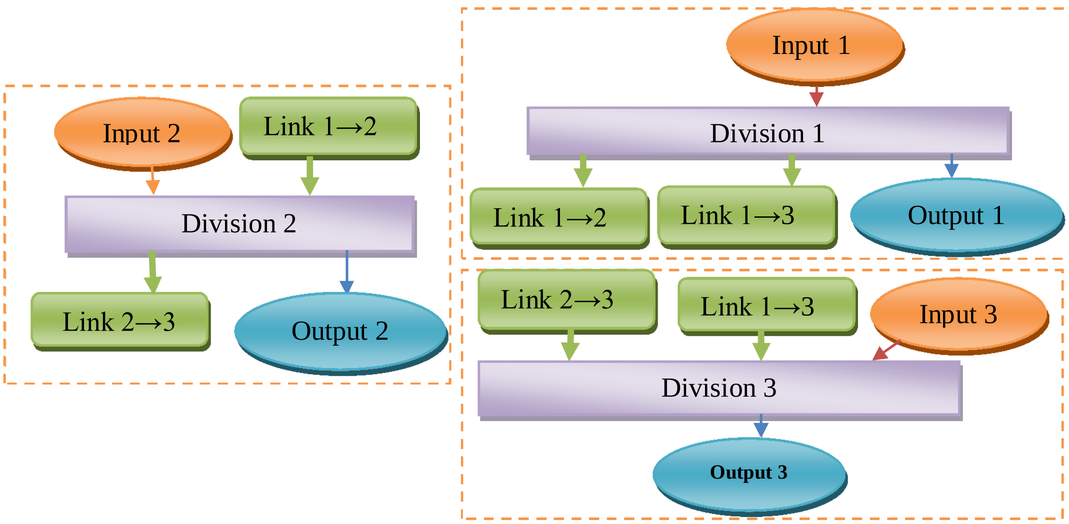

Fig. 7. Separation

Both methods are insufficient to evaluate the efficiency of connection processes in the organization [10]. These issues led researchers to develop a model of DEA called the NDEA, which calculates divisional efficiencies along with overall efficiencies in an integrated framework [35]. Network models are a generalization of classical models that also consider the internal structure of the units [38]. Therefore, in many cases, it may be necessary to examine the inefficiency of a DMU in its subdivisions [39].

Based on the information in this section, we conclude that performance evaluation through NDEA models is more complete and comprehensive than DEA models.

However, there are a variety of NDEA models, most of which evaluate the relative efficiency of DMUs [3].

5.2. Multi-objective programming (MOP)

The MOP is defined by a set of objective functions that must be optimized simultaneously and a set of constraints to be satisfied. This technique tries to combine the logic of optimization in mathematical planning with the decision maker's desire to satisfy several goals. It is a linear mathematical model that seeks the optimal achievement of goals in a “decision-making” environment. In general, it is rarely possible to achieve multiple goals with dry programming techniques. In such cases, achieving goal consistency that leads to a satisfactory solution is more important than an optimal solution [10].

Because in this study each DMU is composed of several subdivisions and each subdivision has its own objective function and our model intends to measure the productivity of DMU by considering connections of its subdivisions in one step and simultaneously, so, in this study, we will use the MOP method.

6.2. Related works

The previous studies on the productivity of DMUs through the NDEA approach are reviewed in this section. As mentioned in the introduction, these studies are few.

Rayeni and saljooghi [40] used the “NDEA approach and the Malmquist Productivity Index” between 2004 and 2009 to measure the efficiency and productivity of universities. The findings showed that the main factor in increasing productivity of universities is the progress in technical change. Azar et al. [23] evaluated the productivity of bank branches through efficiency and effectiveness by the NDEA approach in two steps. A two-stage NDEA model has been used in this research so that the output of the first stage is used as the input of the second stage. The first stage indicates efficiency and the second stage indicates effectiveness. One of the interesting results of this research is that the most efficient branch or the most effective branch is not necessarily the best branch in terms of productivity. Kao and Tai liu [8] propose a model based on the NDEA approach to measure the overall productivity of DMUs in a multi-period system.The overall productivity of 22 commercial banks has been measured through this model and also the Malmquist productivity index technique has been used to measure the efficiency changes between the two periods. Yang et al. [33] surveyed the efficiency and productivity of 64 Chinese universities from 2010 to 2013 using a “general two-stage network directional distance framework”. A “Luenberger productivity index-NDEA” model was used to measure efficiency changes over time. The results showed that the Luenberger productivity index of universities has increased significantly. Lu et al. [41] used the “NDEA approach and the Malmquist Productivity Index” to assess the productivity of the machine tool industry in Taiwan between 2010 and 2014. Their model can avoid overestimation and provide a more objective evaluation method than the traditional DEA model. Tavana et al. [42] used the “fuzzy NDEA approach and the Malmquist Productivity Index” to evaluate the dynamic performance of oil refineries in the presence of undesirable outputs. Their model has more advantages than traditional DEA approach due to its “four-year” time period. Ding et al. [43] first used NDEA approach to measure “overall efficiency, subsystem efficiency, and factor efficiency” of the industrial circular economy system. They then used the Malmquist productivity index method to dynamically evaluate productivity over time. The method proposed by them can finally break down the industrial circular system into four dynamic indicators and provide more details. Wang and Feng [44] used the “Total Factor Productivity Index and the NDEA approach” from 2004 to 2015 to assess the productivity of China's industrial system and industrial subdivisions to examine environmental pollution and energy consumption. They concluded that the overall productivity of the industrial system has improved over time.

