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ROUGH MULTI- PERIOD NETWORK DATA ENVELOPMENT ANALYSIS FOR EVALUATION OF SUPPLY CHAIN: A CASE STUDY OF SKILL TRAINING IN IRAN

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Abstract. *The existence of a comprehensive and complete model, along with accurate and reliable data, helps to evaluate the performance of the supply chain. Given the different layers and various performances in designing the supply chain, a method that can analyze and evaluate such network structure is required. Moreover, data and conditions' uncertainty highlight the need for a method that can also include uncertainty in evaluation. In this paper, designing a multi-period network is carried out with rough data to embed in various layers and levels of supply chain. The supply chain performance evaluation is performed using rough network data envelopment analysis. Rough Network Data Envelopment Analysis (RNDEA) is a proper method since it analyzes all the current factors in evaluation; besides, it provides efficiency scores for inefficient decision-making units and boundary forecasting for these units on an efficient border. The study's outcomes reveal the efficiency of different factors in the designed network. On the other hand, unlike common data envelopment analysis that indicates the maximum of a factor efficiency, the efficiency priority is calculated in the proposed rough network model, and divisional efficiency also is determined in each step.*

Key words: *Network Data Envelopment Analysis, Rough Numbers, Multi-period, Performance Evaluation*

1. INTRODUCTION

Performance evaluation is essential because it acquaints us regarding the amounts of activities' favorability and quality, creates a positive sign in societies, and improves the

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services' quality, particularly in dynamic environments. Recognizing various attitudes regarding performance evaluation indicate that evaluation discipline must be proportional to the growth and development of organizations and can respond to their various and numerous dimensions. On the other hand, if control and evaluation in a system are not carried out, communication with the internal and external environment of the organization is not established leading to make it impossible to performing the required reforms for the growth, development, and improvement of the organization's activities.

In two recent decades, there has been growing interest in evaluating the local governments' performance worldwide [1]. Implementation and performing a performance evaluation system is one factor that ensures organizations' growth and development. According to global competition, organizations continuously improve their quality processes to stay in competition. Companies concluded that competition enhancement supports them in detecting performance enhancement and provides cheaper products than efficient production competitors [2]. The competitiveness of organizations depends on their performance levels. For such cases, it is crucial to have a measurement and evaluation system that provides sets of indicators and reliable information for reflecting their goals and performance evaluation.

In preparing and implementing organizational policies, performance evaluation is a key section. As a principle, each organization must evaluate its performance capacities as far as possible. Several factors influence the countries' growth and development. Based on the performed studies in this regard, efficiency lead to the enhancement of economic development speed. Hence, enhancing organizations' performance and efficiency is an inevitable necessity for survival in today's global market. The mentioned issue is not exclusive to a particular sector or industry and includes all economic sectors within a limited period [3]. The performance measurement system is critical in business management since it provides the required information for decision-making proceedings. Therefore, measuring the proper cases at the appropriate time is critical in the supply chain. Nevertheless, companies often fail in maximizing the limpid strategies benefits due to their failure to develop required performance measurement indicators for inefficiencies evaluation and efficiency improvement [4].

2. Literature Review

The customers' requirements have become more differentiated and diverse, along with the intensification of competitiveness in the market more than ever. In this regard, companies seeking the main market competition must convert the unit operation into a status in which suppliers, customers, and partners can cooperate in various aspects. Accordingly, the necessity of supply chain management is gradually enhanced. In these market spaces, competition between companies converts to competition among supply chains gradually [5]. Nowadays, competition among supply chains has replaced competition among individual companies. Hence, assessing the supply chain efficiency is one of the critical and fundamental issues since the management of each process is impossible without its efficiency assay.

One of the most interesting fields in Data Envelopment Analysis (DEA) is the analysis of the efficiency of the network and multi-stage systems [6]. The supply chain performance issues are evaluated using DEA. In common DEA models (to be used for evaluating the efficiency of decision-maker units), there are several inputs and outputs. Ignoring the intermediate products and link activities is one of the problems of these models [7]. There is extensive literature for assessing and evaluating the performance or efficiency of various systems using DEA. A summary of performed researches for evaluating the supply chain performance is provided in Table 1.

