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Measuring Efficiency of Financial Cloud Services in Banking Industry Using Modified Dynamic DEA with Network Structure (Case study: Iran E-Banking)

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ABSTRACT

Nowadays, the great benefits of cloud computing have dramatically increased the number of e-banking users. Hence, the competition in the banking industry has boosted and managers need to evaluate their branches on a regular basis. To this end, this study aims to evaluate cloud-based banking systems based on the Quality of Service (QoS) attributes using the Dynamic Network Data Envelopment Analysis (DNDEA) model. The main advantage of this research is that the efficiency of cloud-based bank branches can be estimated more realistically according to their internal structure over a specific time span. To conduct the experiment, 40 bank branches in Iran are analysed by considering between-period and divisional interactions during 2018-2019. A cloud-based bank branch is conceptualized as a set of three inter-connected divisions including capabilities, intermediate process, and profitabilities. Some outputs of sub-DMUs 2 and 3 are treated as desirable and undesirable carry-overs between consecutive periods. In addition, the cost items and QoS attributes are considered as the inputs and outputs of divisions, respectively. The results indicate that 28 bank branches were efficient and all of the inefficiencies fall in divisions 1 and 3. Moreover, the number of efficient branches has been reduced from 2018 to 2019.

1 Introduction

With the advent of Internet-based computing technology, the financial markets including the banking industry face a lot of innovative changes. Banks need to respond to these changes by modernizing their information technology (IT), and business procedures [1]. The use of cloud services can offer the banking industry a number of benefits including fault tolerance, cost reduction, time-saving, improved business performance and so on [1]. Cloud-based applications can be used to facilitate daily financial transactions of customers without any extra cost in spite of conventional

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client-server technologies that impose massive resources, time and cost barriers [2]. The tempting and numerous advantages of cloud-based applications have dramatically increased the number of Internet banking users [3]. Due to these unprecedented technological improvements, the competition in banking industry has boosted. Hence, the performance evaluation of banks and if necessary, the adoption of corrective policies are serious concerns of different stakeholders such as depositors, shareholders, regulators and loan customers. To confront these issues, many academic studies have been carried out to evaluate and enhance the performance of commercial banks [4]. Data Envelopment Analysis (DEA) is a generally accepted method that can be used for this purpose. This nonparametric method measures the efficiency of homogeneous organizational units termed as Decision Making Units (DMUs). DMUs are the processing units that convert multiple inputs into multiple outputs. Moreover, it can provide corrective suggestions to improve the efficiency of DMUs for decision-makers. The main advantage over other methods is its independence from any prior assumption about the functional relationship between inputs and outputs [5]. Traditional DEA models are only able to evaluate the efficiency of the DMUs regardless of their internal interactions. In other words, the system is considered as a black box in which only outputs and inputs of DMUs are considered in evaluation time. There are systems in which their operations are composed of more than one process. These processes can be connected to each other in parallel, series, or a combination of them, and each of them can have its own inputs and outputs. The structure of such systems is networked [6, 7].

In the conventional DEA models, the branch of bank is treated as a black-box (assuming inputs are consumed to produce outputs). The major disadvantage of these DEA models is to view branches as a whole when measuring the efficiency, and ignore their internal divisions (processes) interrelated with each other. As a result, bank managers cannot identify inefficient divisions of the branches that need to be improved. Unlike traditional DEA models, Network DEA (NDEA) models can measure overall efficiency as well as the divisions efficiencies [8, 9]. Moreover, conventional DEA models do not account for the effect of carry-over activities between two consecutive terms. For each term, traditional DEA models have inputs and outputs but the connecting activities between terms are not accounted for explicitly. These inter-connecting activities appear in many financial institutions. For example, profit earned forward and non-performing loans are respectively good and bad carry-overs [10]. For dealing formally with these activities, we employ Dynamic DEA (DDEA) models. We are able to evaluate the branches of a bank from a long-term perspective using these models [11]. It can be concluded that the weakness of the traditional DEA models can be resolved by combining Dynamic and Network DEA (DNDEA) models and it is possible to accurately measure the efficiency of all divisions of a bank branch over the entire observed period. In recent years, the banking industry in Iran has been pushed to migrate from classical procedures toward online banking. In detail, cloud computing adoption has been accelerated since establishing private banks and breaking down the monopolistic market of government banks. Therefore, the banks entered the competitive conditions and try to gain a maximum share of the financial market. Therefore, managers and stockholders need to evaluate their organization regularly. In this study, the workflow model of the Internet banking industry is extracted in Iran over multiple periods. Then, a compatible DNDEA model is proposed within the slacks-based framework to rank branches of banks regarding their non-functional attributes. Hence, the performance of banks can be more precisely evaluated and the inefficient processes in a specific time span can be better identified.

The rest of this paper is organized as follows. In the next section, the related works and the role of DEA models in the evaluation of the banking industry are presented. In section 3, the concept of cloud computing and its application in the banking sector are reviewed. The proposed models for evaluation of cloud-based bank branches are constructed in Section 4. In Section 5, an experiment is conducted to describe the results of DEA models using a synthesized dataset. Finally, conclusions are given in Section 6.

2 Review of Literature

DEA is a nonparametric method in research operations for the estimation of the relative efficiency of DMUs. This method was first developed by Charnes et al. [12] and its application gradually expanded to many other scientific fields such as management [13, 14], economics [15], and engineering [16]. Also, in the banking industry, many studies have been carried out to evaluate the performance of bank branches through this method. The first studies on this field have focused more on black-box models. For example, Esfandiar et al. [17] provides a systematic method for assessing the financial performance of banks accepted in Tehran Stock Exchange using the data envelopment of analysis method. Izadikhah [18] employed two bank efficiency measurement approaches based on the data envelopment analysis method and run them on the 15 privet bank branches in Markazi province. These approaches led to finding four regions for all branch performances. Moreover, the status of the return to scale for each bank branch that helps the manager to decide about the future of the bank is calculated. Razipour-GhalehJough et al. [19] presented a model for finding the closest benchmarks of inefficient DMUs in the presence of weight restrictions. Then, they evaluated one of the Iranian Banks by their proposed model. Nasseri et al. [20] proposed a fuzzy stochastic DEA model with undesirable outputs. Their model analyzes the influence of the presence of both fuzzy imprecision and probabilistic uncertainty in the data over the efficiency scores. They also demonstrated the applicability of the proposed model on a case study in the banking industry. In real-life situations, carry-overs may emerge in many financial institutions. For example, in the banking industry, profit earned and non-performing loans are desirable and undesirable carry-overs, respectively [10]. Conventional DEA models cannot consider this type of referrals in their calculations. Hence, several studies examined how to assess the performance of a set of bank branches in a time span covering multiple periods. For example, Kao and Hwang [21] developed a model based on the relational network DEA approach to measure the overall and period performance of 22 Taiwanese banks in a time span and showed that the overall efficiency is the weighted average of the period efficiencies. In another study, Shafiee [22] employed a non-oriented dynamic SBM model to evaluate the performance of 10 branches of an Iranian bank during three consecutive terms.

