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Development of a Hybrid Model for the Evaluation of Sustainable Supply Chains using Dynamic Network Data Envelopment Analysis

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Developing realistic models for the evaluation of sustainable supply chains has turned into a major challenge facing managers. The decision-making approaches proposed here consist of two stages. At the first stage, a dynamic-network data envelopment analysis (DNDEA) model is established for the first time, wherein the current efficiency of a business can be influenced by its prior social and environmental activities, as two main dimensions of sustainability. The second stage correspondingly presents, for the first time, a model in which total efficiency is calculated based on the value of historical data. Sensitivity analysis is exploited to determine the more effective factors of sustainability in efficiency evaluations. To validate the model, it is used to assess the sustainability of the suppliers of an auto spare parts manufacturer. The study results reveal that the model is well-able to evaluate the performance of dynamic network structures, with a very high discriminating power. Following the implementation of this model, only the supplier(KARAN) is found to reach the efficiency limit, and SIRIN S.N. is recognized as the most inefficient supplier with an efficiency score of 0.6409. The sensitivity analysis outcomes demonstrate that the least amount of efficiency change is related to the economic pillar; however, the rising trend in wage costs, compared with other economic factors, brings a better effect on augmenting the efficiency of some inefficient suppliers. The highest efficiency changes during sensitivity analysis are further observed in both social and environmental dimensions. Therefore, it is claimed that investing in these two pillars can have a significant impact on the efficiency of suppliers.

Keywords*: sustainable supply chain, data envelopment analysis, range-adjusted measure, efficiency, three pillars of sustainability*

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1. Introduction

Over recent decades, supply chain management has been extensively researched (Abdel-Basset et al.,[1]). This field significantly evolved between 1970 and 2000 with the advancement of communication technologies and the fading of strict geographical borders, which had exposed most businesses to more

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competitive environments, and even made them realize that operational or financial superiority was not enough to win competitions and attract or retain more customers (Geyi et al., [16]). Today, customers and all people, in general, expect companies and organizations to act responsibly and reflect on future generations in their own activities and operations (Zelazna et al., [39]). Following the introduction of the concept of sustainability to the field of supply chain management, numerous interpretations of this notion emerged (Abdel-Basset et al., [1]). Nevertheless, all these interpretations have been united in terms of taking a three-pronged approach to sustainability, comprised of three parts: economic sustainability, social sustainability, and environmental sustainability (Andarkhora et al., [5]). In this view, a sustainable supply chain is often created where the chain members meet the relevant requirements of environmental, social, and economic sustainability (Alirezaei et al., [3]). Currently, many companies rigorously evaluate their suppliers to ensure that they comply with sustainability considerations (Amiri et al.,[4]). As a result, various methods have been so far developed for such evaluations, including the data envelopment analysis (DEA) (Madadi et al., [27]), which was introduced in its initial form by Charnes et al. [9], based on the idea proposed by Farrell [14]. Over the years, this method has been developed and expanded by many researchers, proposing a number of DEA-based models with their own drawbacks and strengths. Given the multi-stage nature of the supply chain in this study and the flaws of classical DEA, as well as network DEA and dynamic DEA models, in analyzing such chains, the present study uses a model, called dynamic-network data envelopment analysis (DNDEA), which is capable of measuring network efficiency over multiple periods (Koronakos et al., [24]). As only the economic dimension of sustainability has been directly considered in supplier efficiency measurements in many studies, including Kalantary & Farzipoor Saen [22] ; Kalantary et al. [23], according to Giannakis and Papadopoulos [17], social and environmental variables should be also directly incorporated into organizational strategies.

With reference to the interviews with specialized groups of the Iranian Psychological Association and previous studies (Diener & Biswas-Diener, [12]), employees who have been successful in the past and have experienced job satisfaction, a sense of competence and meaning, freedom of choice, etc. feel more empowered to pursue their new goals, as these individuals understand that they have access to the necessary resources to achieve them. In other words, a sense of empowerment and the experience of successful actions can be regarded as a self-reinforcing loop. Such satisfied employees are thus more inclined to improve the efficiency of their employer organization (Ahakwa et al.,[2]). Simply put, people with positive feelings can be much more productive. Conversely, for individuals who have frequently failed in the past and have undergone workplace turmoil and stress, job dissatisfaction, working in poorly run personnel management systems, etc., the negative emotions stemming from these experiences can hinder the self-reinforcing loop, and consequently lead to depression, a sense of resignation, and poor individual efficiency and performance(Piccoli et al., [32]). Therefore, employee satisfaction can have a direct impact on the economic performance and efficiency of most organizations Some researchers even argue that environmental issues can gradually shape the daily operations of businesses, which can have significant implications for their performance in the long run (Yahya & Ha, [37]). For that reason, the past performance of an organization or a business in terms of environmental and social dimensions may affect its current performance. The paper makes the following contributions to the literature:

- Developing, for the first time, a hybrid model for the evaluation of sustainable supply chains, and presenting a case study to illustrate the application of the model.
- Proposing, for the first time, a model for efficiency evaluation based on the historical value of data (smoothing).
- Conducting a sensitivity analysis to determine which factors are more effective in such efficiency evaluations.

This paper aims to develop a DNDEA model based on the Range-Adjusted Measure (RAM) model proposed by Kalantary et al. [23]. Given the above, the authors believe that a company's current efficiency could be influenced by its past social and environmental activities, for the first time in the literature, this study examines how efficiency is impacted by these two variables. Also, for the first time, this study uses the historical value of data to calculate total efficiency; an approach that is expected to offer improved discriminating power and reliability compared to Kalantari's model. The rest of this paper is structured as follows: the theoretical framework of the research is discussed in Section 2. Section 3 describes the materials and methods. The findings and conclusions are presented in Sections ٤ and ٥ respectively.

2. Theoretical framework

In this section, we briefly review the literature on the methods used in the article.

2.1. Evaluation of sustainable supply chains

As mentioned, a sustainable supply chain rests on three main pillars: economic substantiality, social substantiality, and environmental substantiality, which are commonly referred to as the three dimensions of substantiality (Taghipour & Beneteau, [34]). In recent years, evaluation of the substantiality of supply chains has been the subject of many researchers, which have proposed and used various methods for this purpose (Amiri et al., [4]). For example, in Amiri [4]; Moktadir et al.[28], conventional multi-criteria decision-making (MCDM) methods have been used for supplier evaluation and selection. Some researchers such as Cui, Zhao, and Wang [11]; Jomthanachai et al. [21], have used the DEA method alone and Rashidi and Cullinane [33] used a combination of DEA with MCDM. In this paper, we use the model called DNDEA for the evaluation of sustainable supply chains.

2.2. Dynamic Network Data Envelopment Analysis

Early DEA models like CCR (Charnes et al.,[9]) and BCC (Banker et al., [8]) which consider the inputs and outputs of independent decision-making units (DMUs) simultaneously are very good tools for relative efficiency evaluations (Parashkouh et al., [30]). But these models have some drawbacks like ignoring the internal mechanisms of activities and DMUs (Azad et al., [7]). After initial studies of Farrell [14]and subsequent expansions in Chen et al. ([10]; Tone and Tsutsui [35]; Fukuyama and Weber [15] , researchers developed DEA models capable of measuring not only the total efficiency but also the divisional efficiency of DMUs in an integrated framework. This approach is known as Network Data Envelopment Analysis (NDEA). However, NDEA models are static and do not consider time which can cause them to produce misleading results based on short-term analyses (Lu et al., [26]). Later, Nemoto and Goto [29] introduced the Dynamic Data Envelopment Analysis (DDEA) model to address this issue, but this model treats DMUs as black boxes, completely ignoring their internal structure. Therefore, a model was needed to consider time as well as DMUs' internal structure. Several reviews of NDEA and DDEA models (Hashimoto & Fukuyama, [15]; Johnson & Pope, [20]) highlighted the need for extending dynamic DEA to network structures. One of the first studies to do so was Tone and Tsutsui (Tone & Tsutsui, [36]), where researchers considered a dynamic NDEA model and then developed a dynamic network DEA model based on slack variables (SBM).

2.3. Range adjusted measure (RAM) model

The Range Adjusted Measure (RAM) model was first proposed in 1999 by Cooper, Park, and Pasteur for measuring inefficiency in DEA (Park, [31]). Later, this concept was used for efficiency evaluation in classical models, network models (Heydari et al., [19]), and dynamic models(Li et al., [25]). RAM has several important features in terms of measuring efficiency. For example, it can provide a numerical indicator of efficiency even for cases involving negative and zero values (Avkiran & Mccrystal, [6]), different measurement units (Yakob et al., [38]), and large differences between the largest and smallest values (Avkiran & Mccrystal, [6]). This paper uses an input-oriented RAM model that is extended to the dynamic network model.