Table (1) shows a summary of the above studies. It can be seen that the above studies measure the productivity of DMUs through productivity indicators such as “Malmquist productivity index and Luenberger productivity index”, or that they evaluate the productivity of DMUs through efficiency and effectiveness in two stages. For the reasons presented in Section 2.2, those studies that measure productivity through efficiency and effectiveness have more advantages than studies that measure productivity through productivity indicators. In addition, studies based on productivity indicators requires at least two time periods. Studies that measures productivity through efficiency and effectiveness is also two-stages. Also, the above studies do not have the feature of sensitivity analysis.

Therefore, as mentioned in the introduction, we are looking for an approach that measures the productivity of DMUs through efficiency and effectiveness in one stage, in a period, simultaneously and interdependently.

Tab. 1. Studies for measurement of productivity of DMUs through NDEA approach

number	reference	Research object	Methodology
1	Rayani and saljooghi (2010)	Productivity of universities	NDEA and Malmquist Productivity Index
2	Azar et al. (2014)	Productivity of bank branches	Two-stage NDEA, first stage for efficiency and the second stage for effectiveness
3	Kao and Tai liu (2014)	Overall productivity of 22 commercial banks	NDEA and Malmquist Productivity Index

4	Yang et al. (2018)	Inefficiency and productivity of 64 Chinese universities	Luenberger productivity index-NDEA model
5	Lu et al. (2021)	Productivity of the machine tool industry in Taiwan	NDEA approach and the Malmquist Productivity Index
6	Tavana et al. (2019)	Dynamic performance of oil refineries in the presence of undesirable outputs	Fuzzy NDEA approach and the Malmquist Productivity Index
7	Ding et al. (2020)	Overall efficiency, subsystem efficiency, and factor efficiency of the industrial circular economy system	NDEA approach and the Malmquist index method
8	Wang and feng (2020)	Productivity and eco-productivity of China's industrial system and industrial subdivisions	Total Factor Productivity Index and the NDEA approach

3. Experimental Procedure

Based on Section 3.2, the CCR model presented by Charles and Cooper [45] is in Equation (1):

$$Max\,E = \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{i=1}^{m} v_i X_{i0}} \qquad \text{Equation } (1)$$

$$s.t.\ \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \le 1, \qquad j = 1, 2, \ldots, n$$

$$u_r, v_i \ge \varepsilon \quad , r = 1, 2, \ldots, s;\ i = 1, 2, \ldots, m$$

The indices and parameters of this model are as follows:
In this model there are n DMUs (j= 1,2,…, n) under evaluation. Each DMU has m inputs (i=1,2,…, m) and s outputs (r=1,2,…, s), which are shown as “$X_{1j},X_{2j},\ldots, X_{mj}$” and “$Y_{1j},Y_{2j},\ldots, Y_{sj}$” respectively. The “objective function E” is maximized for every DMU Separately. The variables “u_r and v_i” are the weights of the outputs and inputs, respectively and ε is a “small non-archimedean number” for restricting the DMU to determinate 0 weight to unfavorable factors [46].