Table 1 Summary of evaluation methods for the supply chain performance

Reference	Title	Research Methods	Important variables	Year
[8]	Evaluating performance supply chain by a new non-radial network DEA model with fuzzy data	NDEA	Fuzzy number, Non radial model, Performance evaluation, Intermediate production	2012
[9]	A novel network data envelopment analysis model for evaluating green supply chain management	NDEA	Economic performance, Environmental performance, Dual-role factors, Undesirable outputs, Fuzzy set	2014
[10]	A network data envelopment analysis model for supply chain performance evaluation: real case of Iranian pharmaceutical industry	Factor Analysis	Financial factors, Performance Indicators, Intellectual capital, Responsiveness, Cooperation	2014
[11]	Developing a new chance constrained NDEA model to measure the performance of humanitarian supply chains	NDEA	Performance, Humanitarian disasters	2018
[12]	Developing a new chance constrained NDEA model to measure performance of sustainable supply chains	NDEA	Performance, Stochastic data	2018
[13]	Multi-period network data envelopment analysis to measure efficiency of a real business	NDEA	Performance, Process, Consulting, Educational Services	2019
[14]	Efficiency Measurement for Hierarchical Network Systems Using Network DEA and Intuitionistic Fuzzy ANP	Intuitionistic Fuzzy ANP -NDEA	Overall weights, Efficiency, Intuitionistic Fuzzy, Ranking	2020

There are several applications of DEA in evaluating the efficiency of training units [15]. DEA is a strong performance evaluation method when the Decision-Making Units (DMUs) are homogeneous [16]. This method can solve problems with different inputs and outputs without pre-defined weights; hence, it is used more than other performance evaluation methods [17]. This method has been used in various fields such as transportation, supply chain, production [18], training, insurance [19], financial affairs [20], and energy systems [21, 22].

Estimating the system's general efficiency based on initial inputs and final outputs and bypassing the role of the internal structure of production processes are problems of the traditional DEA method. Some production processes produce intermediate products that are used as input for the next step of the final output production [23]. Chen et al. [24] performed a study and recommended a novel Fuzzy BWM-DEA approach for selecting the smart product service module. Providing the applicable model for evaluating the performance of supply chain networks was the purpose in [25].

In this work, the rough set theory has been used to construct a model for evaluating the performance of the supply chain in uncertain conditions. This model creates a novel point of view for utilizing a performance evaluation model to support managerial decision-making in a dynamic environment and uncertain conditions.

3. PROBLEM DEFINITION AND MODELLING

In DEA, various methods are used to assess and evaluate efficiency and performance [26]. In multi-stage supply chains, outputs of a process stage are used as inputs of subsequent stages and have intermediate status. Therefore, the structure of the network data envelopment analysis (NDEA) model is evolved. Several researchers extensively applied the series-DEA model [2]. The considered supply chain system is in series. In most situations that DMUs have a two-step structure, the outputs of the first step are used as input for the next step. The existing DEA multi-step models in literature can be classified into two categories: closed system models and open system models [27]. In closed system DEA models, the intermediate outputs have remained without change from one step to another step. Contrary, in open DEA system models, intermediate outputs of a step are partial inputs of the next step [28]. Various models of DEA have been extended in recent years to use in distinct fields. Selection of models or appropriate models is one of the crucial steps before evaluating the studied units. Thereby, evaluating the efficiency of these types of network structures is critical. The system's general efficiency is decomposed into two steps in the structure of a two-step network. Kao reformed the DEA standard model considering the multi-step series relationship in general processes [29]. In the two-step structure problem, $j \epsilon J=\{1, \dots, n\}$ is the index set of the n DMUs; $j_0 \epsilon J$ denotes the evaluated DMU; x_{ij} is the vector of stage -1 external inputs i used by DMU j; z_{pj} is the vector of intermediate measures p for DMU j; y_{rj} is the vector of stage-2 final outputs r produced by DMU j; $v=(v_1, \dots, v_m)$ is the vector of weights of the stage-1 external inputs; $w=(w_1, \dots, w_q)$ is the vector of weights for the intermediate measures; $u=(u_1, \dots, u_s)$ is the vector of weights of the stage-2 0utputs.