3. Materials and methods

3.1. Model

In this paper, the DNDEA model is developed based on the RAM model proposed by Kalantari et.al [23]. Considering the issues discussed in Section 1 of this paper and also according to Giannakis and Papadopoulos's study [17], organizational strategies should take into account social and environmental variables directly (rather than indirectly through other variables). In many of the existing models, where these two factors are considered indirectly, taking this approach has resulted in reduced discriminatory power, causing the model estimates not to reflect the reality of the situation. To resolve this issue, this study attempts to develop a model where the impact of economic, social, and environmental variables on the efficiency of decision-making units would be considered directly rather than indirectly through other variables. Unlike the model of Kalantari et al. [23], this model is formulated such that not only input variables but also carry-over variables have a direct effect on the objective function. Table (1) shows the Tone and Tsutsui (Tone & Tsutsui, [36]) classification of intermediate and carry-over variables

Table1. Classification of carry-over and intermediate variables

Intermediate measures	Carry-overs
Free	Free
Fixed	Fixed
Input intermediate	Good (play role of output)
Output intermediates	Bad (play role of input)

Thus, the proposed model (1) considers intermediate variables to be fixed and, unlike Kalantari's model [23], assumes carry-over variables to be free. Since the objective function of the RAM model calculates inefficiency, which equals one minus efficiency, that study has assumed that:

$$\min q = 1 - \frac{1}{T}\sum_{t=1}^{T}\frac{1}{K}\sum_{k=1}^{K}\frac{1}{m+u}\sum_{i=1}^{m}\sum_{u=1}^{U}\frac{S^{t}_{iok}}{R^{t}_{iok}} + \frac{S^{t-1,t}_{uok}}{R^{t-1}_{uok}}$$

s.t.

$$\begin{aligned}
&\sum_j^n x^t_{ijk}\lambda^t_{jk} + s^t_{iok} = x^t_{ijk}, && i = 1,\cdots,m,\ \forall K,T\\
&\sum_j^n l^t_{wj(k-h)}\lambda^t_{jk} = \sum_j^n l^t_{wj(k-h)}\lambda^t_{jh}, && w = 1,\cdots,W, k = 1,\cdots,K-1,\ \forall T\\
&\sum_j^n C^{t,t+1}_{ujk}\lambda^t_{jk} = \sum_j^n C^{t,t+1}_{ujk}\lambda^{t+1}_{jk}, && u = 1,\cdots,U,\ t = 1,\cdots,T-1, \forall K\\
&\sum_j^n C^{t,t+1}_{ujk}\lambda^t_{jk} \ge C^{t,t+1}_{uok}, && u = 1,\cdots,U,\ t = 1,\cdots,T-1, \forall K\\
&\sum_j^n C^{t-1,t}_{ujk}\lambda^t_{jk} + s^{t-1,t}_{uok} = C^{t-1,t}_{uok}, && u = 1,\cdots,U,\ \forall K\\
&\sum_j^n \lambda^t_{jk} = 1,\ \forall K,T, && \lambda^t_{jk}, s^t_{iok}, s^{t-1,t}_{uok} \ge 0,\ \forall i,j,r
\end{aligned} \tag{1}$$

Where:

x_{ijk}^{t} : The i_{th} input of the j_{th} DMU in the k_{th} station in time t

$C_{ujk}^{t,t+1}$: The $u_{th}(u=1,...,U)$ carry-over of the j_{th} DMU in the k_{th} station that is transferred from time t to time t+1

$C_{ujk}^{t-1,t}$: The $u_{t-1h}(u=1,...,U)$ carry-over of the j_{th} DMU in the k_{th} station that is transferred from time t-1 to time t

$l_{wj(k-h)}^{t}$: The $w_{th}(u=1,...,W)$ intermediate of the j_{th} DMU that is transferred from the k_{th} station to the h_{th} station at time t

R_{iok}^{t} : Range of inputs in time t; $R_{iok}^{t}=\max(x_{ijk}^{t})-\min(x_{ijk}^{t})$،

R_{uok}^{t-1} : Range of carry-over variables in time t-1; $R_{uok}^{t-1}=\max(C_{ujk}^{t-1,t})-\min(C_{ujk}^{t-1,t})$،