However, Equation (1) only measures the efficiency of DMUs. In order to be able to measure the productivity of DMUs through efficiency and effectiveness, it is necessary to formulate effectiveness in Equation (1). As discussed in Section 1.2, we can define effectiveness as follows:

$$\text{effectiveness} = \frac{\text{outputs}}{\text{goals}}.$$

We define the effectiveness of a DMU as follows:

$$\text{effectiveness of DMU}_0 = \frac{\text{weighted outputs of DMU}}{\text{weighted standard outputs (goals) of DMU}} = \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{r=1}^{s} \eta_r g_{r0}} \qquad \text{Equation } (2)$$

As discussed in Sections 1.2 and 2.2, productivity is the sum of efficiency and effectiveness; then the Equation (2) is incorporated in the Equation (3) as follows:

$$\text{Max } p = \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} + \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{r=1}^{s} \eta_r g_{r0}} \qquad \text{Equation } (3)$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \le 1, \qquad j = 1, 2, \dots, n$$

$$\frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{r=1}^{s} \eta_r g_{r0}} \le 1, \qquad j = 1, 2, \dots, n$$

$$u_r, v_i, \eta_r \ge \varepsilon, \; r = 1, 2, \dots, s; \; i = 1, 2, \dots, m$$

The Equation (3) says if p is equal to 2, then the DMU is productive and if it is less than 2, it is non-productive. The DMU may be efficient but not productive but if the DMU is productive, it will certainly be efficient. Using Equation (3), we can to measure productivity of DMUs through effectiveness and efficiency easily, in one stage, in a period, simultaneously and interdependently. As discussed in Section 4.2, through Equation (3), the productivity of DMUs can be evaluated in "black box" or "separation". In order to consider the internal connections of the subdivisions of a DMU, we deal with n DMUs consisting K divisions (k=1,2,…,K) as the Equation (4). The parameters "m_k and r_k" are the number of inputs and outputs from division k, respectively. The connection of division k to division h is shown as (k, h) and set of connections is shown by L. The observed input resources to DMU_j at division k are ($X_j^k \,\varepsilon\, R_+^{mk}$) (j=1,…,n; k=1,…,K); the output products from DMU_j at division k are ($y_j^k \,\varepsilon\, R_+^{rk}$) (j=1,…,n; k=1,…,K); the linking intermediate products from division (k) to division (h) are ($z_j^{(k,h)} \,\varepsilon\, R_+^{t(k,h)}$) (j=1,…,n; (k,h) ε L) where t(k,h) is the number of items in link (k,h).

$$Max\, E_0 = \sum_{k=1}^{K} (W_k E_0^k) \qquad \text{Equation } (4)$$

$$(\text{DMU: firm level})$$

$$Max\, E_0^k = \frac{\sum_{r=1}^{rk} u_r^k Y_{r0}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_k^h z_{op}^{(k,h)}}{\sum_{i=1}^{mk} v_i^k X_{i0}^k + \sum \forall (g,k) \sum_{q=1}^{t(g,k)} \omega_g^k z_{oq}^{(g,k)}}$$

$$k = 1, 2, \dots, K \; (\text{divisional level})$$

$$s.t. \quad \frac{\sum_{r=1}^{rk} u_r^k Y_{rj}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_k^h z_{jp}^{(k,h)}}{\sum_{i=1}^{mk} v_i^k X_{ij}^k + \sum \forall (g,k) \sum_{q=1}^{t(g,k)} \omega_g^k z_{jq}^{(g,k)}} \le 1 \qquad j = 1, 2, \dots, n; \; k = 1, 2, \dots, K$$

$$u_r^k, v_i^k, u_k^h, \omega_g^k \ge \varepsilon, r = 1, 2, \dots, ; \; i = 1, 2, \dots, ; \; all \; (k,h), \; (g,k) \; \varepsilon \; L$$

In the NDEA-MOP models, the objective function E_0^k measures the efficiency of division k at DMU_0 where the weighted links outgoing from division k "$u_k^h z_{jp}^{(k,h)}$, $\forall (k,h)$, p=1,…,t(k,h)" are regarded as the (intermediate) outputs of division k and the incoming inputs to division h "$\omega_g^k z_{jq}^{(g,k)}$". The overall efficiency E_0 of DMU_0 is defined as the convex combination "$Max\, E_0 = \sum_{k=1}^{K} (W_k E_0^k)$" of K efficiency scores, where W_k denotes the weight representing the relative contribution of division k.

Equation (4) evaluates the efficiency considering the connections between the subdivisions of a DMU. In case of evaluating the productivity of a DMU considering the internal interactions between its divisions, it is necessary to combine Equation (3) with Equation (4).

