International Journal of Industrial Engineering & Management Science, Vol. 8, Issue 2, (2020) 36-44

University of Hormozgan

International Journal of Industrial Engineering & Management Science

journal homepage: www.ijiems.com

A Hybrid Modeling Approach for Measuring Efficiency of Organizations Considering Dynamic Effects

Seyed Javad Salehzadeh [a,*], Seyed Farzad Hoseini [b], Ahmadreza Zareian[a], Ali Shahandeh[a]

[a] *Industrial Engineering and Systems Department, Isfahan University of Technology, Isfahan, Iran*
[b] *Industrial Engineering Department, Faculty of Engineering, University of Hormozgan, Bandar Abbas, Iran*

ARTICLE INFO

Article history:
Received: 2021-02-05
Received in revised form: -
Accepted: 2021-03-17

Keywords:
Input Output
Performance Evaluation
Dynamic Effects
DEA
BSC

ABSTRACT

Performance evaluation and feedback systems are two important factors in success of any organization. One of the newest and most applicable methods to evaluate performance of systems is Network Data Envelopment Analysis. This method considers the system as a network where after a series of interactions, inputs are transformed into intermediate products, and eventually come out from system as the final products. On the other hand, Balanced Scorecard, as an influential evaluation method, is used to evaluate and execute strategies of organizations successfully. In recent years, a new method has been developed based on combination of these two methods to evaluate performance of organizations. Such studies mainly concentrate on use of BSC and classical DEA without considering the links between the units and the effects of performance during different time periods (dynamic effects). In this paper, a combinatorial approach is presented which is able to measure efficiency of organizations during various time periods based on BSC. This approach enables organizations to compare their performances in different periods and detect inefficient resources to make appropriate decisions and achieve higher performances. Finally, to evaluate the efficiency of the proposed model a numerical example is presented.

1. Introduction

Nowadays, organizations and companies are major parts of human societies. Some of them experience a short time of existence and some last up to hundreds of years. Some of them become the source of enormous changes and some sink among the waves of the competitive markets.

In free and competitive markets, at least three basic factors are needed to succeed: achieving necessary resources to perform operations, having appropriate technologies to transform the data into the needs of the market, and success in presenting products and services to the target markets and final customers. In this situation, being informed of the performance of organization can be helpful for managers to get success.

Performance evaluation is a process which measures, and makes judgments about the performance of an organization during a determined period. If performance evaluation be done on the basis of a procedural approach and in a correct continual way, then it will help organizations to promote their performance. Today, most organizations spend considerable amount of time, energy, and resources to evaluate their performance in order to achieve their strategic goals. But studies show that traditional performance evaluation systems do not conform to the dominant mechanisms of modern organizations and are not capable of evaluating intangible assets such as knowledge of staff, relation of the organization with the customers and suppliers, and innovative cultures.

On the other hand, although in the new world of business, pivotal strategy has become important than any other time before but, just few organizations have been successful in implementing their strategies. But recently, balanced scorecard (BSC) method has been useful as an effective tool to recognize, explain, and

* Corresponding author.
E-mail address: j.salehzadeh@gmail.com

translate intangible assets into real perceptive values for the stakeholders of organization and also it helps strategies to be implemented successfully.

From introduction of BSC in 2004 as a new performance evaluation method, lots of companies have adopted this method and have become literally successful beside implementing their strategies [1]. Another method which is highly utilized in evaluating performance of organizations is Data Envelopment Analysis (DEA). This method considers inputs and outputs of the organizations accompanied with their relations and then use mathematical programming models to evaluate organizational performance. Benefits of this method compared to the previous methods has made this method more applicable.

In recent years, a new organizational evaluation method based on combination of BSC and DEA has been constructed. But these studies concentrate on methods based on BSC and classical DEA without considering relations among units and effects of performance in different time periods. This research aims to propose an appropriate method to measure performance of the organizations based on network structures and considering dynamic effects in different periods of time.

In the following sections, network DEA, BSC, and their combination are discussed and then dynamic effects is studied in the section 2. In the section 3, a hybrid method to measure the performance accompanied with dynamic effects is proposed. At the end, in the sections 4 and 5, an illustrative example and conclusions are represented, respectively.

2. Background

2.1. Network Data Envelopment Analysis

The classical DEA was firstly introduced by Farrel (1957) [2], and then was developed by Charnes (1978) [3]. Then, as there were some problems in the results of the classic method, network-based model called Network DEA was introduced. In fact, Network DEA portraits the whole organizational relations as a model and then measures its performance. For the first time, Fare in 2000 introduced Network DEA [4]. Sexton (2003), proposed DEA for measuring double-staged and complicated structures [5]. Pieto in 2007 compared technologies fitted to different economies using potential technical efficiency [6].

Yu and Lin (2008), provided a multi-activity network data envelopment analysis model that represents both production and consumption technologies in a unified framework [7]. Kao (2009), proposed a model that any network system is transformed into a serial system using a virtual process where each stage of this serial system consists of a parallel structure; as a result based upon serial and parallel structures, efficiency of the production system is calculated based on the efficiency of the serial stages [8]. Also, inefficiencies of each stage in these series is the summation of inefficiencies of small processes which are linked together in a parallel manner.