Another part of the literature addressed the necessity of considering the internal structure of DMUs in the assessment of the banking systems. Izadikhah et al. [23] defined a two-stage DEA model where each DMU is composed of two connected sub-DMUs such that both of them can have initial inputs. Then, it was used to evaluate the efficiency of 15 branches of the Philadelphia National Bank. Mahmoudabadi et al. [24] designed the efficiency of evaluation scheme of the banking industry using a three-stage SBM DEA model and applied it to 37 branches of a commercial bank in Iran. Akbari et al. [25] evaluated the performance of the branches of an Iranian bank using a network DEA model based on their internal structure. Huang et al. [26] extended the network DEA model to a coupla-based network SFA model that embodies a multi-stage production process for banks under the framework of simultaneous equations. They collected data from US banks in 2009 to illustrate the feasibility and usefulness of their modeling. Barat et al. [27] proposed a DEA-based methodology to deal with the problem of evaluating the relative efficiencies of a set of DMUs whose internal structures are nonhomogeneous and applied it to a real data-set on the bank industry. Mahmoudi et al. [28] proposed a novel game-DEA model for efficiency assessment of network structure DMUs. They also presented the usefulness of their model using a real case study of bank branches. Zhong et al. [29] employed the integrated network DEA to assess urban commercial banks in China in terms of the situation of them. Chao et al. [30] employed the convex meta-frontier network data envelopment analysis model to measure the profitability efficiency (PE) and marketability efficiency (ME) of non-homogenous Taiwanese banks. They also identified the source of inefficiency of these banks using the employed model.

In recent years, dynamic and network dimensions of DEA models are brought together to enable more accurate performance evaluation of the bank branches. Tavana et al. [31] evaluated the efficiency of 29 branches of the Detroit National Bank by introducing a two-stage dynamic model that is able to treat negative data as well as desirable and undesirable carry-overs. Yu et al. [32] developed a model called 2S-SBM-DNDEA to evaluate the dynamic performance of banks in Taiwan regarding their network and dynamic structure. Niknafs et al. [33] proposed a method to estimate the efficiency of the bank branches in the future to prevent the occurrence of the stages' inefficiency. Their method consisted of the Dynamic Network Data Envelopment Analysis and the Artificial Neural Network. Wanke et al. [34] developed a dynamic network DEA model in order to handle the underlying relationships among major accounting and financial indicators of the banking industry of the Middle East and North Africa (MENA) countries. Kweh et al. [35] applied a non-oriented, variable return to scale, dynamic network slack-based measure to compare dual banking systems, namely conventional and Islamic banks with emphasis on risk measure for the period 2008-2012. Zhou et al. [36] proposed a relative dynamic two-stage network data envelopment analysis model to measure the efficiency of the 27 banks in Ghana during the period of 2009–2014. They also presented useful suggestions for improvement in bank efficiency based on the empirical results. Applications of cloud computing in the banking industry can be found in [1, 37, 38]. On the other hand, there are several studies that evaluated cloud services using DEA models [39-42]. Hence, an unsupported factor that can be addressed in the banking industry is the comprehensive assessment of cloud-based banking performance using DEA models. To fill this gap, in this study, we introduce a modified dynamic network SBM model to evaluate the cloud-based banking branches.

3 Preliminaries

This section presents the concepts related to DEA, and cloud computing and its role in the banking sector.

3.1 The Slacks-Based Measure of Efficiency in DEA

Tone [43] developed a slacks-based measure (SBM) of efficiency in DEA. This scalar measure deals directly with input excess and the output shortfalls of DMU under evaluation. It is unit invariant and has close connection with other measures e.g., CCR, BCC and Russell measure of efficiency. This model and its related variables are briefly reviewed below.

$$
\begin{aligned}
&\rho^* = \min_{\lambda, s^-, s^+} \frac{1-\frac{1}{m}\left(\sum_{i=1}^{m}\frac{s_i^-}{x_{io}}\right)}{1+\frac{1}{r}\left(\sum_{r=1}^{r}\frac{s_r^+}{y_{ro}}\right)} \\
&\text{S.T.} \\
&\sum_{j=1}^{n}\lambda_j x_{ij} - s_i^+ = x_{io} && (i = 1, \dots, \mathrm{m}) \\
&\sum_{j=1}^{n}\lambda_j y_{rj} - s_r^+ = y_{ro} && (r = 1, \dots, \mathrm{s}) \\
&\lambda_j \geq 0 && (j = 1, \dots, n) \\
&s_i^- \geq 0 && (i = 1, \dots, \mathrm{m}) \\
&s_r^+ \geq 0 && (r = 1, \dots, \mathrm{r})
\end{aligned} \tag{1}
$$

In model (1), x_{ij} and y_{rj} respectively represent the ith input and rth output of DMU_j where $i = (1, \dots, m), r = (1, \dots, s)$ and $j = (1, \dots, n)$. The optimal value of index ρ is always between 0 and 1. The DMU under evaluation is DMU_o. If $\rho^*=1$, then DMU_o is efficient. Otherwise, this DMU is inefficient. The vectors s^+ and s^- indicate output shortfall and input excess, respectively. The variable λ is a nonnegative vector that indicates the contribution of DMU_j in finding the best virtual DMU for DMU_o, where $j = (1, \dots, n)$.

3.2 Cloud Computing

The term "cloud computing" was first used around 2007 in a joint project between Google and IBM. Buyya et al. [44] defined cloud computing in this way: ''Cloud is a parallel and distributed computing system involving a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on Service-Level Agreements (SLA) established through negotiations between the service provider and consumers''. The National Institute of Standards and Technology (NIST) defines cloud computing as: ''a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released by the minimal management effort or service provider interaction'' [45]. Despite a variety of definitions for cloud computing, its major characteristics are as follows: (1) pricing model based on "pay for what you use" (measured service) (2) on-demand self-service without need to the service provider intervention (3) broad network access by diverse customers' platforms (4) virtualized resources of which architectures are transparent for users (5) ease of provision and de-provision of computing resources including functions, infrastructures and information (rapid elasticity and scalability) [1]. Financial cloud computing is defined as the cloud-based services and applications employed by banks or other financial institutions to provide high-end facilitates for their customers. This type of cloud computing can enhance key features of financial institutions like customer satisfaction, cost reduction, business agility, reliable data storage, etc. for these institutions. These advantages can lead to the adoption of cloud computing by banks and other financial institutions. Larger banks are currently expanding their adoption of cloud computing. Generally, they pick specific task areas and radically cloud-enabled ones using Software as a Service (SaaS) or other models of cloud services [46]. In the following, advantages using cloud technologies in the banking sector are discussed.

Cost reduction: Using financial cloud computing, the banking industry need no extra investment in new software applications and hardware. The unique nature of cloud computing allows financial institutions to employ their required services based on the pay-per-use paradigm. Therefore, they can outsource their procedures to cost-effective and confident services so that they are able to save their capitals.

Customer satisfaction: Cloud computing makes financial services more accessible, easier to use and more convenient and can be more personalized with respect to the needs of customers and their lifestyles. With the help of rich resources that belong to the private cloud [47], commercial banks can deliver on-demand high-quality services to their customers. Moreover, data mining techniques [48] and cloud computing can be combined together to extract valuable information from available data and build more convenient services for individuals.

Scalability and mobility: Well-designed cloud services can provide opportunities for banks to meet customer demands even in the peak load time. Also, with the proliferation of smartphones, customers of banks want to access financial operations on the move. Cloud services can change the overhead of their servers over time and e-banking is able to react to these changes appropriately. Cloud computing permits a bank to scale its business operation by allocating its resources without limitations. Using cloud technology, a company can take the economic benefits of scaling without a need to add more servers. As a result, cloud computing can provide a flexible architecture for banks that scale resources rapidly based on instant requests.

Business agility: Financial institutions must acquire the agility to respond faster to periodic changes in their business. The on-demand provisioning of computer resources reduces the initial set-up time of IT infrastructure. Hence, cloud computing lets financial institutions manage their resources faster than traditional client-server technologies. Therefore, cloud computing supports the banking industry to quickly adapt its products to new regulations. Moreover, banks can focus more on the commercial aspects of their financial services rather than IT [49].