We define the effectiveness of division k in a DMU as Equation (5):

effectiveness of division k=

$$\frac{\text{weighted outputs of division k+weighted links outgoing from division k}}{\text{weighted standard outputs}\left(\text{goals}\right)\text{of division k+weighted links standard outgoing}\left(\text{goals}\right)\text{from division k}}$$

$$=\frac{\sum_{r=1}^{rk} u_r^k Y_{r0}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_h^k z_{0p}^{(k,h)}}{\sum_{r=1}^{rk} \eta_r^k g_{r0}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} t_h^k a_{0p}^{(k,h)}} \qquad \text{Equation } (5)$$

Where, $\eta_r^k g_{r0}^k$ is "weighted standard outputs (goals) of division k from DMU_0" and $t_h^k a_{0p}^{(k,h)}$ is "weighted links standard outgoing (goals) from division k in DMU_0".

We now formulate Equation (5) in Equation (4), and Equation (6) is extracted as follows:

$$Max\ p_0 = \sum_{k=1}^{K} (W_k\, p_0^k) \qquad \text{Equation } (6)$$

$$\left(\text{DMU: firm level}\right)$$

$$Max\ p_0^k = \frac{\sum_{r=1}^{rk} u_r^k Y_{r0}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_k^h z_{op}^{(k,h)}}{\sum_{i=1}^{mk} v_i^k X_{i0}^k + \sum \forall (g,k) \sum_{q=1}^{t(g,k)} \omega_g^k z_{oq}^{(g,k)}} + \frac{\sum_{r=1}^{rk} u_r^k Y_{r0}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_h^k z_{0p}^{(k,h)}}{\sum_{r=1}^{rk} \eta_r^k g_{r0}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} t_h^k a_{0p}^{(k,h)}}$$

$$k = 1, 2, \ldots, K \left(\text{divisional level}\right)$$

$$s.t. \quad \frac{\sum_{r=1}^{rk} u_r^k Y_{rj}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_k^h z_{jp}^{(k,h)}}{\sum_{i=1}^{mk} v_i^k X_{ij}^k + \sum \forall (g,k) \sum_{q=1}^{t(g,k)} \omega_g^k z_{jq}^{(g,k)}} \le 1 \qquad j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, K$$

$$\frac{\sum_{r=1}^{rk} u_r^k Y_{rj}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_h^k z_{jp}^{(k,h)}}{\sum_{r=1}^{rk} \eta_r^k g_{rj}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} t_h^k a_{jp}^{(k,h)}} \le 1 \qquad j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, K$$

$$u_r^k, v_i^k, u_k^h, \omega_g^k, \eta_r^k, t_h^k \ge \varepsilon,\ r = 1, 2, \ldots, ;\ i = 1, 2, \ldots, ;\ all\ \left(k,h\right), \left(g,k\right)\ \varepsilon\ L$$

The Equation (6) says if P_0 is equal to 2, then the DMU is productive considering the internal links of its divisions. The DMU may be efficient but not productive. Also, if p_0^k is equal to 2, the division k is productive in the intended DMU. It is possible that the intended division be efficient but not productive.

In this section, we formulate a model that, unlike other studies, can measure the productivity of DMUs by considering the connection of their subdivisions through effectiveness and efficiency easily, in one stage, in a period, simultaneously and interdependently.

1.3. The proposed model solving process

To ensure the solvability, two extra constraints are added for each division k in DMU_o to transform the fractional DEA model into a linear programming model According to the solution provided by Charnes and Cooper as Equation (7) [45].

$$\sum_{i=1}^{mk} v_i^k X_{i0}^k + \sum \forall (g,k) \sum_{q=1}^{t(g,k)} \omega_g^k z_{oq}^{(g,k)} = 1 \quad \text{Equation } (7)$$

$$\sum_{r=1}^{rk} \eta_r^k g_{r0}^k + \sum \forall \left(k,h\right) \sum_{p=1}^{t(k,h)} t_h^k a_{0p}^{(k,h)} = 1$$

Therefore, the linear model of Equation (6) is obtained as Equation (8):

$$Max\ p_0 = \sum_{k=1}^{K} (W_k p_0^k) \quad \text{Equation } (8)$$

$\left(\text{DMU: firm level}\right)$

$$Max\ p_0^k = \sum_{r=1}^{rk} u_r^k Y_{r0}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_k^h z_{op}^{(k,h)} + \sum_{r=1}^{rk} u_r^k Y_{r0}^k + \sum \forall \left(k,h\right) \sum_{p=1}^{t(k,h)} u_h^k z_{0p}^{(k,h)}$$

$$\sum_{i=1}^{mk} v_i^k X_{i0}^k + \sum \forall (g,k) \sum_{q=1}^{t(g,k)} \omega_g^k z_{oq}^{(g,k)} = 1$$

$$\sum_{r=1}^{rk} \eta_r^k g_{r0}^k + \sum \forall \left(k,h\right) \sum_{p=1}^{t(k,h)} t_h^k a_{0p}^{(k,h)} = 1$$