An issue in the field of network DEA is considering the effects of several time periods or dynamic effects. Sengupta, presented a paper in order to evaluate dynamic efficiency in 1999 [9]. Nemoto (2003), proposed a model in which dynamic conditions and their effects on efficiency of production facilities are studied [10]. Study performed by Chen (2009), is known as one of the most important activities in this field [11]. In this study, he has analyzed dynamic effects in production networks.

Chen (2012), studied application of a relational network data analysis envelopment to the systematic evaluation of the innovation efficiency of China's regional innovation systems by decomposing the innovation process into the two connecting sub-processes, technological development and subsequent technological commercialization [12]. Khalili-Damghani (2013), developed a new network DEA model for measuring the performance of agility in supply chains. The uncertainty of the input and output data is modeled with linguistic terms parameterized with fuzzy sets [13]. Mirhedayatian (2014), proposed a novel network DEA model for evaluating the Green Supply Chain Management in the presence of dual-role factors, undesirable outputs, and fuzzy data [14].

2.2. Balanced Scorecard

As we mentioned before, he initial idea of the BSC model was proposed by Kaplan (1992) [15].The Philosophy behind this method is based upon transforming vision, mission and strategy of organization into objectives and appropriate measures. This method covers financial and non-financial performance aspects of organization and constructs a balanced framework between financial and non-financial aspects which leads to make organizational goals more transparent and to increase cooperation among managers. Kaplan, suggested that the managers should collect some information in a card about four perspectives. These perspectives consist of financial, customer, internal processes, and learning perspectives and then, this information should be analyzed [15].

The financial perspective acts as the focus for entire evaluation. BSC long-term financial goals and measures should play two roles in balanced evaluation. First, they should define the expected financial performance of the strategy. Second, they should act as the final goal of measures and the determined goals of the other approaches. Then in customer perspective, organizations and companies try to detect customers and those parts of market to compete within them. Customer perspective attracts organizations to integrate general measures such as satisfaction, loyalty, attraction, and benefits of customers and target markets.

The third perspective is internal processes of business. In this perspective, those processes which are important in achieving financial goals are detected. In balanced scorecard method it is recommended that a complete value chain be defined for internal processes. This value chain begins with innovation process and continues with operational processes, and eventually, ends with after sales services. Process of designing goals and measures in internal processes view reveals one of the deepest differences between balanced scorecard and traditional performance evaluation systems. Of course, organizations strive to increase quality measures, efficiency, and cycle times in their performance evaluation systems; but although this can be an improvement, however most practices are used for separated units' improvement without considering an integrated business process. Nowadays, having multiple measures for continuous multi-purpose processes is an important point for most organizations and companies. Some activities such as improvements in cycle time, quality efficiency, and cost reduction cannot lead organizations to a unique eligibility. Such activities may be helpful in temporal omission of competitors and survival of the organization for now; but will not lead to an important competitive merit to guarantee long time survival of the organization.

The fourth perspective in balanced scorecard is growth and learning which is in charge of developing goals and learning stimulations for the organization. The determined goals in growth and learning perspective construct infrastructures that can be accessed by the goals set by the prior perspectives.

Norton and Kaplan presented three main sets for the growth and learning perspective:

1. Capabilities of employees.
2. Capabilities of information systems.
3. Strengthening, motivating, and integrating the employees.

One of the main changes in managerial thinking during the last 15 years has been in the change of roles of employees in organizations. Today, almost the whole iterative works are automatically performed by machines. Moreover, performing a task in a constant level of productivity is no more sufficient for success of companies. If an organization intends to maintain its current performance level, it should improve itself continuously. Needed ideas for improving processes should be nourished by the employees working in the front line who are the closest people to internal processes and customers of the organization [1].

2.3. Combination of BSC and DEA

Combination of BSC and DEA is a new approach in measuring the performance of organizations and determining the improvement path. Many researchers have implemented this hybrid approach to evaluate companies. Chen (2008), employed a data envelopment analysis framework using four kinds of performance indices selection, which include basic input/output items, balance scorecard indices, balanced scorecard with risk management, and traditional financial indices, to evaluate banking operations [16].

Rouse (2002), in the division of engineering services in an international airport, devised a performance evaluation system based on mathematical programming methods in which BSC approach has been used. Also in order to allocate the numerical values to the changes during continual improvement process, DEA was adopted [17]. Banker (2004), proposed a method in their paper in which by using DEA, existing fields in the BSC are investigated and then the fields where a tradeoff should be made among, were determined [18]. Eilat (2006), presented a method to build and analyze efficient and balanced portfolios from Research and Development (R&D) projects in which by using an extensive DEA model, qualitative concepts existing in the BSC were transformed into quantitative values [19]. Afterwards, this research group reported the results of a case study about using a new multiple attribute method in an industrial lab [20]. A similar case study was performed by [21] on 90 active companies working in the field of R&D projects. A model proposed by [22] solved the problem of selecting IT projects from existing portfolios where BSC was used as a framework to define evaluation measures of IT projects. In this research, DEA was used to rank the projects.

Amado (2012), developed a conceptual framework which aims to assess Decision Making Units (DMUs) from multiple perspectives. The proposed conceptual framework combines the Balanced Scorecard method with Data Envelopment Analysis DEA by using various interconnected models which try to encapsulate four perspectives of performance [23]. Shafiee (2014), applied a network DEA with BSC approach to evaluate the performance of supply chain. at first, all relationships between the four perspectives of BSC determined and then the DEMATEL approach employed to obtain a network structure. Since it was not possible to calculate the efficiency evaluation score by BSC, the data envelopment analysis model was used for such an evaluation [24].