λ_{jk}^{t} : Intensity vector of the j_{th} DMU in the k_{th} station in time t

The total efficiency values obtained from the implementation of the model (1) and Kalantari's model [23] are equal to the arithmetic averaging of the annual efficiency of suppliers; an approach that assumes all data to be equal and ignores the potential significance of more (or less) data. in other words, many of the previous studies in this field have ignored an important issue, which is the time - period of the data for the evaluation, i.e., how older actions and achievements should have less impact on the evaluation so that more emphasis is put on more recent developments. To address this issue, the present study proposes, for the first time, a model that uses the historical value of data (namely, smoothing) to calculate the total efficiency of suppliers. For this purpose, in addition to calculating the total efficiency with Equation (1), the total efficiency of suppliers is recalculated with Equation (2).

$$\theta_T=\sum_{i=1}^{n}\frac{2\times i\times\theta_i}{n^2+n} \tag{2}$$

Where:

θ_i: Annual efficiency at time $i\left(i=1,2,\ ...\ ,n\right)$

n : The period of interest

Model (2) gives higher weights to the efficiency of more recent years. In other words, the weights given to the years increase depending on how close they are to the end of the studied period (Zhu et al., [40]). In other words, more recent efficiency values are better indicators of future potential than a significant yet unsustainable success achieved in the past. After executing the model of this research repeatedly with and without specific inputs and outputs, the examination of the results showed that it is highly practical, reflects reality, and provides reliable results.

3.2. Case study

To validate the proposed model, it was used to examine the sustainability of a company named Nirou Moharekeh Industries (NMI) from 2011 to 2015. NMI is an Iranian manufacturer of auto spare parts and has 12 suppliers. It is assumed that NMI aims to evaluate the overall, divisional, and annual efficiency of its suppliers. Each supplier has three stations including production, packaging, and distribution. The structure of the input, carry over, and intermediate variables over the five years are shown in Figure 1.

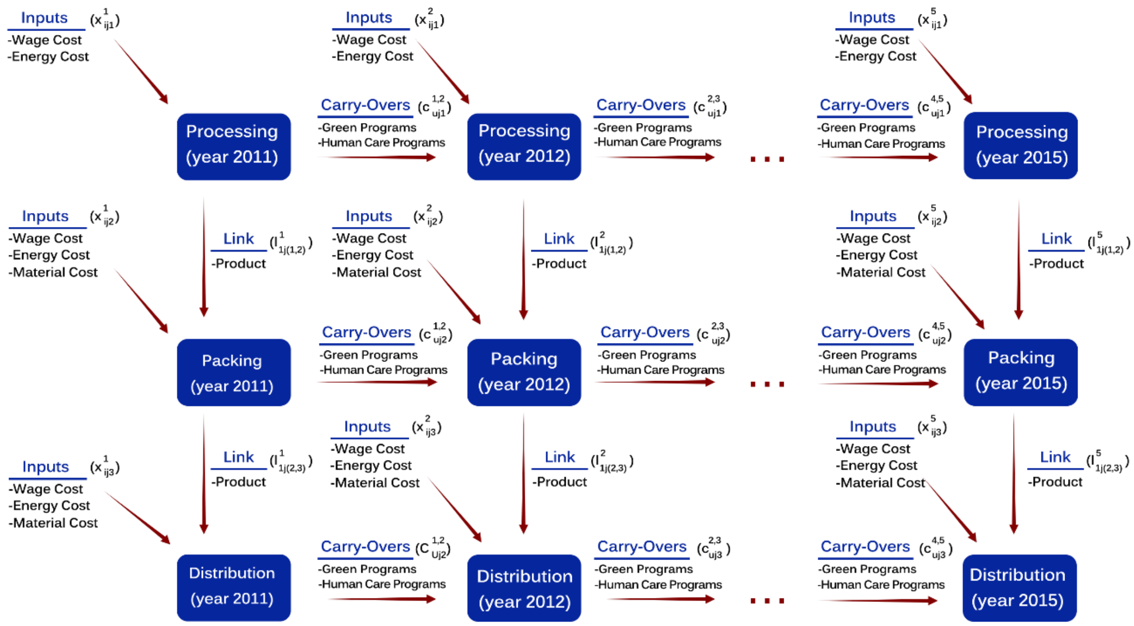

Figure1. Structure of the suppliers of NMI

Given that there are large differences between the smallest and largest input values, as stated earlier, the proposed model (Model 1) can be used. Table (2) shows the efficiency (divisional, annual, and total) of each supplier.