$k = 1, 2, \ldots, K \left(\text{divisional level}\right)$

$$s.t. \quad \sum_{r=1}^{rk} u_r^k Y_{rj}^k + \sum \forall (k,h) \sum_{p=1}^{t(k,h)} u_k^h z_{jp}^{(k,h)} - \left(\sum_{i=1}^{mk} v_i^k X_{ij}^k + \sum \forall (g,k) \sum_{q=1}^{t(g,k)} \omega_g^k z_{jq}^{(g,k)}\right) \le 0$$

$j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, K$

$$\sum_{r=1}^{rk} u_r^k Y_{rj}^k + \sum \forall \left(k,h\right) \sum_{p=1}^{t(k,h)} u_h^k z_{jp}^{(k,h)} - \left(\sum_{r=1}^{rk} \eta_r^k g_{rj}^k + \sum \forall \left(k,h\right) \sum_{p=1}^{t(k,h)} t_h^k a_{jp}^{(k,h)}\right) \le 0$$

$j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, K$

$$u_r^k, v_i^k, u_k^h, \omega_g^k, \eta_r^k, t_h^k \ge \varepsilon,\ r = 1, 2, \ldots,;\ i = 1, 2, \ldots,;\ all\ \left(k,h\right),\ \left(g,k\right)\ \varepsilon\ L$$

Because there is one objective function for each division in a DMU, thus the proposed model is MOP. Based on the fuzzy approach proposed by Zimmermann [47], The following algorithm has been developed to solve Equation (8):

Step1: Every objective is optimized independently of other objectives. For DMU_o, we maximize p_0^k, (k=1,…,K) individually to determine their ideal objective values, p_0^{k*}, (k=1,…,K).

Step 2: Every objective is computed in the opposite way regardless of other objective. We minimize p_0^k, (k=1,…,K) to determine their anti-ideal solution p_0^{k-}, (k=1,…,K).

Step 3: define the membership function of every objective by its ideal and anti-ideal solutions as follows:

$$up_0^k(p_0^k) = \frac{p_0^k - p_0^{k-}}{p_0^{k*} - p_0^{k-}}$$

Step 4: maximize the minimal membership function for all objectives as Equation (9):

$$Max = \alpha \quad \text{Equation } (9)$$

$$s.t. \quad \alpha \le up_0^k(p_0^k), \quad k = 1, 2, \ldots, k$$

$$all\ original\ constrains$$

So that α is the minimum of all member functions that are maximized. Each division in the DMU_0 can be evaluated simultaneously and the overall score $p_0 = \sum_{k=1}^{K} (W_k p_0^k)$ is evaluated for the DMU_0.

As regard to the linking constraints, we have two possible cases [10, 11]:

I) Free link: In this case, the connections between the divisions are freely determined in order to maintain the continuity between the input and output.

II) Fixed link: In this case, the connections between the divisions remain unchanged. This case is used when the interconnection activities between divisions are not under the control of the DMU.

The free link scenario will be considered in this study. In other words u_h^k is the weight of the connection $z_{jp}^{(k,h)}$ in the division k and ω_g^k is the weight entered to the link $z_{jq}^{(g,k)}$ in the division g for the model which is discretionary and freely incorporated in the optimal model.

As a result, in this section, the MOP technique was used to link the divisions of a DMU. This model has the ability to analyze sensitivity because it is linear programming.

4. Results

This section presents the experimental study on the branches of bank. Scientific research has increased significantly on the performance evaluation of financial institutions in recent years [48]. The banking plays the role of mediator between the net savers and net borrowers [32]. The efficiency and quality of services provided by banks not only have a significant impact on economic growth but also play a very important role in the daily life of each individual [49]. Therefore, analyzing the performance of banking industry and identifying techniques for evaluating these industry, has become the focus of managers, policymakers, economists, institutions and academic researchers [7, 50].