Hatefi (2019), used balanced scorecard for determining performance indicators in hospitals and fuzzy data envelopment analysis for assessing the efficiency score of hospitals [25]. The use of BSC measures reflects the overall strategic objectives of the hospitals in the performance evaluation process. They depicted that, applying the BSC and fuzzy DEA methods provided a comprehensive performance assessment tool for hospitals. Sarraf (2020), evaluated the performance and ranked water and wastewater companies by using grey relational analysis and data envelopment analysis approaches based on balanced scorecard criteria [26]. Shafiee (2020), proposed a new method of project performance evaluation, by which project performance data can be better, understood and combines Balanced Scorecard and data envelopment analysis approaches to enhance the efficiency of decision-making units more accurately [27].

2.4. Dynamic Effect

In real world lots of cases can be found where the output of a sub-unit is consumed in several time periods. As an example, effectiveness of inter-organizational training courses doesn't have the same impacts on the productivity of different people and it happens in several periods such as long-term or short-term ones. This situation where the output of a sub-unit is consumed during several periods of time is called dynamic state. In Figure 1, two sub-units A and B belonging to the decision making unit j are displayed. Here j has dynamic effects. If $z_{AB}^{jt_0}$ is the intermediate output of the sub-unit A in period t_0 and $\alpha z_{AB}^{jt_0}$ $(0 \leq \alpha \leq 1)$ is the percentage of the intermediate output consumption in t_0, then $(1-\alpha) z_{AB}^{jt_0}$ demonstrates the remaining output to be used in the sub-unit B during future time periods (such as t_1). In reality, it happens a lot that storage conditions for a good is not always fixed. Therefore, inventory level during a time period is not fixed and is accompanied by decreasing in quality and amount of the good. Hence, a coefficient called drop is usually used to push the model closer to the reality. Here this coefficient I represented by β. Also in a network there could be several dynamic effects.

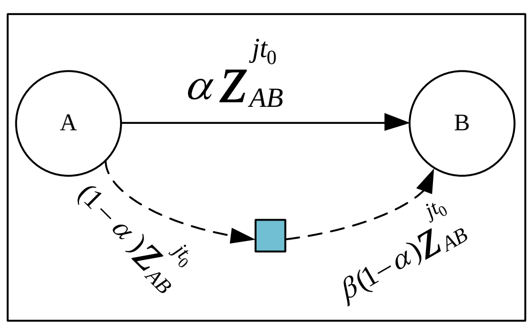

Fig. 1. Dynamic Link

As noted before, classic models which try to combine BSC and DEA have some weaknesses beside their merits. As an instance, these models do not consider time delays of some perspectives' output effects such as growth and learning perspective. For example, in the field of human capital and information lots of capitals are being invested but positive effects of such investments on the outputs appears several periods later. Another issue which has not been overlooked in former studies is the efficiency of BSC or in other words, the entire decision-making unit. So, in order to tackle this drawback, an appropriate and dynamic structure should be adopted. In the following section, an appropriate network structure is proposed and several mathematical programming models have been pointed out to measure the efficiency of the presented structures.

3. The proposed method

In this section, a hybrid method based on BSC and Network DEA is proposed in three different states. at first, some notifications are made about how dynamic links and network structures can be modeled along with the assumption of the models. Then the developed models are represented in order to calculate efficiency of networks.

3.1. Dynamic Link

As noted before, a condition where the output of a sub-unit is consumed during several time periods is called dynamic condition. In order to model the dynamic link, a virtual unit is defined in the first time period. Therefore, the dynamic link acts as the input of the virtual unit and the allocated values act as the output of the virtual unit in different periods.

The definition of the virtual unit has several merits including:

1. Dynamic effects are transported to the next periods.
2. β will be influential on the overall efficiency of the organization. Its proof is straightforward. Output decrease resulted from drop coefficient affects the efficiency of the virtual unit and then according to considering the virtual unit in the calculations, these effects is induced through the entire organization.
3. The whole links are used in calculations as integers.

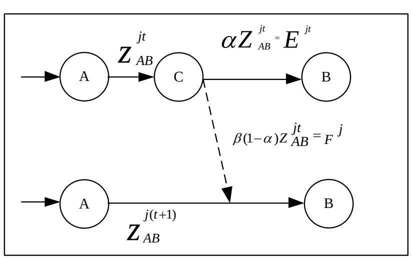

Fig. 2. A dynamic link after defining virtual unit

Therefore, the structure represented in Figure 1 after adding virtual unit is considered in the form of Figure 2, then dynamic constraints in the second condition will be as below:

$$z_{AB}^{jt} \le \sum_{s=1}^{n} z_{AB}^{st}\lambda_{As}^{t} \quad (1)$$

$$z_{AB}^{jt} \ge \sum_{s=1}^{n} z_{AB}^{st}\lambda_{Cs}^{t} \quad (2)$$

$$F^{j} \le \sum_{s=1}^{n} F^{s}\lambda_{Cs}^{t} \quad (3)$$

$$E^{jt} \le \sum_{s=1}^{n} E^{st}\lambda_{Cs}^{t} \quad (4)$$

$$E^{jt} \ge \sum_{s=1}^{n} E^{st}\lambda_{Bs}^{t} \quad (5)$$

$$\sum_{s=1}^{n} z_{AB}^{st}\lambda_{As}^{t} = \sum_{s=1}^{n} z_{AB}^{st}\lambda_{Cs}^{t} \quad (6)$$