4 Methodology

In this section, we aim to customize a DNDEA model to evaluate bank branches in a time span covering T periods. For this purpose, we consider a branch of a bank as a DMU which was consisted of K divisions. Fig. 1 depicts the network DEA model of a bank branch over 2 consecutive periods. Each division has inputs, outputs, links and carry-over items as represented in this Figure. As it is seen, all divisions have common inputs and outputs (Red arrows). In other words, we consider cost items and Quality of Service (QoS) attributes as inputs and outputs of divisions, respectively. The black arrows are intermediate links that connect divisions together and transmit commercial data between them (This is discussed further in Section 4.2). In addition, in the banking systems, divisions may be linked together over two consecutive periods using carry-overs (Green arrows). Each of these carry-overs may contain several items. In the following, we examine all constraints related to the above-mentioned referrals and determine which of these constraints should be considered in our DNDEA model in order to assess the cloud-based banking system accurately. There are several studies that have developed or used the radial-based DNDEA model [40, 50]. The slack-based model can compute the efficiency of weakly efficient DMUs faster than the radial models. Moreover, in the radial DEA models, it is necessary to determine the assurance interval of the non-Archimedean infinitesimal ε, which forestalls weights from being zero.

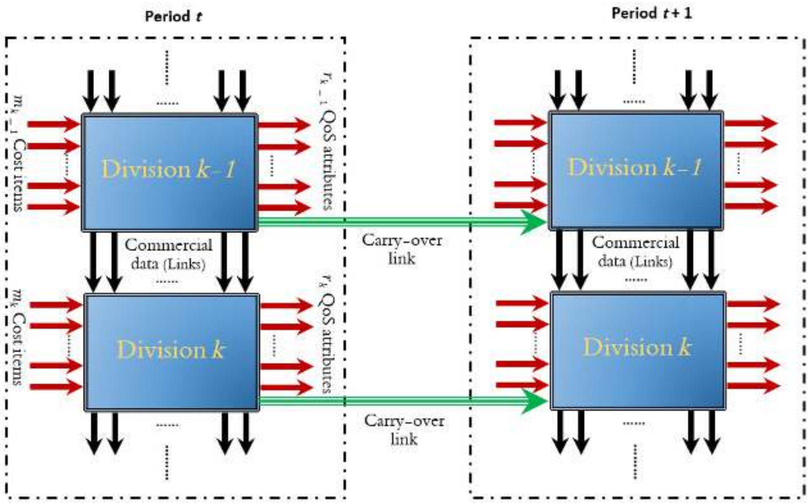

Fig. 1: The DEA Model for Evaluating Banking Branches

Otherwise, they may suffer from problems such as unbounded (for the envelopment side) and infeasible ones (for the multiplier side) [51, 52] whereas slack-based models are free from these problems [53, 54]. Hence, in this study, we employ the DNDEA model proposed by Tone and Tsutsui [10] which is based on the SBM approach, and adapt it to evaluate the cloud-based banking system in Iran.

4.1 Inputs and Outputs Constraints

Since the input and output variables of the Banking systems can change disproportionately, we construct our model based on the Variable Return to Scale (VRS) hypothesis. This assumption imposes an additional constraint of $\sum_{j=1}^{n} \lambda_j^{k,t} = 1$ for evaluation of each division at a certain period. The inputs and outputs constraints of DMU_o $(\mathrm{o} = 1, \dots, \mathrm{n})$ can be expressed as follows:

$$
\begin{array}{ll}
\sum_{j=1}^{n} \lambda_j^{k,t} x_{ij}^{k,t} + s_i^{k,t-} = x_{io}^{k,t} & (i = 1, \dots, m_k;\ k = 1, \dots, K;\ t = 1, \dots, T) \\
\sum_{j=1}^{n} \lambda_j^{k,t} y_{rj}^{k,t} - s_r^{k,t+} = y_{ro}^{k,t} & (r = 1, \dots, r_k;\ k = 1, \dots, K;\ t = 1, \dots, T) \\
\sum_{j=1}^{n} \lambda_j^{k,t} = 1 & (k = 1, \dots, K;\ t = 1, \dots, T) \\
\lambda_j^{k,t} \geq 0 & (j = 1, \dots, n;\ k = 1, \dots, K;\ t = 1, \dots, T) \\
s_i^{k,t-} \geq 0 & (i = 1, \dots, m_k;\ k = 1, \dots, K;\ t = 1, \dots, T) \\
s_r^{k,t+} \geq 0 & (r = 1, \dots, r_k;\ k = 1, \dots, K;\ t = 1, \dots, T)
\end{array}
\qquad (2)
$$

Where $\lambda^{k,t} \in R^n$ is the intensity vector corresponds to division k $(k = 1, \dots, K)$ at period t $(t = 1, \dots, T)$. We notice that $x_{io}^{k,t}$ and $y_{ro}^{k,t}$ on the right of the above equations are respectively observed positive input i and output r of division k at period t of DMU under evaluation where $i = (1, 2, \dots, m_k)$ and $r = (1, 2, \dots, r_k)$. Also, $x_{ij}^{k,t}$ and $y_{rj}^{k,t}$ on the left of these equations are respectively cost items and QoS values of other DMUs connected to the intensity variable $\lambda_j^{k,t}$. The slack variables $s_i^{k,t-}$ and $s_r^{k,t+}$denoting, respectively, excess of input i of division k at period t and shortfall of output r of division k at period t.

4.2 Links

As it is seen in Fig. 1, commercial data are transmitted through intermediate links between divisions. To evaluate cloud services properly, we should consider the internal structure of DMUs in our model. In this study, we classify the internal activities of DMUs into four categories. As respect to these categories, we have four possible types of constraints in modeling cloud services as follows:

(a) The non-discretionary case

The linking activities are beyond the control of divisions but they should be included in the DEA model to ensure fair comparisons. We symbolize this kind of link flows as z^{fixed}. In order to identify item (p) in the link (k, h) of DMU$_j$ at period t, we employ the notation $z_{jp}^{(kh)fixed,t}$ $j = (1, \dots, n)$. The continuity of non-discretionary link flows between divisions k and h at period t can be guaranteed by the following constraints:

$$\sum_{\mathrm{j}=1}^{\mathrm{n}} \lambda_j^{k,t} z_{jp}^{(kh)fixed,t} = z_{op}^{(kh)fixed,t} \quad (\forall (k,h)fixed, \forall p \epsilon (k,h)fixed; k = 1, \dots, K;\ t = 1, \dots, T)$$
$$\sum_{j=1}^{n} \lambda_j^{h,t} z_{jp}^{(kh)fixed,t} = z_{op}^{(kh)fixed,t} \quad (\forall (k,h)fixed, \forall p \epsilon (k,h)fixed; k = 1, \dots, K;\ t = 1, \dots, T) \tag{3a}$$

Where $(k, h)fixed$ is the non-discretionary link between division k and division h.

(b) The discretionary case

DMUs can vary this type of intermediate products freely while keeping continuity between inputs and outputs. We symbolize this kind of link flows as z^{free}. In order to identify item (p) in the link (k, h) of DMU$_j$ at period t, we employ the notation $z_{jp}^{(kh)free,t}(j = 1, \dots, n)$. The continuity of discretionary link flows between divisions k and h at period t can be guaranteed by the following constraint:

$$\sum_{i=0}^{n} \lambda_j^{k,t} z_{jp}^{(kh)free,t} = \sum_{i=0}^{n} \lambda_j^{h,t} z_{jp}^{(kh)free,t} \quad (\forall (k,h)free, \forall p \epsilon (k,h)free; k = 1, \dots, K;\ t = 1, \dots, T) \tag{3b}$$

Moreover, we have the following relationship between the free links values and the current link value:

$$\sum_{j=1}^{n} \lambda_j^{k,t} z_{jp}^{(kh)free,t} + s_{op}^{(kh)free,t} = z_{op}^{(kh)free,t} \quad (\forall (k,h)free, \forall p \epsilon (k,h)free; k = 1, \dots, K; \; t = 1, \dots, T) \tag{3c}$$

Where slack $s_{op}^{(kh)free,t} \in R^{l_{kh}}$ is free in sign, and $(k,h)free$ is discretionary link between division k and division h.