By reviewing the literature on evaluating the performance of banks, we find that there are several methods for this purpose, such as “financial ratio analysis, regression analysis, and frontier efficiency analysis” [51]. The financial ratios analysis (such as return on assets, loans to assets, loans per employee, deposits per employee and cost to income) [52] and the regression analysis, although have a significant impact in many areas of business but they have limitations that make them unsuitable for evaluating the performance of bank branches. Some limitations of these methods are: “failure to use multiple inputs and outputs in each evaluation”, “need to a special function to identify different aspects of bank branch operations” and “inability to consider all variables” [51, 53] (for further information on the limitations of these methods, see references [51], [52], and [53]). The frontier efficiency method evaluates the performance of the branch in comparison with the best branch in terms of performance. One of the methodologies for this method can be DEA [51]. Referring to the advantages of the DEA technique in Section 3-2, it can be stated that this technique does not have the limitations of the previous two methods. Also, this method has been used successfully to evaluate the performance of banks and numerous studies have been conducted on measuring the performance of banks by this method [53, 54]. Another reason for using DEA technique in evaluating the performance of banks is its ability to adapt to small sample sizes and application of categorical variables. This advantage is especially important for banking datasets which are small in nature [7, 55].

The choice of inputs and outputs is perhaps the most important activity in employing NDEA to measure the efficiency and productivity of DMUs. Most previous studies are limited to a single dimension of banks performance and do not fully reflect the overall performance of the branches of bank. The present study will consider two divisions for a branch. Then, branches are considered as a series of productive sequential processes which convert human and physical resources to financial benefits. There are two main approaches to determine inputs and outputs in this study. One of which is the production approach and the other is intermediation approach. In the production approach, banks are as a firm to produce deposits by employing labor, fixed assets and non-operational expenses. In intermediation approach, banks are considered financial intermediaries that transform deposit and operational expenses into interest and non-interest income [48]. The deposits are therefore the output for the production approach and the input for the intermediation approach, which is the connection activity mentioned in the previous descriptions. There is no interest income on production approach due to the fact that only the operational process is considered in it. The deposits are one of the major outputs of this stage [56]. The bank accepts deposits from customers, converts them into loans and gives applicants and earns money in intermediation approach. Also, financial resources (deposits) and operational costs are considered as inputs in this approach, because deposits are the most important raw materials, transformed in the financial intermediation processes [35]. Incomes and other "income-generating" activities are also output [57, 58].

The network performance process in the banking industry is shown in Figure 8 according to the conducted research in this area. In division 1, which is based on the production approach, the inputs such as "number of employees, assets and non-operational costs" (including personnel costs, general and administrative costs, awards and promotions, etc.) are consumed to generate the deposits. The "operating costs (including the interest costs) and the deposits generated from division 1" are the inputs for division 2 (intermediation approach). Interest incomes and non-interest income are outputs of division 2.

The research data, related to Maskan Bank Branches by Zarei Mahmoudabadi [35], are provided in Table (2). The data were non-scaled using the norm $n_{ij} = \frac{a_{ij}}{\sum a_{ij}}$ [59]. The columns related to the goals indicate the standard output (goal) against the actual output.