$$z_{AB}^{j(t+1)} + F^{j} \ge \sum_{s=1}^{n}(F^{s} + z_{AB}^{s(t+1)})\lambda_{Bs}^{(t+1)} \quad (7)$$

$$z_{AB}^{j(t+1)} \le \sum_{s=1}^{n} z_{AB}^{s(t+1)}\lambda_{As}^{(t+1)} \quad (8)$$

$$\sum_{s=1}^{n} E^{st}\lambda_{Cs}^{t} = \sum_{s=1}^{n} E^{st}\lambda_{Bs}^{t} \quad (9)$$

$$\sum_{s=1}^{n} z_{AB}^{s(t+1)}\lambda_{As}^{(t+1)} + \sum_{s=1}^{n} F^{s}\lambda_{Cs}^{t} = \sum_{s=1}^{n}(F^{s} + z_{AB}^{s(t+1)})\lambda_{Bs}^{(t+1)} \quad (10)$$

Where F^{j} represents the remaining output of the sub-unit A to be used in the next period or in other words $\beta(1-\alpha)z_{AB}^{jt}$, E^{jt} represents the output value of sub-unit A which is consumed by sub-unit B during period t. The above equations can easily be generalized to several time periods.

3.2. Network Structures

The network structures have composed of three main components: node, input and output. In fact, these components represent the system's component and the relation between them. In the other word, nodes are decision making units that input enters them and outputs ensues from them. So, inputs and outputs indicate the amount and the status of decision-making unit relations. In this section as the perspectives and indexes of balanced scorecard connect by cause and effect relations, the network structures are used for modeling process.

1.3.3. The First State: The network structure of the decision maker unit by using the outputs of the BSC

In the first state, a structure similar to that of Figure 3 is presented. In this structure perspectives of the BSC are considered as the decision-making sub-units in which each one has several inputs and several outputs. Therefore, the variables of the model are defined as below:

x_{ijk}: i^{th} external input to the j^{th} sub-unit of the k^{th} decision-making unit.

y_{sjk}: s^{th} final output of the j^{th} sub-unit from the k^{th} decision-making unit.

z_{prjk}: p^{th} intermediate output from the r^{th} sub-unit of the k^{th} decision-making unit.

where k=1, 2, …, K is the number of decision making units, i=1, 2, …, n is the number of initial inputs, j,r are the numbers of sub-units, (j,r=1, 2, 3,4), s=1, …, m is the number of final outputs, and p=1, …, q is the number of intermediate outputs (products). Also, two equations $\mathrm{n} = \mathrm{n}_1 + \mathrm{n}_2 + \mathrm{n}_3 + \mathrm{n}_4$ and $\mathrm{m} = \mathrm{m}_1 + \mathrm{m}_2 + \mathrm{m}_3 + \mathrm{m}_4$ can be considered where n_i and m_i represent the initial inputs and final outputs of each decision-making sub-unit, respectively.

It is worth mentioning that the outputs of each perspective have the same defined attribute values of that perspective.

SDMU1= growth and learning perspective.
SDMU2= internal process perspective
SDMU3=customer perspective
SDMU4=financial perspective

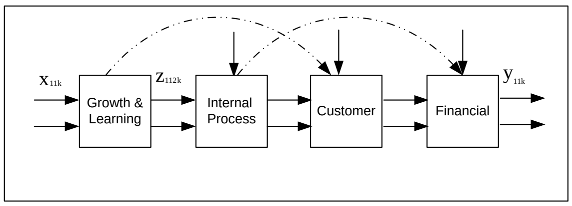

Fig. 3. Network structure of the k^{th} decision-making unit using the outputs of BSC

As it can be observed in Figure 3, this structure can be used in cases where several decision making units are needed to be evaluated in one period. The above network structure has some benefits including:

- Since the structure is in the form of a network and the output of perspectives are used as the inputs of other perspectives, then effects of different perspectives on each other can be evaluated.
- The network structure causes that the effects of a perspective consider in other perspectives. In previous models, it can be observed that in hierarchical structure of BSC the output of a perceptive was used as the input of the next perspective, but in this structure, different perspectives can be in relation with each other.
- If the goals and attributes of each perspective separate and their cause and effect relations determine, then a more detailed network could be considered which includes internal connections of each perspective. In other words, the effects of each perspective goals can also be considered on other goals of that perspective.

Even though the above structure covers some of the drawbacks of former methods, but it still has a weakness. This weakness is about not considering the delay effects of some perspectives (performance of attributes) during time periods. In other words, there are lots of different real cases where lots of investments and inputs enter the system but the outputs appear with a delay. As an example, we can mention to the outputs of the growth and learning perspective. Therefore, in some cases in order to compare and evaluate organizations with each other, considering a planned horizon and then measuring the efficiency of organizations in this horizon seems to be more reasonable. To do this, a structure should be considered which is able to measure efficiency in such a situation. Finally, it can be stated that if we do not aim in considering the delays, then this situation can be very helpful for measuring the efficiency.