(c) The "as-input" link

The link flows are treated as inputs to the succeeding division and their excesses are accounted to compute the relative efficiency.

$$\sum_{j=1}^{n} \lambda_j^{k,t} z_{jp}^{(kh)in,t} + s_{op}^{(kh)in,t} = z_{op}^{(kh)in,t} \quad (\forall (k,h)in, \forall p \epsilon (k,h)in; k = 1, \dots, K; \; t = 1, \dots, T) \tag{3d}$$

Where slack $s_{op}^{(kh)in,t} \in R^{l_{kh}}$ is non-negative, and $(k,h)in$ is "as-input" link from division k.

(d) The "as-output" link

The link flows are treated as outputs from the preceding division and their shortages are accounted to compute the relative efficiency.

$$\sum_{j=1}^{n} \lambda_j^{k,t} z_{jp}^{(kh)out,t} - s_{op}^{(kh)out,t} = z_{op}^{(kh)out,t} \quad (\forall (k,h)free, \forall p \epsilon (k,h)out; k = 1, \dots, K; \; t = 1, \dots, T) \tag{3e}$$

Where slack $s_{op}^{(kh)out,t} \in R^{l_{kh}}$ is non-negative, and $(k,h)out$ is "as-output" link from division k.

4.3 Carry-Overs

As it is seen in Fig. 1, divisions can be connected to each other in two consecutive periods using carry-overs. Hence, to evaluate cloud services more accurately, we should consider some additional constraints according to these activities. Regarding the linking carry-overs, we have four possible constraints between periods as follows:

(a) The good link

This indicates desirable carry-over, e.g. profit earned in financial institutions and treated as outputs in the model.

(b) The bad link

This indicates undesirable carry-over, e.g. non-performing loans, deadstock, and bad debt in financial institutions, and treated as inputs in the model.

(c) The free link

This indicates discretionary carry-over so that its value is in the control of the DMU manager. In other words, it is possible to decrease or increase its value from the observed level.

(d) The fixed link

This indicates non-discretionary carry-over so that its value cannot handle freely by DMU manager, and is fixed at the observed one.

Regarding these link flows, we have the common carry-over constraint, which can be formulated as follows:

$$\sum_{\mathrm{j}=1}^{\mathrm{n}} \lambda_j^{k,t}\, z_{j\alpha}^{k_l,(t,t+1)} = \sum_{\mathrm{j}=1}^{\mathrm{n}} \lambda_j^{k,(t+1)}\, z_{j\alpha}^{k_l,(t,t+1)} \quad (\forall k;\ \forall k_l,;\ \ t = 1, \dots, T-1) \tag{4}$$

Where the symbol α stands for good, bad, free, and fixed carry-overs. k_l indicates carry-overs that connects division k at the current period to the next period, and $z^{k_l,(t,t+1)}$ represents its value in the mentioned period. This constraint should be considered for the dynamic network model since it connects consecutive terms together. Thus, it affects the intensity vectors of corresponding periods as well as their slack variables indirectly.

Corresponding to each category of carry-overs, we can have the following equations in our model:

$$\sum_{\mathrm{j}=1}^{\mathrm{n}} \lambda_j^{k,t}\, z_{jgood}^{k_l,(t,t+1)} - s_{ogood}^{k_l,(t,t+1)} = z_{ogood}^{k_l,(t,t+1)} \quad (k_l = 1, \dots, ngood_k; \forall k;\ \forall t) \tag{5a}$$

$$\sum_{\mathrm{j}=1}^{\mathrm{n}} \lambda_j^{k,t}\, z_{jbad}^{k_l,(t,t+1)} + s_{obad}^{k_l,(t,t+1)} = z_{obad}^{k_l,(t,t+1)} \quad (k_l = 1, \dots, nbad_k; \forall k;\ \forall t) \tag{5b}$$

$$\sum_{\mathrm{j}=1}^{\mathrm{n}} \lambda_j^{k,t}\, z_{jfree}^{k_l,(t,t+1)} + s_{ofree}^{k_l,(t,t+1)} = z_{ofree}^{k_l,(t,t+1)} \quad (k_l = 1, \dots, nfree_k; \forall k;\ \forall t) \tag{5c}$$

$$\sum_{j=1}^{n} \lambda_j^{k,t}\, z_{jfixed}^{k_l,(t,t+1)} = z_{ofixed}^{k_l,(t,t+1)} \quad (k_l = 1, \dots, nfixed_k; \forall k;\ \forall t) \tag{5d}$$

$$s_{ogood}^{k_l,(t,t+1)} \geq 0, s_{obad}^{k_l,(t,t+1)} \geq 0, \text{ and } s_{ofree}^{k_l,(t,t+1)}: free(\forall k_l; \forall t)$$

Where $s_{ofree}^{k_l,(t,t+1)}$, $s_{obad}^{k_l,(t,t+1)}$ and $s_{ogood}^{k_l,(t,t+1)}$ are slacks denoting, respectively, carry-over deviation, carry-over excess and carry-over shortfall. Also, the constants $nfree_k$, $nbad_k$, and $ngood_k$ indicate, respectively, the number of free, undesirable (bad) and desirable (good) carry-overs of division k.

4.4 Non-Oriented Overall Efficiency

The quality of cloud technologies can be determined using QoS attributes such as security, availability, reliability, throughput, and so on [55]. The cloud-based banks' branches are not exceptional and their quality can be computed based on these attributes too. In this study, we aim to evaluate the performance of them based on their QoS attributes. We define our objective function in terms of the QoS-related factors in the case of the non-oriented model as presented in (6). This objective function maximizes QoS-related factors and minimizes cost items simultaneously. Its numerator includes the average input efficiency of division k $(k = 1, \dots, K)$ at period t $(t = 1, \dots, T)$ measured based on the slacks of cost items. Whereas the denominator contains the inverse of the average output efficiency of divisions at different periods measured by the slacks of QoS attributes (outputs). If all slacks are zero, the optimum value of this model (θ_o^*) attains unity; otherwise ,its values range between 0 and 1. As mentioned, we assume that link flows and carry-overs contain commercial (functional) data (see Fig. 1), so we don't incorporate terms related to their slacks into the objective function. Hence, the related constraints that include free slacks are not considered in the proposed model because they do not affect the amount of efficiency score (Constraints (3c) and (5c)). Accordingly, we only select constraints (2), (3d), (3e), (4), (5a), (5b), (5d) and [(3a) or (3b)] in our model to exert an indirect effect in the efficiency evaluation. The selection between discretionary and non-discretionary constraints depends on the properties of the business environment. This model is units-invariant, hence different measurement metrics of QoS attributes do not affect the accuracy of results.

$$\theta_o^* = \min_{\lambda^{k,t}, s^{k,t-}, s^{k,t+}} \frac{\sum_{t=1}^{T} w^t \left[\sum_{k=1}^{K} w^k \left[1-\frac{1}{m_k}\left(\sum_{i=1}^{m_k} \frac{s_{io}^{k,t-}}{x_{io}^{k,t}}\right)\right]\right]}{\sum_{t=1}^{T} w^t \left[\sum_{k=1}^{K} w^k \left[1+\frac{1}{r_k}\left(\sum_{r=1}^{r_k} \frac{s_{ro}^{k,t+}}{y_{ro}^{k,t}}\right)\right]\right]} \tag{6}$$

Subject to: $(2), (3d), (3e), (4), (5a), (5b), (5d), \text{and } [(3a) \text{ or } (3b)]$

Where w^k $(k = 1, \dots, K)$ represent the relative weight of division k in the composite service and pre-specified by the service provider exogenously where satisfies the following condition:

$$\sum_{k=1}^{K} w^k = 1, \quad w^k \geq 0, \quad (\forall k) \tag{7}$$

Also, w^t $(t = 1, \dots, T)$ represent the relative weight of period t which pre-specified by the service provider exogenously and satisfies the following condition:

$$\sum_{t=1}^{T} w^t = 1, \quad w^t \geq 0, \quad (\forall t) \tag{8}$$

If $\theta_o^* = 1$ then DMU$_o$ is efficient; otherwise, it is inefficient and its efficiency score lies in the range of 0–1.