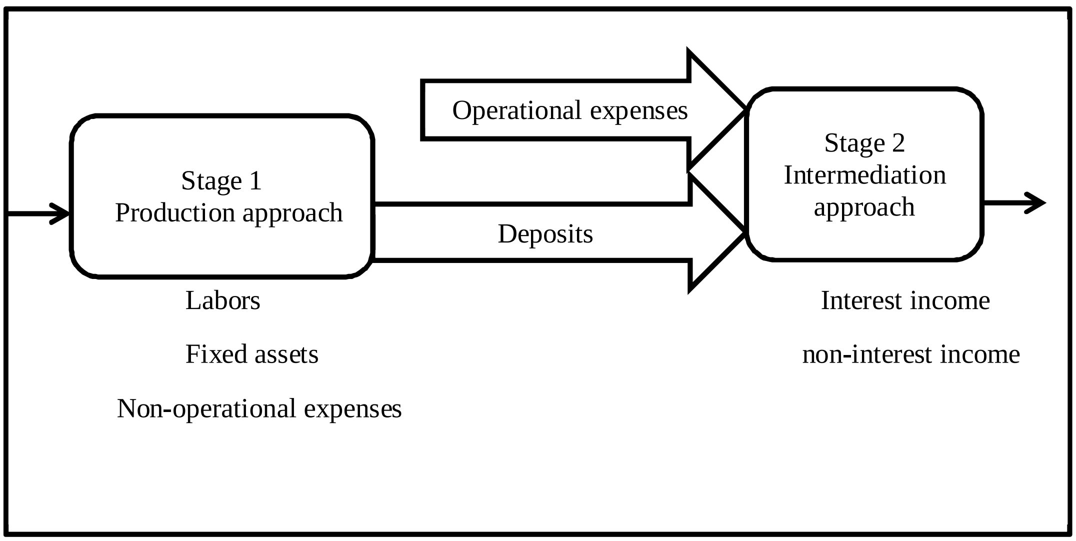

Fig. 8. Network process for banking industry performance evaluation

Tab. 2. The bank branches performance evaluation data

DMUs	Division1			Link 1-2		Division2				
	Input1	Input2	Input3	Actual	Goal	Input1	Output1	Goal1	Output2	Goal2
1	0.0543	0.0476	0.0764	0.0405	0.0400	0.0403	0.0445	0.0500	0.1038	0.1000
2	0.0870	0.0878	0.0905	0.1219	0.1000	0.1159	0.0806	0.0800	0.1331	0.1000
3	0.0543	0.0770	0.0762	0.0999	0.1000	0.1028	0.0719	0.0700	0.0918	0.1000
4	0.0652	0.0338	0.0534	0.0480	0.0400	0.0511	0.0330	0.0300	0.0536	0.0600
5	0.0435	0.0502	0.0475	0.0511	0.0500	0.0511	0.0523	0.0500	0.0367	0.0400
6	0.0435	0.0400	0.0459	0.0244	0.0300	0.0233	0.0430	0.0400	0.0264	0.0300
7	0.0543	0.0361	0.0422	0.0361	0.0400	0.0343	0.0370	0.0400	0.0432	0.0400
8	0.0543	0.1069	0.0628	0.0674	0.0700	0.0812	0.1006	0.1000	0.0605	0.0600
9	0.0652	0.0494	0.0601	0.0552	0.0600	0.0537	0.0489	0.0500	0.0448	0.0500
10	0.0543	0.0811	0.0593	0.0624	0.0600	0.0652	0.0863	0.0900	0.0511	0.0500
11	0.0652	0.0457	0.0610	0.0647	0.0700	0.0640	0.0451	0.0500	0.0456	0.0500
12	0.0435	0.0320	0.0344	0.0352	0.0400	0.0342	0.0347	0.0300	0.0382	0.0400
13	0.0543	0.0466	0.0461	0.0480	0.0500	0.0411	0.0435	0.0400	0.0677	0.0700
14	0.0652	0.0719	0.0531	0.0568	0.0500	0.0601	0.0805	0.0800	0.0590	0.0600
15	0.0435	0.0335	0.0411	0.0349	0.0400	0.0319	0.0384	0.0400	0.0296	0.0300
16	0.0543	0.0498	0.0488	0.0597	0.0600	0.0545	0.0488	0.0500	0.0395	0.0400
17	0.0435	0.0422	0.0395	0.0438	0.0500	0.0407	0.0400	0.0400	0.0366	0.0400
18	0.0543	0.0683	0.0572	0.0499	0.0500	0.0547	0.0709	0.0700	0.0388	0.0400

1.4. The results of bank branches efficiency evaluation using NDEA-MOP approach:

The Equation (4) and the fuzzy approach proposed by Zimmermann (see the Equation (9) in section 1.3) have been used in this section to evaluate the efficiency of bank branches. The overall efficiency is calculated based on the weighted average of the efficiency scores of the subdivisions. Based on experts and managers opinions in the bank branches, the importance weight of subdivisions 1 and 2 is equal (w1=w2=0.5); then, the overall efficiency is obtained using the relation $0.5\times p_0^1+0.5\times p_0^2$. The results of this evaluation provided in Table (3).

The second and fourth columns of Table (3) show the efficiency of the subdivisions of the bank branches separately and the sixth column shows the overall efficiency of them with respect to the connection of their subdivisions by the MOP method. If we look closely at Table (3), we find that if both subdivisions of a branch in conjunction with each other are efficient, then it will be efficient. Relying on the efficiency of a subdivision, it cannot be said that the branch is efficient. The branch 8 is known as the most efficient DMU, because the efficiency percentage of both its subdivisions in conjunction with each other is high. These results raise the need to deal with DMUs in a network approach in DEA.