1.3.4. The Second State: Network structure of the decision-making unit using the outputs of BSC during several time periods without dynamic effects

According to the drawback stated about the first state, in the second and the third states a structure is proposed which can measure the efficiency of the decision-making units during a planning horizon. It is possible that the plan arranged for short-term, mid-term, and long-term periods have different performance effects during different years. Therefore, it is necessary to analyze the planning horizon. In this situation, the structure presented in the first state has been considered in the planning horizon periods in such a way that the connections between the time periods are ignored. In other words, it is assumed that the connections among different time periods are only related to the values of the planned inputs during short-term, mid-term, and long-term periods.

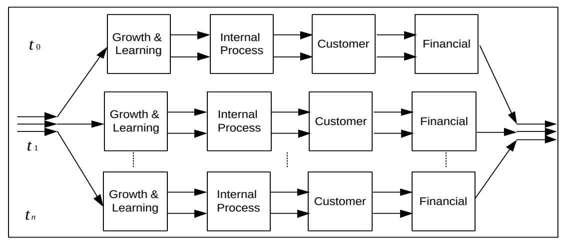

Fig. 4. DMU network using BSC perspectives during n time periods without dynamic effects

As it can be seen in Figure 4, furthermore of having the strength of the first state the proposed network also can calculate the efficiency of the organizations during the planning horizon. It is clear that the performance of the whole plan is important for us. In this state, dynamic effects would be considered in the next state.

1.3.5. The third state: Network structure of the decision-making unit using the outputs of BSC during several time periods with considering dynamic effects

Dynamic effects may happen in the attributes defined for the BSC, therefore, in order to measure the efficiency of the decision-making unit during the planning horizon, the following structure is proposed (fig.5).

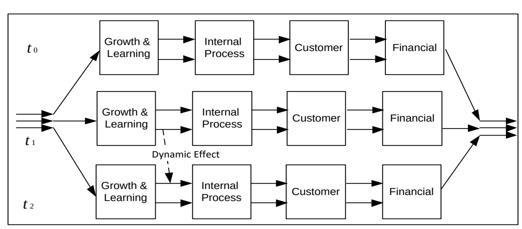

Fig. 5. DMU network using BSC perspectives during three time periods considering dynamic effects

It is worth mentioning that the assumptions of this model are similar to the first and second states. Also, if there are dynamic links in the network, then the relations of dynamic links can be adopted.

The proposed models to measure efficiency of networks

In this section, we propose the models to calculate the efficiency in any of the states. It should be mentioned that all three models proposed here are output-based and this situation can easily be transformed into input-based situation.

The proposed model to measure efficiency of networks similar to the first state

In order to calculate the efficiency of network structures in the first state, a model similar to [6] model is used. The output-based model in general form is as follows:

$$\text{Max} \quad \theta_l \tag{11}$$

S.T.

$$\sum_{k=1}^{K} \lambda_{jk} x_{ijk} \leq x'_{ijl} \quad . \ i = 1. \dots . n \ . \ j = 1.2.3.4 \tag{12}$$

$$\sum_{k=1}^{K} \lambda_{jk} y_{sjk} \geq y'_{sjl} \quad . \ s = 1. \dots . m \ . \ j = 1,2,3,4 \tag{13}$$

(if the output of the sub-unit r is used by the j^{th} sub-unit)

$$\sum_{k=1}^{K} \lambda_{jk} z_{prjk} = \sum_{k=1}^{K} \lambda_{rk} z_{prjk} \tag{14}$$

$$\sum_{k=1}^{K} \lambda_{jk} z_{prjk} \leq z'_{prjl} \tag{15}$$

$$\sum_{k=1}^{K} \lambda_{rk} z_{prjk} \geq z'_{prjl} \tag{16}$$

$$y'_{sjl} \geq \theta_l \, y_{sjk} \quad , \ \forall s . \forall j \tag{17}$$

$$x'_{ijl} \leq x_{ijk} \quad , \ \forall i . \forall j \tag{18}$$

$$\text{x, y}, \lambda \geq 0$$

Where:

X'_{ijk} : The amount allocated to the i^th^ initial input of the sub-unit j of the k^th^ decision-making unit.

Y'_{sjk} : The amount allocated to the s^{th} final output of the sub-unit j of the k^{th} decision-making unit.

Y'_{prjl} : The amount allocated to the intermediate output of the kind p, which are produced in sub-unit r and are consumed in sub-unit j.

θ_l: Reverse of the efficiency of the decision-making unit l.