4.5 Non-Oriented Divisional and Period Efficiencies

Using the optimal solutions of (5) $\left(s_i^{k,t-*} \text{ and } s_r^{k,t+*}\right)$, we compute divisional and period efficiencies by (9) and (10), respectively.

$$\delta_o^{k*} = \frac{\sum_{t=1}^{T} w^t \left[1-\frac{1}{m_k}\left(\sum_{i=1}^{m_k} \frac{s_{io}^{k,t-*}}{x_{io}^{k,t}}\right)\right]}{\sum_{t=1}^{T} w^t \left[1+\frac{1}{r_k}\left(\sum_{r=1}^{r_k} \frac{s_{ro}^{k,t+*}}{y_{ro}^{k,t}}\right)\right]}, \quad (k = 1, \dots, K) \tag{9}$$

$$\tau_o^{t*} = \frac{\sum_{k=1}^{K} w^k \left[1-\frac{1}{m_k}\left(\sum_{i=1}^{m_k} \frac{s_{io}^{k,t-*}}{x_{io}^{k,t}}\right)\right]}{\sum_{k=1}^{K} w^k \left[1+\frac{1}{r_k}\left(\sum_{r=1}^{r_k} \frac{s_{ro}^{k,t+*}}{y_{ro}^{k,t}}\right)\right]}, \quad (t = 1, \dots, T) \tag{10}$$

Finally, the period-divisional efficiency is computed by (11).

$$\rho_o^{k,t*} = \frac{1-\frac{1}{m_k}\left(\sum_{i=1}^{m_k}\frac{s_{io}^{k,t-*}}{x_{io}^{k,t}}\right)}{1+\frac{1}{r_k}\left(\sum_{r=1}^{r_k}\frac{s_{ro}^{k,t+*}}{y_{ro}^{k,t}}\right)},\ (t=1,\dots,T),(k=1,\dots,K) \tag{11}$$

5 Evaluating Bank Branches

In this section, we conduct our experiment using (6) to evaluate 40 branches of a commercial bank in Iran in a specific time span.

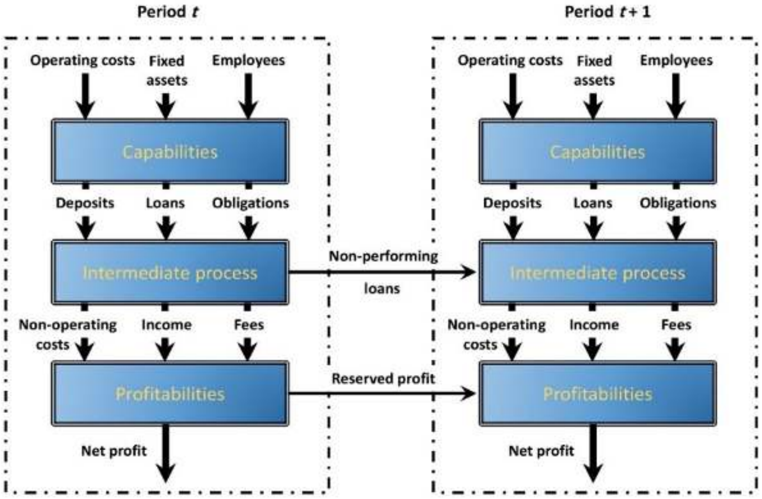

Fig. 2: The Commercial Perspective of The Banking Example in Iran Over Two Consecutive Periods

Table 1: The Identified Variables in the Cloud-Based Banking System

Type	Variable name	Description
Inputs	Operating costs	They are expenditures associated with the administration and maintenance of the organization on a daily basis.
	Fixed assets	They are tangible long-term assets or parts of the equipment that are not anticipated to be consumed within a year or converted into cash.
	Employees	Persons who hired under specific contracts to do jobs.
Intermediate links	Deposits	Sum of money that held at a bank for safekeeping.
	Loans	Amount of money that has been borrowed by customers.
	Obligations	Bank obligations mean all liabilities and indebtedness of borrowers to banks under the agreement documents.
	Non-operating costs	They are the expenses which not related to the principal activities of a business, such as paying profits to deposits.
	Income	Money obtained from loans granted.
	Fees	They cover all charges received by a bank from its customers, such as transaction and deposit fees.
Carry-overs	Non-performing loan	It is a loan in which the debtor has not made the scheduled payments for a specified period of time, and be considered as the undesirable carry-overs.
	Reserved profit	Part of the profits that are reserved for future investments and projects, and be considered as the desirable carry-overs.
Output	Net profit	It is calculated by subtracting the total earned profit from the reserved profit.

Fig. 2 demonstrates the commercial perspective of branches which were consisted of three sequential cloud-based divisions in two consecutive periods and after that, interviews with business environment experts is extracted. In this section, we aim to evaluate branches in a time span covering these periods. The inputs, intermediate links, carry-overs, and output of this system are explained in Table 1.

Table 2: A QoS Model to Evaluate the Internet Banking Industry in Iran

Dimensions	**Attributes**	**Definitions**
Cost	Price	Execution fee per a request.
Performance	Response-time	It is the elapsed time between sending a request to a cloud service and receiving the response from it.
Dependability	Availability	It is calculated as the percentage of time that the cloud service is accessible and responds to requests.
Dependability	Reliability	It is defined as the probability that the cloud service performs its function, without failure.

In this study, we evaluate the cloud-based banking branches based on their QoS attributes. In this regard, there are several measurement indices that have been identified by the Cloud Service Measurement Index Consortium (CSMIC) and have been aggregated under a framework called Service Measurement Index (SMI) [56]. These measurements can be used by decision-makers to evaluate the quality of Internet banking services. Response-time, stability, transparency, suitability, reliability, availability, adaptability, cost, usability, and elasticity are examples of the proposed metrics of SMI. In this experiment, we define a QoS model which was consisted of four attributes. The chosen QoS attributes are explained in Table 2. Fig. 3 depicts the non-functional perspective of the branches under evaluation regarding the defined QoS model. As it is seen, we considered response-time, reliability, and availability as outputs and cost as an input. Since response-time is an undesirable output, it is treated as an input so that its values are limited to be not greater than the observed ones.

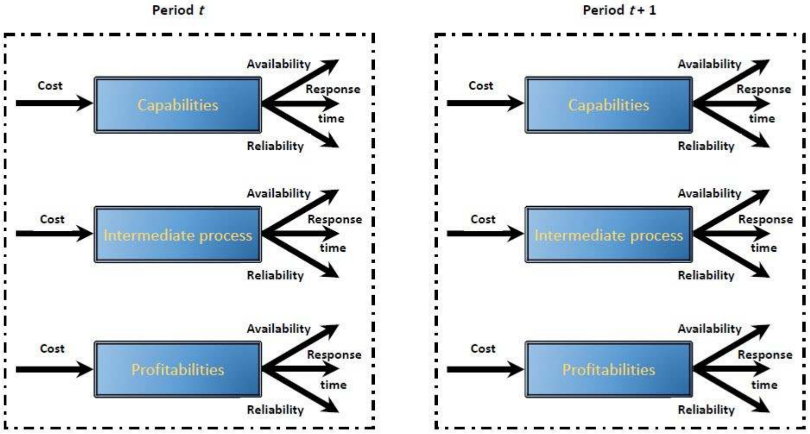

Fig. 3: The Non-Functional Perspective of The Banking Example in Iran Over Two Consecutive Periods

This study proposed a DNDEA model within the slack-based framework to evaluate cloud-based bank branches. To conduct our experiment, we should find an appropriate dataset that includes the QoS attributes as well as commercial data of the banking industry over two consecutive periods. There is currently no open dataset that includes all of this data.