Tab. 3. The results of bank branches efficiency evaluation using NDEA-MOP approach ((Equation (4) and (9))

DMUs	Efficiency (division1)	Rank (division1)	Efficiency (division2)	Rank (division2)	Overall Efficiency	Overall Rank
1	0/6078	17	1	1	0.8034	3
2	1	1	0.5295	14	0.7647	6
3	1	1	0.5035	17	0.7517	8
4	1	1	0.5286	15	0.7643	7
5	0.8206	7	0.5987	11	0.7097	17
6	0.4374	18	1	1	0.7187	14
7	0.7154	13	0.7109	8	0.7132	16
8	0.8186	8	0.8469	3	0.8328	1
9	0.7965	11	0.5561	13	0.6763	18
10	0.8026	10	0.7848	6	0.7937	4
11	1	1	0.4507	18	0.7254	12
12	0.7962	12	0.6551	10	0.7257	11
13	0.7942	14	0.7846	7	0.7894	5
14	0.8159	9	0.8378	4	0.8269	2
15	0.7420	15	0.6922	9	0.7171	15
16	0.9331	5	0.5222	16	0.7277	10
17	0.8458	6	0.5952	12	0.7205	13
18	0.6654	16	0.8062	5	0.7358	9

2.4. The results of bank branches productivity evaluation using NDEA-MOP approach:

The overall productivity of the bank branches is evaluated by Equation (8) and the fuzzy approach proposed by Zimmermann (see Equation (9) in section 1.3) in this section. The evaluation results are provided in Table (4). The branch 8 was known as the most efficient branch in Table (3), but it is not the most productive branch, because in Table (4) the most productive branch is Branch (14). This is due to the effectiveness formula in the model. This shows that the most efficient branch is not necessarily the most productive branch.

Tab. 4. The results of bank branches productivity evaluation using NDEA-MOP approach ((Equation (8) and (9))

DMUs	Productivity Division1	Rank Division1	Productivity Division2	Rank Division2	Overall Productivity	Overall Rank
1	1.2174	17	2	1	1.6087	3
2	2	1	1.0590	14	1.5295	6

3	1.6390	4	1.0070	17	1.3230	15
4	1.9688	2	1.0572	15	1.5130	7
5	1.6411	3	1.1973	11	1.4192	11
6	0.8749	18	2	1	1.4374	10
7	1.4541	13	1.4218	8	1.4379	9
8	1.5797	8	1.6939	3	1.6368	2
9	1.5094	11	1.1121	13	1.3107	17
10	1.6053	7	1.5695	6	1.5874	4
11	1.5165	10	0.9015	18	1.2090	18
12	1.4438	12	1.3102	10	1.3770	13
13	1.5751	9	1.5692	7	1.5721	5
14	1.6318	6	1.6756	4	1.6537	1
15	1.4315	15	1.3845	9	1.4080	12
16	1.6325	5	1.0445	16	1.3385	14
17	1.4372	14	1.1903	12	1.3137	16
18	1.3308	16	1.6125	5	1.4716	8

5. Discussion and Conclusion

A NDEA-MOP Approach proposed in this study to evaluate the productivity of DMUs. Compared to other approaches, this approach is able to evaluate the productivity of DMUs according to the connection and conjunction of their subdivisions through efficiency and effectiveness in one stage, in a period, simultaneously and interdependently. All the approaches presented in Table (1) require at least two time periods or must evaluate the productivity of decision units in two stages. As a result, in these time periods or in these stages, the connection and conjunction between the subdivisions of the DMUs may be difficult. The effectiveness formula in this approach is also the second advantage of this study. Through this formula, the DMU can be aware of the amount of achievement of its goals, but in the mentioned studies, this is not possible. In other words, the DMU incorporates its predetermined goals into productivity calculations. This provides another advantage for the DMU. This advantage is in the sensitivity analysis of the model, so that through sensitivity analysis, it can be understood that by changing the amount of predetermined goals, what change will occur in the amount of productivity of the DMU and its subdivisions.

Finally, with the proposed approach, we find that a DMU may be efficient through the black box approach but not efficient considering its subdivisions. It is also possible for a DMU to be efficient by considering its subdivisions separately but not by considering the conjunction between its subdivisions. In addition, a DMU may be efficient by considering the conjunction between its subdivisions but not productive. This means that if the effectiveness is also entered in the NDEA approach, it is possible to provide a complete model of NDEA based on the productivity. Based on the obtained results, it is possible to simultaneously evaluate the productivity of different DMUs using the proposed model, considering the connection of their internal divisions.

Some suggestions for future research, based on the results of this research include:

- Considering that the model proposed in this study is based on the CCR approach, it can also be implemented using the BCC approach.
- The model proposed in this study is based on a free link that further studies can be done considering fixed link.
- The model parameters are all quantitative and precise, which can be considered as qualitative and imprecise in case of using fuzzy approach.
- The proposed model can be applied in an organization and sensitivity analysis can be performed in it.

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