Using Model (1) and Table (2), the general status of DMUs in terms of efficiency/inefficiency was determined. Examining the efficiency scores showed that the proposed model has much higher discriminating power than Kalantari's model [23]. Next, the total efficiency of suppliers was recalculated while taking into account the historical value of data (Model 2) as discussed in Section 3-1. The results are presented in Table (3).

Table 2. Total efficiency while taking into account the historical value of data

DMUs	Overall efficiency	Rank	DMUs	Overall efficiency	Rank
TECH A.T	0.9877	4	PIROZ	0.9832	6
STEEL.P	0.8734	9	ALSAN	0.9851	5
D.L.KARAN	0.7713	11	KARAN	1.0000	1
PARSHAM	0.8278	10	TIR	0.9043	8
FARAZAN	0.9917	3	BARAN	0.9500	7
.SIRIN.S.N	0.6343	12	HAMRAH	0.9998	2

Using Model (2) changed the efficiency scores of some suppliers, which led to some changes in their ranking. This effect is discussed in the following section.

Table 3. Efficiency values of the suppliers of NMI

NO	DMUs	Rank	overall efficiency	Divisional efficiency			Term efficiency														
				div.1	**div.2**	**div.3**	**2011**			**2012**			**2013**			**2014**			**2015**		
							div1	div2	div3	div1	div2	div3	div1	div2	div3	div1	div2	div3	div1	div2	div3
1	TECH A.T	3	0.9926	1.0000	0.9794	0.9985		1.0000			1.0000			1.0000			1.0000			0.9631	
							1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8971	0.9923
2	STEEL.P	9	0.7910	0.8221	0.7842	0.7667		0.4460			0.6506			0.9690			1.0000			0.8894	
							0.4886	0.4220	0.4273	0.7455	0.6019	0.6046	1.0000	1.0000	0.9071	1.0000	1.0000	1.0000	0.8762	0.8972	0.8948
3	D.L.KARAN	10	0.7682	0.8165	0.7036	0.7845		0.4416			1.0000			1.0000			0.8703			0.5292	
							0.4649	0.4306	0.4293	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.6109	1.0000	0.6176	0.4767	0.4932
4	PARSHAM	11	0.7552	0.7640	0.7500	0.7515		0.5089			0.6867			0.6845			0.9973			0.8984	
							0.4558	0.5357	0.5352	0.7499	0.6554	0.6548	0.7169	0.6668	0.6697	0.9920	1.0000	1.0000	0.9055	0.8920	0.8978
5	FARAZAN	5	0.9865	0.9883	0.9854	0.9857		0.9845			0.9505			1.0000			0.9973			1.0000	
							0.9899	0.9815	0.9820	0.9598	0.9455	0.9462	1.0000	1.0000	1.0000	0.9920	1.0000	1.0000	1.0000	1.0000	1.0000
6	SIRIN S.N.	12	0.6409	0.6182	0.6346	0.6700		0.5939			0.7865			0.5878			0.5981			0.6383	
							0.5418	0.6180	0.6219	0.7918	0.7829	0.7848	0.6351	0.5307	0.5975	0.5121	0.6319	0.6504	0.6102	0.6096	0.6951
7	PIROZ	6	0.9827	0.9827	0.9825	0.9828		1.0000			0.9400			1.0000			1.0000			0.9735	
							1.0000	1.0000	1.0000	0.9409	0.9392	0.9399	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9725	0.9735	0.9742
8	ALSAN	4	0.9910	0.9923	0.9903	0.9903		0.9996			1.0000			1.0000			1.0000			0.9553	
							0.9988	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9627	0.9516	0.9516
9	KARAN	1	1.0000	1.0000	1.0000	1.0000		1.0000			1.0000			1.0000			1.0000			1.0000	
							1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	TIR	8	0.8490	0.8615	0.8412	0.8443		0.6640			0.6683			1.0000			1.0000			0.9127	
							0.6350	0.6762	0.6809	0.7638	0.6201	0.6210	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9090	0.9098	0.9194
11	BARAN	7	0.9120	0.9624	0.8550	0.9187		0.7059			0.9256			1.0000			0.9499			0.9787	
							0.8919	0.6128	0.6129	0.9445	0.8324	1.0000	1.0000	1.0000	1.0000	1.0000	0.8496	1.0000	0.9754	0.9803	0.9803
12	HAMRAH	2	0.9994	0.9983	1.0000	1.0000		0.9972			1.0000			1.0000			1.0000			1.0000	
							0.9917	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

3.3. Sensitivity analysis

The results of sensitivity analysis of efficiency scores of model (1) with respect to the cost of wages, raw materials, energy, investment in green projects, and human care programs are presented in Tables 4-8, respectively.