Table 3: Statistics of Dataset

Types of attributes	Type	Attribute name	Period	Minimum	Maximum	Mean	Standard deviation
Non-functional (QoS) attributes	Input	Cost	t	9.1149	98.9199	50.9351	15.9863
			t+1	7.9461	89.6899	48.1534	13.0780
	Outputs	Response-Time	t	43	3484	405.510	568.637
			t+1	42.5	4480.8	389.914	667.367
		Availability	t	18	100	80.9500	17.8550
			t+1	19	100	81.6250	17.9181
		Reliability	t	50	83	68.6166	8.38684
			t+1	42	83	69.1583	7.72967
Commercial attributes	Inputs	Operating costs	t	0.12245	0.35788	0.26458	0.04908
			t+1	0.23369	0.47960	0.36925	0.05626
		Fixed assets	t	0.01117	0.02757	0.01956	0.00388
			t+1	0.01350	0.02516	0.01944	0.00347
		Employees	t	2	14	7.75	2.16910
			t+1	2	15	8.95	2.85504
	Intermediate links between division 1 and 2	Deposits	t	0.52156	0.95118	0.72160	0.11077
			t+1	0.59425	1.03022	0.82878	0.11246
		Loans	t	0.21445	0.47191	0.35886	0.05505
			t+1	0.07214	0.17178	0.12826	0.02558
		Obligations	t	0.05847	0.13799	0.10691	0.01731
			t+1	0.04977	0.12967	0.09974	0.01833
	Intermediate links between division 2 and 3	Non-operating costs	t	0.01076	0.02732	0.01932	0.00376
			t+1	0.00963	0.02898	0.01896	0.00392
		Income	t	0.01244	0.02304	0.01662	0.00247
			t+1	0.01045	0.02447	0.01635	0.00361
		Fees	t	0.00155	0.00467	0.00331	0.00072
			t+1	0.00225	0.00488	0.00357	0.00059
	Output	Net profit	t	0.01003	0.02732	0.02012	0.00332
			t+1	0.01252	0.03162	0.02164	0.00360
	Carry-overs	Non-performing loans	t -> (t+1)	1.20748	2.12287	1.63852	0.24680
		Reserved profit	t -> (t+1)	0.36366	2.47854	1.62373	0.41418

Hence, to be more realistic, we use a synthesized dataset. In detail, we randomly selected 40 cloud services and their corresponding QoS values from the QWS dataset which was collected by Al-Masri and Quasay [57]. The missing QoS parameter (cost item) and their corresponding values were randomly generated using a controlled random generation methodology by MATLAB R2019b Software. We analyzed the generated data using the Kolmogorov-Smirnov and Shapiro–Wilk tests by IBM SPSS Statistics 23 Software, and the results revealed that the cost items were normally distributed [58, 59]. Moreover, the commercial values of our dataset consist of observations on 40 branches of an Iranian bank in 2018 and 2019. Table 3 includes a summary of our dataset used in the experiment[1]. In this experiment, we consider pre-specified equal weights for all divisions and periods. In detail, we assign an equal weight of 0.33333 to all divisions and an equal weight of 0.5 to all periods so that it meets (7) and (8).

Table 4: Evaluation Results of the Proposed Model

DMUs	Overall	Division 1	Division 2	Division 3	Period 1	Period 2
DMU01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU02	0.9391	0.8183	1.0000	1.0000	0.8786	1.0000
DMU03	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU04	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU05	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU06	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU07	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU08	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU09	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU12	0.8847	0.6694	1.0000	1.0000	0.8310	0.9410
DMU13	0.9755	1.0000	1.0000	0.9276	1.0000	0.9514
DMU14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU15	0.8005	0.8104	1.0000	0.6245	0.6295	1.0000
DMU16	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU17	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU18	0.9388	0.8163	1.0000	1.0000	1.0000	0.8775
DMU19	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU20	0.9564	0.8692	1.0000	1.0000	0.9128	1.0000
DMU21	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU22	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU23	0.9432	1.0000	1.0000	0.8305	1.0000	0.8867
DMU24	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU26	0.8927	0.6967	1.0000	1.0000	0.7918	1.0000
DMU27	0.9687	1.0000	1.0000	0.9079	1.0000	0.9380
DMU28	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU29	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU31	0.9200	1.0000	1.0000	0.7630	1.0000	0.8410
DMU32	0.9126	0.7400	1.0000	1.0000	1.0000	0.8259
DMU33	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU34	0.9385	1.0000	1.0000	0.8171	0.8775	1.0000
DMU35	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU36	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU37	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU38	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU39	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU40	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Regarding properties of the banking industry, all links and carry-overs are assumed free, e.g.

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[1] The unit of all data except Employees is Billion Rials.

Deposits and Fees. Therefore, to model intermediate links, we choose constraint (3a) from constraints (3a) and (3b). Now, we run the proposed model coded using GAMS 24.1.2 Software.

Table 5: The Period-Divisional Efficiencies of The Banking Example in Iran Over Two Consecutive Periods

DMUs	Overall	Division1 at period 1	Division 1 at period 2	Division 2 at period 1	Division 2 at period 2	Division 3 at period 1	Division 3 at period 2
DMU01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU02	0.9391	0.6392	1.0000	1.0000	1.0000	1.0000	1.0000
DMU03	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU04	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU05	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU06	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU07	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU08	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU09	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU12	0.8847	0.5348	0.8231	1.0000	1.0000	1.0000	1.0000
DMU13	0.9755	1.0000	1.0000	1.0000	1.0000	1.0000	0.8584
DMU14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU15	0.8005	0.6402	1.0000	1.0000	1.0000	0.3537	1.0000
DMU16	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU17	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU18	0.9388	1.0000	0.6326	1.0000	1.0000	1.0000	1.0000
DMU19	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU20	0.9564	0.7383	1.0000	1.0000	1.0000	1.0000	1.0000
DMU21	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU22	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU23	0.9432	1.0000	1.0000	1.0000	1.0000	1.0000	0.6640
DMU24	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU26	0.8927	0.4415	1.0000	1.0000	1.0000	1.0000	1.0000
DMU27	0.9687	1.0000	1.0000	1.0000	1.0000	1.0000	0.8205
DMU28	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU29	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU31	0.9200	1.0000	1.0000	1.0000	1.0000	1.0000	0.5348
DMU32	0.9126	1.0000	0.4867	1.0000	1.0000	1.0000	1.0000
DMU33	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU34	0.9385	1.0000	1.0000	1.0000	1.0000	0.6389	1.0000
DMU35	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU36	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU37	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU38	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU39	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU40	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 4 reports overall, divisional, and period efficiencies of the bank branches. All of these results lie in the range of 0–1, and this issue confirms that our DEA model is feasible and bounded. The second column of this table represents the overall efficiency of branches. As it is seen, 28 efficient DMUs were identified and branch 15 has the worst efficiency score among them. The next three columns represent the results of (9). We can also detect inefficient divisions using the obtained results. For example, the main potential inefficiencies (improvements) of DMU 2 lie in division 1. From another aspect, divisions 2 are all efficient while the majority of inefficiencies are embedded in divisions 1 and 3.