The proposed model to measure efficiency of structures similar to the second state

$$\text{Max} \quad \sum_{s=1}^{m} u_s y_{sl} \tag{19}$$

S.T.

$$\sum_{i=1}^{n} v_i x_{il} = 1 \tag{20}$$

$$\sum_{s=1}^{m} u_s y_{sl} - \sum_{i=1}^{n} v_i x_{il} + s_l = 0 \tag{21}$$

$$\sum_{s=1}^{m} u_s y_{sl}^t - \sum_{i=1}^{n} v_i \, x_{il}^t + s_l^t = 0 \quad , \text{t=1,…, T} \tag{22}$$

$$\sum_{s=1}^{m} u_s y_{sk} - \sum_{i=1}^{n} v_i x_{ik} \leq 0 \qquad .k = 1. \dots . K \ .k \neq l \tag{23}$$

$$\sum_{p=1}^{q} w_{p1}^t z_{p1}^t - \sum_{i=1}^{n} v_i \, x_{ik}^t \leq 0 \quad , \ \text{t=1,…, T} \ , \ k = 1. \dots . K . k \neq l \tag{24}$$

$$\sum_{p=1}^{q} w_{pj}^t z_{pj}^t - \sum_{p=1}^{q} w_{p(j-1)}^t z_{p(j-1)}^t \leq 0 \ \text{,t=1,…, T} \ , \ \text{j=2,3} \ ,k = 1. \dots . K \ . \ k \neq l \tag{25}$$

$$\sum_{s=1}^{m} u_s y_{sk}^t - \sum_{p=1}^{q} w_{p3}^t z_{p3}^t \leq 0 \quad , \ \text{t=1,…, T} \ , \ k = 1. \dots . K \ . \ k \neq l \tag{26}$$

$$u, v \geq \epsilon$$

Where s_l and s_l^t are surplus variables. If the summation in Eq. 22 is done for all Ts, then this equation will be equal with Eq. 21. Moreover, the inefficient surplus variable of the system is equal with the total inefficient surplus variables of the entire sub-units, $\sum_{t=1}^{T} s_l^t = s_l$. It should be noted that s_l is the complement of the efficiency of the decision-making unit l. u_s and v_i values are the weight of the outputs and inputs, respectively. This model has numerous optimal solutions since for example if u^* and v^* be the optimal weight vectors, then αu^* and αv^* will be optimal for all $\alpha > 0$. It should be mentioned that serial and parallel structures are efficient only if their entire detailed processes are efficient.

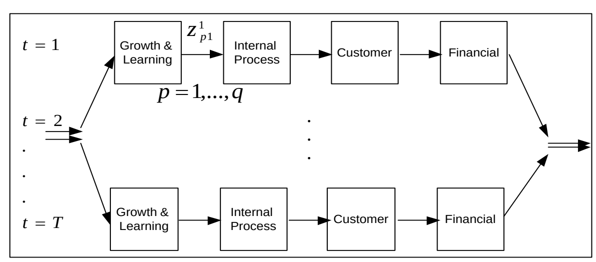

Fig. 6. DMU network using BSC perspectives during time periods without dynamic effects

The proposed model to calculate the efficiency of structures similar to the third state

According to the abovementioned discussions, in this section a model is proposed to calculate the efficiency of structures represented in Figure 6. In this model we have:

$x_{il}^{t\prime}$: The amount of allocation to the initial input i, which is consumed by the first sub-unit of the lth decision-making unit during time period t.

$y_{sl}^{t\prime}$: The amount of allocation to the final output s, which is consumed by the fourth sub-unit of the lth decision-making unit during time period t.

$z_{prjl}^{t\prime}$: The allocated amount to the intermediate output p, which is produced by sub-unit r and consumed by sub-unit j.

θ_l : Reverse of the efficiency of the decision-making unit l.

$$\text{Max} \quad \theta_l \tag{27}$$

S.T.

$$\sum_{k=1}^{K} \lambda_{1k}^{t} x_{ik}^{t} \leq x_{il}^{t\prime} \quad . \; i = 1. \dots . n \quad . \quad t = 1. \dots . T \tag{28}$$

$$\textstyle\sum_{k=1}^{K} \lambda_{jk}^{t} z_{prjk}^{t} \leq z_{prjl}^{t\prime} \text{ ,t=1,…, T , r,j=1,2,3,4 , p=1,…,q} \tag{29}$$

$$\textstyle\sum_{k=1}^{K} \lambda_{rk}^{t} z_{prjk}^{t} \geq z_{prjl}^{t\prime} \text{ ,t=1,…, T , r, j=1,2,3,4 , p=1,…,q} \tag{30}$$

$$\sum_{k=1}^{K} \lambda_{rk}^{t} z_{prjk}^{t} = \sum_{k=1}^{K} \lambda_{jk}^{t} z_{prjk}^{t} \tag{31}$$

$$\textstyle\sum_{k=1}^{K} \lambda_{jk}^{t} y_{sk}^{t} \geq y_{sl}^{t\prime} \text{ ,t=1,…, T , s=1,…,m} \tag{32}$$

$$\sum_{t=1}^{T} x_{il}^{t\prime} \leq x_{il} \quad . \; i = 1. \dots . n \tag{33}$$

$$\sum_{t=1}^{T} y_{sl}^{t\prime} \geq \theta_l y_{sl} \quad . \; s = 1. \dots . m \tag{34}$$

$$x_{il} = \sum_{t=1}^{T} x_{il}^{t} \tag{35}$$

$$y_{sl} = \sum_{t=1}^{T} y_{sl}^{t} \tag{36}$$

Eq. 28 relates to the initial inputs and Eq. 29 and Eq. 30 relate to the intermediate products which are used as inputs and outputs. Eq. 31 relates to tradeoff equations. Eq. 32 is about the final output. Eq. 33 and Eq. 34 are also related to the initial allocated inputs and final allocated outputs.