Table 4: sensitivity analysis of efficiency scores of suppliers given wage cost

increments	W[1]	TECH A.T	STEEL.P	D.L.KARAN	PARSHAM	FARAZAN	SIRIN.S.N.	PIROZ	ALSAN	KARAN	TIR	BARAN	HAMRAH
current	0	0.9926	0.7910	0.7682	0.7552	0.9865	0.6409	0.9827	0.9910	1	0.8490	0.9120	0.9994
1st	10	0.9938	0.7983	0.7943	0.7557	0.9865	0.6674	0.9827	0.9910	1	0.8490	0.9120	0.9994
2st	20	0.9965	0.8032	0.8011	0.7578	0.9865	0.6679	0.9827	0.9910	1	0.8490	0.9120	0.9985
3st	30	1	0.8033	0.8072	0.7579	0.9865	0.6681	0.9827	0.9910	1	0.8490	0.9120	0.9985
4st	40	1	0.8057	0.8092	0.7579	0.9871	0.6683	0.9827	0.9910	1	0.8490	0.9122	0.9985

1-(wage cost*10000000)

As Table (4) shows, the efficiency scores of every supplier changed with the wage cost. The efficiency scores of D.L.KARAN, STEEL.P, PARSHAM, and SIRIN.S.N. showed an increase in all four stages of sensitivity analysis. As is seen, the efficiency score of TECH.A.T is increased and after the third increase, this factory is an efficient supplier. But the efficiency score of HAMRAH decreased after the second increase in wage cost. There was no change in the efficiency scores of other suppliers. According to Table (5), the efficiency scores of D.L.KARAN, SIRIN S.N., and Tir decreased after the first increase in energy cost. Overall, a supplier KARAN remained efficient and the other suppliers had constant efficiency scores.

Table 5. Sensitivity analysis of efficiency scores of suppliers given energy cost

increments	E[1]	TECH A.T	STEEL.P	D.L.KARAN	PARSHAM	FARAZAN	SIRIN.S.N.	PIROZ	ALSAN	KARAN	TIR	BARAN	HAMRAH
current	0	0.9926	0.7910	0.7682	0.7552	0.9865	0.6409	0.9827	0.9910	1	0.8490	0.9120	0.9994
1st	10	0.9926	0.7910	0.7345	0.7552	0.9865	0.6389	0.9827	0.9910	1	0.8367	0.9120	0.9994
2st	20	0.9926	0.7910	0.7356	0.7552	0.9865	0.6388	0.9827	0.9910	1	0.8367	0.9120	0.9994
3st	30	0.9926	0.7910	0.7356	0.7552	0.9865	0.6388	0.9827	0.9910	1	0.8367	0.9120	0.9994
4st	40	0.9926	0.7910	0.7356	0.7552	0.9865	0.6388	0.9827	0.9910	1	0.8367	0.9120	0.9994

1-(energy cost*10000000)

As shown in Table (6), the efficiency scores of D.L.KARAN, SIRIN.S.N., HAMRAH, and Tir decreased after the first increase in the cost of raw materials. However, increasing this cost made no change in the efficiency scores of other suppliers.

Table 6. Sensitivity analysis of efficiency scores of suppliers given materials cost

increments	M[1]	TECH A.T	STEEL.P	D.L.KARAN	PARSHAM	FARAZAN	SIRIN.S.N.	PIROZ	ALSAN	KARAN	TIR	BARAN	HAMRAH
current	0	0.9926	0.7910	0.7682	0.7552	0.9865	0.6409	0.9827	0.9910	1	0.8490	0.9120	0.9994
1st	10	0.9926	0.7970	0.7486	0.7552	0.9865	0.6390	0.9827	0.9910	1	0.8367	0.9120	0.9976
2st	20	0.9926	0.7970	0.7487	0.7552	0.9865	0.6390	0.9827	0.9911	1	0.8367	0.9120	0.9976
3st	30	0.9926	0.7970	0.7487	0.7552	0.9865	0.6390	0.9827	0.9910	1	0.8367	0.9120	0.9976
4st	40	0.9926	0.7970	0.7487	0.7552	0.9865	0.6390	0.9827	0.9910	1	0.8367	0.9120	0.9975

1-(materials cost*10000000)

Table (7) shows the change in efficiency scores after increasing the cost of investment in green projects. The efficiency scores of all suppliers except KARAN, and HAMRAH increased with the increase in this cost. Tech.a.t is an inefficient supplier. However, after the third increase, it turns to an efficient DMU.