Table 6: Overall and Period Efficiencies of The Input-Oriented DNDEA Model

DMUs	Overall	Period 1	Period 2
DMU01	1.0000	1.0000	1.0000
DMU02	0.9414	0.8829	1.0000
DMU03	1.0000	1.0000	1.0000
DMU04	1.0000	1.0000	1.0000
DMU05	1.0000	1.0000	1.0000
DMU06	1.0000	1.0000	1.0000
DMU07	1.0000	1.0000	1.0000
DMU08	1.0000	1.0000	1.0000
DMU09	1.0000	1.0000	1.0000
DMU10	1.0000	1.0000	1.0000
DMU11	1.0000	1.0000	1.0000
DMU12	0.9051	0.8692	0.9410
DMU13	0.9829	1.0000	0.9657
DMU14	1.0000	1.0000	1.0000
DMU15	0.8647	0.7293	1.0000
DMU16	1.0000	1.0000	1.0000
DMU17	1.0000	1.0000	1.0000
DMU18	0.9388	1.0000	0.8775
DMU19	1.0000	1.0000	1.0000
DMU20	0.9564	0.9128	1.0000
DMU21	1.0000	1.0000	1.0000
DMU22	1.0000	1.0000	1.0000
DMU23	0.9460	1.0000	0.8920
DMU24	1.0000	1.0000	1.0000
DMU25	1.0000	1.0000	1.0000
DMU26	0.9204	0.8407	1.0000
DMU27	0.9774	1.0000	0.9549
DMU28	1.0000	1.0000	1.0000
DMU29	1.0000	1.0000	1.0000
DMU30	1.0000	1.0000	1.0000
DMU31	0.9259	1.0000	0.8519
DMU32	0.9152	1.0000	0.8304
DMU33	1.0000	1.0000	1.0000
DMU34	0.9426	0.8853	1.0000
DMU35	1.0000	1.0000	1.0000
DMU36	1.0000	1.0000	1.0000
DMU37	1.0000	1.0000	1.0000
DMU38	1.0000	1.0000	1.0000
DMU39	1.0000	1.0000	1.0000
DMU40	1.0000	1.0000	1.0000

We can analyze the efficiency of branches using this Table in more detail. Each column of this

Table includes the efficiency of a specific division at a certain period. In the output-oriented DNDEA model, the overall efficiency is the weighted harmonic mean of the period-efficiencies and the overall efficiency of the input-oriented DNDEA model is the weighted arithmetic mean of them whereas in the case of non-oriented, the overall efficiency is neither harmonic nor arithmetic mean of the period-efficiencies [10]. Also, branches 12 and 15 have respectively least efficiencies with respect to the divisions 1 and 3. The two next columns include the results of (10). Using these columns, we can probe the efficiency of branches in specific time spans (2018 and 2019). In 2018, 34 branches were efficient and branch 15 has had the worst performance. In 2019, the number of efficient branches has been reduced to 33, and branch 32 has the worst efficiency score. The results of (10) are given in Table 5. The results of Table 4 are obtained from (6). Hence, we cannot find any meaningful relationship among its columns. Table 6 includes the input-oriented efficiencies of our DNDEA model. The second column of this table represents the overall system efficiency. The two next columns are corresponding results of (10) and represent period efficiencies in 2018 and 2019. We observe that the overall efficiency is the arithmetic mean of these columns. The GAMS program code, which is used to calculate the results of Table 4, is given in the appendix.

Table 7: The QoS Aggregation Functions for Sequential Composition Model

QoS Attributes	**Aggregation Functions**
Cost (C)	$\sum_{i=1}^{k} C(s_i)$
Response Time (RT)	$\sum_{i=1}^{k} RT(s_i)$
Availability (A)	$\prod_{i=1}^{k} A(s_i)$
Reliability (R)	$\prod_{i=1}^{k} R(s_i)$

In Tables 4 and 5, the proposed model rated 28 DMUs (the majority of DMUs) as the overall efficient ones and they cannot be ranked more precisely. This issue may be unsuitable for business analysts who wish to uncover the source of inefficiencies in the organizations since they cannot detect all of the inefficient organizations correctly. To test the discrimination power of our model, we compare the proposed model against the conventional slack-based DEA model [43]. To this end, we aggregate the QoS values of our dataset at each period using the aggregation functions of Table 7 [60]. This Table only includes aggregation functions of sequential patterns because the divisions of this experiment are all connected together sequentially. Note that in the sequential composition model, k indicates the number of divisions. The aggregative QoS values can be computed by recursively applying functions represented in this Table. In the classical slack-based DEA model, the number of DMUs conforms to the rule of thumb $n \geq max\{3 \times (m + s)\ ,\ (m \times s)\}$ where m and s are the numbers of inputs and outputs, respectively [61]. Hence, the CCR DEA model has sufficient DMUs in its evaluations. Table 8 includes the results of the CCR model. As it is seen in this Table, 25 DMUs drop out from the class of the overall efficient DMUs compared to the DMUs in Table 4 (For example see DMUs 14 and 40), and the number of overall efficient DMUs was reduced from 28 to 4. We can easily conclude that the proposed model suffers from the discrimination power problem when the number of available DMUs is relatively small with respect to the number of intermediate links, carry-overs, inputs, and outputs. In other words, the internal structure of the banking systems over multiple periods has many referrals. Thus, the evaluation of banking branches requires many DMUs which may be unavailable for decision-makers. We can consider this problem as the main drawback of using our DNDEA model in the banking industry.

Table 8: The Results of The Classical Slack-Based DEA Model

DMUs	Efficiency	DMUs (Cont.)	Efficiency (Cont.)
DMU01	0.498	DMU21	0.324
DMU02	0.417	DMU22	0.525
DMU03	1.000	DMU23	0.510
DMU04	0.518	DMU24	0.324
DMU05	0.337	DMU25	0.577
DMU06	0.444	DMU26	0.450
DMU07	0.329	DMU27	0.557
DMU08	0.515	DMU28	0.433
DMU09	0.606	DMU29	0.162
DMU10	1.000	DMU30	0.509
DMU11	1.000	DMU31	0.557
DMU12	0.385	DMU32	1.000
DMU13	0.529	DMU33	0.472
DMU14	0.379	DMU34	0.700
DMU15	0.227	DMU35	0.632
DMU16	0.228	DMU36	0.446
DMU17	0.442	DMU37	0.186
DMU18	0.628	DMU38	0.348
DMU19	0.363	DMU39	0.371
DMU20	0.375	DMU40	0.105

6 Conclusions

In the recent decade, with the proliferation of cloud computing, intense competition has been formed among banks of Iran. Thus, banks need to evaluate their performance regularly in order to achieve significant market shares in the highly competitive environment of the e-banking industry. Although there are considerable studies in this field, this paper presents a higher level of sophisticated DEA model to evaluate the e-banking industry in more depth. In detail, this paper proposed a modified DNDEA model regarding the internal structure of the banks' branches over two consecutive periods to evaluate their performance based on the QoS attributes in a specific time span. The proposed model is able to consider all possible interactions among cloud-based divisions across time to obtain more realistic results.

The evaluation results of 40 bank branches in Iran indicated that the number of efficient units has been reduced from 2018 to 2019. Moreover, they represented that most of the inefficiencies found in divisions 1 and 3. Decision-makers are also able to analyze the cloud-based divisions at a specific period using our model. Finally, we observed that the proposed model faces the challenge of lack of discrimination power when the number of DMUs is not sufficiently large as compared to the total number of referrals. In future work, we plan to improve the discrimination power of our model using methods such as goal programming [62] and minimizing the coefficient of variation (CV) for inputs-outputs weights [63]. In addition, due to the uncertainty of QoS values, we intend to extend our model to the uncertain DEA approaches such as fuzzy DEA [64-66], interval DEA [67-69], and robust DEA [70-72]. Also, we plan to apply our model to other applications [73-75] in future studies.