Also in the above model, it is assumed that the output of the sub-unit r is used by the sub-unit j (as intermediate product). By this model, efficiency of the arranged plan for the decision making units can be calculated during the planning horizon considering delays.

4. A Numerical Example

Suppose that the BSC attributes of the company X are as represented in Table 1.

Table 1. Attributes of the BSC of the company X

Internal Process Perspective	Growth & Learning Perspective
✓ Reworking percentage ✓ Reduction in problems of customers	✓ Number of trained employees ✓ Number of innovations
Financial Perspective	**Customer Perspective**
✓ Profitability value	✓ Customer satisfaction ✓ Number of newly absorbed customers

Also, the values of each attribute for 5 similar organizations are represented during two time periods in Table 2.

Table 2. Values of the sample attributes for 5 similar organizations during two time periods

Time Period	Sub-unit Name	X_{11k}	x_{21k}	z_{112k}	z_{212k}	z_{123k}	z_{223k}	z_{134k}	z_{234k}	Y
t_0	Dmu_1	10	45	50	2	60	40	45	28	12
	Dmu_2	13	38	40	4	40	35	40	25	38
	Dmu_3	9	40	55	1	40	45	50	12	41
	Dmu_4	11	48	60	5	60	80	80	48	72
	Dmu_5	7	50	70	4	80	62	70	36	63
t_1	Dmu_1	11	40	60	6	70	85	73	42	64
	Dmu_2	14	36	55	4	50	50	65	20	50
	Dmu_3	9	41	70	5	75	68	73	51	72
	Dmu_4	10	48	65	3	70	75	87	42	89
	Dmu_5	7	45	65	4	75	70	78	28	80

Using the proposed models for the first state, second state, and the classic model, we try to calculate the efficiency of the first organization against the other ones during two periods of time.

At first we introduce the steps of the method:

Step1: Drawing the network

The network being drawn is represented in Figure 7 and its variables are defined in Table 3

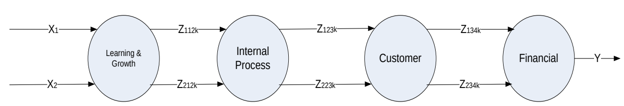

Fig. 7. The considered network in the experimental model

Table 3. Variables of the experimental model

Variable Name	Variable Definition
x_1	Fixed cost of production
x_2	Variable cost
z_{112k}	Percentage of trained employees
z_{212k}	Number of innovations
z_{123k}	Percentage of the omitted reworks
z_{223k}	Reduction in the problems of customers
z_{134k}	Customer’s satisfaction
z_{134k}	Number of newly absorbed customers
Y	Profitability value

Step2: Drawing the network in two time periods accompanied with the coefficients of intermediate products and sub-units. (Figure 8)

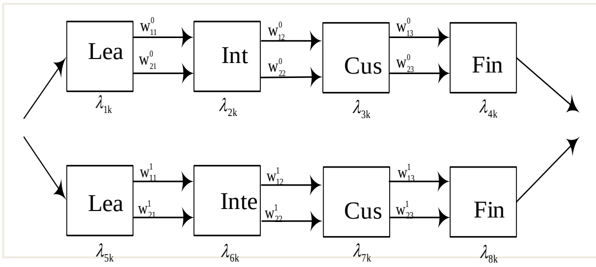

Fig. 8. The network in two time periods

Step3: Modeling

Step4: Solving the linear programming problem.

The problem in this paper is solved by the QSB software. According to the extracted assumptions, the final results are shown in table 4:

Table 4. The resulting efficiencies obtained from the first, second, and the classic method

Method	The First Method	The Second Method	The Classic Method
Efficiency (θ)	0.34534	0.34534	0.5331

As it can be observed, calculated result for both the first and the second methods are similar and both differ from the result of the classic method. This is because that in classic method, inter-unit relations are ignored; hence some of inefficiencies are not taken into account. Because of this ignorance, their results are less than the classic method. On the other hand, the results of the first and the second method are equal. This is because there does not exist any connection between the performances of the time periods. This leads to the capability of considering a continuous network as two separated networks during two periods.

5. Conclusions

Nowadays the performance evaluation and feedback systems are considered as effective factors in the success of organizations. Efficiency measurement is one of the most important performance evaluation methods. The results of efficiency measurement enable organizations to have a better understanding of the performance of their business units and also eliminate inefficient causes of their performances so that they could improve it. On the other hand, in the current century, analyzing business environment and strategies has become more important than ever. Thus, the balanced scorecard method has been widely used as an effective tool to provide the possibility of successful implementation of strategies.

Since introducing the balanced scorecard method many organizations around the world achieved significant success by using it and implementing their own strategies. In recent years, by combining the BSC and DEA, a new method for evaluating organizational performance has been established. This research focuses on presenting methods for performance evaluation based on BSC and DEA without considering the relations among the units, different perspectives, and the performance effects during various time periods. Therefore, in this study, by considering dynamic effects in several periods an appropriate method for measuring the performance of organizations with network structure is proposed. The results can be widely used in measuring efficiency and effectiveness of organizations which have strategic planning. One of the important issues is targeting and developing the organization's future plans in long horizons. Therefore, investigating on the application of this method can be a good topic for future studies. Also, in this study, we have considered the assumption of constant return to scale. So, variable efficiency to scale assumption can also be regarded for further studies. Finally, by the usage of network structures in this paper we can utilize the proposed models in directing different strategic levels of an organization.