Table7. Sensitivity analysis of efficiency scores of suppliers given green projects

increments	G[1]	TECH A.T	STEEL.P	D.L.KARAN	PARSHAM	FARAZAN	SIRIN.S.N.	PIROZ	ALSAN	KARAN	TIR	BARAN	HAMRAH
current	0	0.9926	0.7910	0.7682	0.7552	0.9865	0.6409	0.9827	0.991	1	0.8490	0.912	0.9994
1st	10	0.9931	0.7994	0.7942	0.7556	0.987	0.6479	0.9947	0.991	1	0.8494	0.9363	0.9994
2st	20	0.9987	0.8021	0.7942	0.8184	0.9952	0.6539	0.9947	0.9922	1	0.8511	0.9363	0.9994
3st	30	1	0.8024	0.8101	0.8227	0.9952	0.6607	0.9947	0.9999	1	0.8511	0.9369	0.9994
4st	40	1	0.8148	0.8117	0.8267	0.9952	0.6705	0.9958	0.9999	1	0.8511	0.9389	0.9994

1-(investment in green projects*10000000)

After increasing the cost of investment in human care programs, the efficiency scores of TECH A.T. STEEL.P, D.L.KARAN, FARAZAN, SIRIN S.N, PARSHAM, ALSAN, TIR and BARAN increased, but there was no change in the efficiency scores of other suppliers (Table 8).

Table 8. Sensitivity analysis of efficiency scores of suppliers given human care programs

increments	H[1]	TECH A.T	STEEL.P	D.L.KARAN	PARSHAM	FARAZAN	SIRIN.S.N.	PIROZ	ALSAN	KARAN	TIR	BARAN	HAMRAH
current	0	0.9926	0.7910	0.7682	0.7552	0.9865	0.6409	0.9827	0.991	1	0.8490	0.9120	0.9994
1st	10	0.9926	0.7914	0.7931	0.7559	0.9865	0.6709	0.9827	0.9926	1	0.8490	0.9220	0.9994
2st	20	0.9928	0.7921	0.7942	0.7559	0.9865	0.6741	0.9827	0.9968	1	0.8672	0.9269	0.9994
3st	30	0.9928	0.7923	0.7942	0.7559	0.9866	0.7284	0.9827	0.9985	1	0.8671	0.9269	0.9994
4st	40	0.9928	0.8043	0.7942	0.7559	0.9873	0.7284	0.9827	0.9985	1	0.8695	0.9271	0.9994

1-(human care program*10000000)

The results showed that efficiency scores are most sensitive to the cost of investment in green projects and human care programs. Accordingly, it can be claimed that these costs play a major role in this area, for example, increasing the investment in environmental and human care programs increased the efficiency score of SIRIN.S.N., which was the most inefficient supplier.