Appendix

In this section, we present the GAMS program code which computed the results of Table 4 as follows:

```
$title A Dynamic Network Slack-based Measure (DNSBM) Model to assess the efficiency of bank
branches in Iran.
$ontext
"Dynamic Network DEA: A slacks-based measure approach Branches of
Commercial Banks in Iran".
$offtext
$onsymxref
$onsymlist
$onuellist
$onuelxref
Sets
  i  "Inputs"           /i1 "Cost", i2 "Response-Time"/
  r  "Outputs"          /o1 "Reliability", o2 "Availability"/
  j  "Units"            /DMU01*DMU40 "Cloud services"/
  k  "divisions"        /div1*div3 "Divisions"/
  kh "Free links"       /kh12  "Between divisions 1 & 2", kh23  "Between divisions 2 & 3"/
  p  "Items in link"  /p1*p3 "Intermediate links between divisions"/
  t  "periods"          /0 "Period t", 1 "Period (t+1)"/;

Alias(j,iteration);

Variables
    e                  "Overall efficiency"
    Lambda(k,t,j)  "Intensity vectors"
    s(i,k,t)            "Input excess of divisions over periods"
    q(r,k,t)           "Output shortfall of divisions over periods"
    u(k,p,t)           "Slacks of as-input  links for divisions over periods"
    v(k,p,t)           "Slacks of as-output links for divisions over periods"
    g                  "Slack of desirable   carry-over (Reserved profit) of division 2"
    b                  "Slack of undesirable carry-over (Non-performing loans) of division 3"
    k1                 "Efficiency of division 1 over periods"
    k2                 "Efficiency of division 2 over periods"
    k3                 "Efficiency of division 3 over periods"
    t1                 "Efficiency of period t"
    t2                 "Efficiency of period (t+1)";
    Positive Variables
        Lambda
        s
        q
        u
        v
        g
        b;
```

```
Parameters
*     Weights of divisions:
      w1(k) /div1 0.33333333, div2 0.33333333, div3 0.33333333/
*     Weights of periods:
      w2(t) /0 0.5, 1 0.5/
      xo(i,k,t)     "Inputs  of divisions of DMU under evaluation over periods"
      yo(r,k,t)     "Outputs of divisions of DMU under evaluation over periods"
      zoIn(k,p,t)   "Current as-inputs  link values between divisions over periods"
      zoOut(k,p,t) "Current as-outputs link values between divisions over periods"
     m              "Number of inputs of divisions"
     n              "Number of outputs of divisions"
     Results(iteration,*) Results of loop;

scalars
     co1 "Current carry-over (Non-performing loans) value between periods t & (t+1)"
     co2 "Current carry-over (Reserved profit) value between periods t & (t+1)";

m=Card(i);
n=Card(r);

Equations
     Objective     "Objective function"
     Const1(i,k,t) "Input  constraints over periods"
     Const2(r,k,t) "Output constraints over periods"
     Const3(p,t)   "Free link constraints between division 1 and division 2 over periods"
     Const4(p,t)   "Free link constraints between division 2 and division 3 over periods"
     Const5(k,p,t) "As-input  link constraints of divisions over periods"
     Const6(k,p,t) "As-output link constraints of divisions over periods"
     Const7        "Undesirable carry-over (Non-performing loans) constraint of division 2"
     Const8        "Desirable   carry-over (Reserved profit) constraint of division 3"
     Const9        "Common carry-over constraint for keeping Continuity between periods of division
2"
     Const10       "Common carry-over constraint for keeping Continuity between periods of division
3"
     BCC(k,t)      "BCC constraints";

Objective..e=e=Sum(t,w2(t)*Sum(k,w1(k)*(1-
(1/m)*Sum(i,s(i,k,t)/xo(i,k,t)))))/Sum(t,w2(t)*Sum(k,w1(k)*(1+(1/n)*Sum(r,q(r,k,t)/yo(r,k,t)))));
Const1(i,k,t) .. Sum(j,x(i,k,t,j)*Lambda(k,t,j))+s(i,k,t)       =e= xo(i,k,t);
Const2(r,k,t) .. Sum(j,y(r,k,t,j)*Lambda(k,t,j))-q(r,k,t)       =e= yo(r,k,t);
Const3(p,t)   .. Sum(j,zFree('kh12',p,t,j)*Lambda('div1',t,j))=e=
Sum(j,zFree('kh12',p,t,j)*Lambda('div2',t,j));
Const4(p,t)   .. Sum(j,zFree('kh23',p,t,j)*Lambda('div2',t,j))=e=
Sum(j,zFree('kh23',p,t,j)*Lambda('div3',t,j));
Const5(k,p,t).. Sum(j,zIn(k,p,t,j) *Lambda(k,t,j))+u(k,p,t)   =e= zoIn(k,p,t);
Const6(k,p,t).. Sum(j,zOut(k,p,t,j)*Lambda(k,t,j))-v(k,p,t)  =e= zoOut(k,p,t);
```

```
Const7        .. Sum(j,c1(j)*Lambda('div2','0',j))+b           =e= co1;
Const8        .. Sum(j,c2(j)*Lambda('div3','0',j))-g           =e= co2;
Const9        .. Sum(j,c1(j)*Lambda('div2','0',j))             =e= Sum(j,c1(j)*Lambda('div2','1',j));
Const10       .. Sum(j,c2(j)*Lambda('div3','0',j))             =e= Sum(j,c2(j)*Lambda('div3','1',j));
BCC(k,t)     .. Sum(j,lambda(k,t,j)) =e= 1;

Option decimals=4;
Option mip=Cplex;
Model  DNSBM_model /All/;

Loop(iteration,
    Loop(t,
       Loop(k,
           Loop(i,xo(i,k,t) =x(i,k,t,iteration));
           Loop(r,yo(r,k,t) =y(r,k,t,iteration));
           );
    Loop(p,zoIn(k,p,t)  =zIn(k,p,t,iteration));
    Loop(p,zoOut(k,p,t) =zOut(k,p,t,iteration));
        );
    co1=c1(iteration);
    co2=c2(iteration);
    Solve DNSBM_model using NLP Minimizing e;
    k1.l=Sum(t,w2(t)*((1-
(1/m)*Sum(i,s.l(i,'div1',t)/xo(i,'div1',t)))))/Sum(t,w2(t)*((1+(1/n)*Sum(r,q.l(r,'div1',t)/yo(r,'div1',t)))))
;
    k2.l=Sum(t,w2(t)*((1-
(1/m)*Sum(i,s.l(i,'div2',t)/xo(i,'div2',t)))))/Sum(t,w2(t)*((1+(1/n)*Sum(r,q.l(r,'div2',t)/yo(r,'div2',t)))))
;
    k3.l=Sum(t,w2(t)*((1-
(1/m)*Sum(i,s.l(i,'div3',t)/xo(i,'div3',t)))))/Sum(t,w2(t)*((1+(1/n)*Sum(r,q.l(r,'div3',t)/yo(r,'div3',t)))))
;
    t1.l=Sum(k,w1(k)*(1-
(1/m)*Sum(i,s.l(i,k,'0')/xo(i,k,'0'))))/Sum(k,w1(k)*(1+(1/n)*Sum(r,q.l(r,k,'0')/yo(r,k,'0'))));
    t2.l=Sum(k,w1(k)*(1-
(1/m)*Sum(i,s.l(i,k,'1')/xo(i,k,'1'))))/Sum(k,w1(k)*(1+(1/n)*Sum(r,q.l(r,k,'1')/yo(r,k,'1'))));
    Results(iteration,'e*') = e.l;
    Results(iteration,'k1*')= k1.l;
    Results(iteration,'k2*')= k2.l;
    Results(iteration,'k3*')= k3.l;
    Results(iteration,'t1*')= t1.l;
    Results(iteration,'t2*')= t2.l;
    );

display Results;
```

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