References

[1] Kaplan, R., & Norton, D. (2004). Strategy maps converting intangible assets into tangible outcomes. Boston, MA: Harv. Bus. School Press.

[2] Farrell, M.J., (1957). The measurement of productive efficiency. Journal of the Royal Statistical Society. Series A (General), 120(3), 253-290.

[3] Charnes, A., Cooper, W.W. & Rhodes, E. (1978). Measuring the efficiency of decision making units. European journal of operational research, 2(6), 429-444.

[4] Färe, R. & Grosskopf, S. (2000). Network dea. Socio-economic planning sciences, 34(1), 35-49.

[5] Sexton, T.R. & H.F. Lewis, Two-stage DEA: An application to major league baseball. Journal of Productivity Analysis, 2003. 19(2-3): p. 227-249.

[6] Prieto, A.M. & Zofío, J.L. (2007). Network DEA efficiency in input–output models: With an application to OECD countries. European Journal of Operational Research, 178(1), 292-304.

[7] Yu, M.-M. & Lin, E.T. (2008). Efficiency and effectiveness in railway performance using a multi-activity network DEA model. Omega, 36(6), 1005-1017.

[8] Kao, C., (2009). Efficiency decomposition in network data envelopment analysis: A relational model. European Journal of Operational Research, 192(3), 949-962.

[9] Sengupta, J.K. (1999). A dynamic efficiency model using data envelopment analysis. International Journal of Production Economics, 62(3), 209-218.

[10] Nemoto, J. and Goto, M. (2003). Measurement of dynamic efficiency in production: an application of data envelopment analysis to Japanese electric utilities. Journal of Productivity Analysis, 19(2-3), 191-210.

[11] Chen, C.-M. (2009). A network-DEA model with new efficiency measures to incorporate the dynamic effect in production networks. European Journal of Operational Research, 194(3), 687-699.

[12] Chen, K. & Guan, J. (2012). Measuring the efficiency of China's regional innovation systems: application of network data envelopment analysis (DEA). Regional Studies, 46(3), 355-377.

[13] Khalili-Damghani, K. & Tavana, M. (2013). A new fuzzy network data envelopment analysis model for measuring the performance of agility in supply chains. The

International Journal of Advanced Manufacturing Technology, 69(1-4), 291-318.

[14] Mirhedayatian, S.M., Azadi, M. & Farzipoor Saen, R. (2014). A novel network data envelopment analysis model for evaluating green supply chain management. International Journal of Production Economics, 147, 544-554.

[15] Kaplan, R. & Norton, D. (1992). The Balanced Scorecard œ Measures That Drive Performance—, in: Harvard Business Review.

[16] Chen, T.-y., Chen, C.-B. & Peng, S.-Y. (2008). Firm operation performance analysis using data envelopment analysis and balanced scorecard: A case study of a credit cooperative bank. International Journal of Productivity and Performance Management, 57(7), 523-539.

[17] Rouse, P., Putterill, M., & Ryan, D. (2002). Integrated performance measurement design: insights from an application in aircraft maintenance. Management Accounting Research, 13(2), 229-248.

[18] Banker, R.D., et al., (2004). A balanced scorecard analysis of performance metrics. European Journal of Operational Research, 154(2), 423-436.

[19] Eilat, H., Golany, B., & Shtub, A. (2006). Constructing and evaluating balanced portfolios of R&D projects with interactions: A DEA based methodology. European Journal of Operational Research, 172(3), 1018-1039.

[20] Eilat, H., Golany, B., & Shtub, A. (2008). R&D project evaluation: An integrated DEA and balanced scorecard approach. Omega, 36(5), 895-912.

[21] García-Valderrama, T., Mulero-Mendigorri, E., & Revuelta-Bordoy, D. (2009). Relating the perspectives of the balanced scorecard for R&D by means of DEA. European Journal of Operational Research, 196(3), 1177-1189.

[22] Asosheh, A., Nalchigar, S., & Jamporazmey, M. (2010). Information technology project evaluation: An integrated data envelopment analysis and balanced scorecard approach. Expert Systems with Applications, 37(8), 5931-5938.

[23] Amado, C.A., Santos, S.P., & Marques, P.M. (2012). Integrating the Data Envelopment Analysis and the Balanced Scorecard approaches for enhanced performance assessment. Omega, 40(3), 390-403.

[24] Shafiee, M., Hosseinzadeh Lotfi, F., & Saleh, H. (2014). Supply chain performance evaluation with data envelopment analysis and balanced scorecard approach. Applied Mathematical Modelling.

[25] Hatefi, S.M., & Haeri, A. (2019). Evaluating hospital performance using an integrated balanced scorecard and fuzzy data envelopment analysis. Journal of Health Management & Informatics, 6(2), 66-76.

[26] Sarraf, F., & Nejad, S.H. (2020). Improving performance evaluation based on balanced scorecard with grey relational analysis and data envelopment analysis approaches: Case study in water and wastewater companies. Evaluation and program planning, 79, 101762.

[27] Shafiee, M., Saleh, H., & Ziyari, R. (2020). Projects Efficiency Evaluation by Means Data Envelopment Analysis and Balanced Scorecard. Journal of Decisions and Operations Research.