4. Findings and managerial implications

This section points out the potential managerial implications of the study and the proposed model. In this paper, a sustainable supply chain model is initially developed to provide an overview of the multitude of factors and relationships involved in this discussion. The study findings highlight the need for the development and adoption of integrated strategies for supply chains. With some adjustments in the intervals of analyses and simulations of causal relationships, this method to supply chain analysis can thus aid managers predict the risks and threats that may obstruct the transition of a chain toward sustainability and then devise a plan, accordingly. Thus, the method provides managers with a framework for conservative decision-making in this area. Since the proposed model is independent of the criteria utilized in this paper, decision-makers can introduce more criteria to the system or remove those they feel are not appropriate for their specific cases. This enables managers to adjust their supply chain strategies more easily, especially when they feel the chain is exposed to some risks originating from sustainability-related pressures and concerns. As the model developed in this study quantifies efficiency, while simultaneously considering process structure, process stages, and time, it can be practiced to accurately trace the source of inefficiency of each decision-making unit (DMU: supplier) in each year. For example, HAMRAH, as the supplier, became inefficient, with a score of 0.9994, because of inefficiency at Stage 1 (i.e., production) in 2011 while it had efficient packaging and distribution. Thus, in that year, this supplier should have focused on the production stage. The results presented in Tables 2 and 3 show that the highest and lowest efficiency scores are obtained for KARAN and SIRIN.S.N, respectively. As a result, the NMI decision-makers should reassess whether or not they want to continue cooperating with SIRIN S.N. For all suppliers, except for SIRIN.S.N. and HAMRAH, Stage 1 (viz. production) is more efficient than other divisions. After taking the value of historical data into account (Table 3), KARAN and SIRIN.S.N. retain their position as the suppliers with the highest and lowest efficiency scores, respectively. The efficiency scores of eight suppliers (STEEL.P, D.L.KARAN, PARSHAM, FARAZAN, PIROZ, TIR, BARAN, HAMRAH) also increased, which means they have had better efficiency in the final years of the five-year period, and the efficiency scores of three suppliers (ALSAN, SIRIN S.N., TECH A.T) decreased, indicating that they have not performed well in the final years of this period. A supplier (KARAN) also showed consistent efficiency throughout the period studied. In general, using Model 2 changed the ranking of the five suppliers (FARAZAN, TECH A.T, ALSAN, PARSHAM, D.L.KARAN). According to the results, it can be said that organizations can use the above method to rank their suppliers because more recent efficiency values are better indicators of future potential than a significant yet unsustainable success achieved in the past.

As discussed in Section 4.1, the use of sensitivity analysis shows that Supplier No. 6, as the most inefficient one, and No. 3, reacted to the increase in investment in all three pillars of sustainability. The efficiency of both of them also grew with some changes in wage costs, investment in green projects, and human care programs. Following the changes in energy and material costs, efficiency dropped. The efficiency of supplier No. 7 (PIROZ) only grew with changes in investment in green projects. In general, the rising trend of supplier efficiency in both environmental and social dimensions suggests that investment in environmental projects and human care programs can have a great impact and even play a major role in the efficiency of suppliers. Therefore, the managers of organizations should pay special attention to these two areas to achieve sustainability and boost their efficiency.

5. Conclusion

Given the importance of the efficiency evaluation of DMUs, in this paper, a DNDEA model based on the RAM model was developed. This model allows us to not only calculate the overall efficiency of DMUs throughout the time period but also consider the dynamic change of the time period efficiency and dynamic change of the divisional efficiency of DMUs. The developed model (Model 2) was used to assess the efficiency of the suppliers of a company named Nirou Moharekeh Industries (NMI) in the period 2011-2015. The efficiency scores of each supplier were determined separately for each stage and year, and their total efficiency scores were also calculated (Table 2). Subsequently, the source of inefficiency of each supplier was identified. The paper also presented, for the first time, a model that measures total efficiency based on the historical value of data (Model 2). This model gives more weight to the efficiency of more recent years. The sensitivity analysis of inputs (economic dimension) and outputs (environmental and social dimensions) revealed that investment in environmental projects and human care programs plays a significant role in the efficiency of the studied suppliers. Thus, knowing that, the suppliers could have made better plans for resource distribution. In general, since the models presented in this article are independent of the number of criteria and their values, they can be applied to any type of activity in production or service sectors. The findings of this paper are also expected to assist the managers of NMI in making better decisions for improved management and risk minimization in their supply chain in order to achieve sustainability. Compared to the model developed by Kalantary et al. [23] and previous research, the main advantages of the proposed model are as follows: (1) this model measures the direct impact of three pillars of sustainability on efficiency, thereby its discriminating power and reliability are increased and reflect reality, (2) using sensitivity analysis, it is established which of the sustainability pillars is more effective in efficiency evaluation, (3) the time-periods of the data for evaluations had been ignored in the study by Kalantari et al. [23], i.e., how older actions and achievements should have less impact on the evaluation, so that more emphasis is put on more recent developments. To remove this issue, the present study proposes, for the first time, a model that has used the value of historical data (namely, smoothing) to calculate the efficiency of suppliers, which can be considered as another contribution of this work. In line with this paper, it is suggested to exercise the proposed model in the evaluation of production lines, gas distribution companies, etc. in future studies.

Declaration of competing interest

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. This study also does not violate other relevant ethical issues.

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