Suppose a case where each DMU converts the x external inputs to y final outputs through z intermediate indicators with a two-step process. Nothing except first step inputs are entered in these initial settings, and nothing except second step outputs are not exited from the system. $E^{1(vrs)}{}_j$ is the efficiency of the first stage for DMU j. Commonly, the efficiency of DMU_j in the first step is defined as follows:

$$E_j^{1(vrs)} = \frac{\sum_{p=1}^{q} w_p\, z_{pj}}{\sum_{i=1}^{m} v_i x_{ij}} \tag{1}$$

The efficiency of DMU *j* in the second step is defined as follows:

$$E_j^{2(vrs)} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{p=1}^{q} w_p z_{pj}} \tag{2}$$

The overall efficiency of DMU *j* is defined as follows:

$$E_j^{(vrs)} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \tag{3}$$

After simplification, we have Model I as follows:

$$max\ E_k^{(vrs)} = \sum_{r=1}^{s} u_r y_{rk} \tag{4}$$

s.t.

$$\sum_{i=1}^{m} v_i x_{ik} = 1 \tag{5}$$

$$\sum_{p=1}^{q} w_p z_{pj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, j = 1, \dots, n \tag{6}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{p=1}^{q} w_p z_{pj} \leq 0, j = 1, \dots, n \tag{7}$$

$$v_i \geq 0, i = 1, \dots, m \tag{8}$$

$$w_p \geq 0, p = 1, \dots, q \tag{9}$$

$$u_r \geq 0, r = 1, \dots, s \tag{10}$$

Since the designed model of the problem is examined in real conditions in different periods, designing the evaluation model as a multi-period is required due to assessing the evaluation output in different periods, and the requirement of revision or improvement is planned for each period exclusively [30].

Model II: Periods are added to examine the mathematical model of NDEA as multi-period in Model I; therefore, the proposed model having period index *t* is given below:

$$max\ E_k^{(vrs)} = \sum_{r=1}^{s} u_{rt} y_{rkt} \tag{11}$$

s.t.

$$\sum_{i=1}^{m} v_{it} x_{ikt} = 1 \tag{12}$$

$$\sum_{p=1}^{q} w_{pt} z_{pjt} - \sum_{i=1}^{m} v_{it} x_{ijt} \leq 0, j = 1, \dots, n \tag{13}$$

$$\sum_{r=1}^{s} u_{rt} y_{rjt} - \sum_{p=1}^{q} w_{pt} z_{pjt} \leq 0, j = 1, \dots, n \tag{14}$$

$$v_i \geq 0, i = 1, \dots, m \tag{15}$$

$$w_p \geq 0, p = 1, \dots, q \tag{16}$$

$$u_r \geq 0, r = 1, \dots, s \tag{17}$$

3.1 Rough Network Data Envelopment Analysis

In recent decades, the performance evaluation with rough network data envelopment analysis is attracted scholars worldwide. The outputs and inputs in rough envelopment analysis are interval numbers obtained based on the up and down approximate of the rough set theory. The rough network data envelopment analysis (RNDEA) process has been used in this research due to subjective and ambiguous skill learners' judgments and opinions regarding obtained feedback from the training process. There are studies that made use of uncertainty in evaluation processes in supply chain and production scheduling [31]. Further, possibility theory using correlation study was applied in mechanical specification analysis [32]. The following steps of the RNDEA process are presented. According to the rough data envelopment analysis model, the envelopment analysis model with rough multi-period network data is defined as follows:

$$Max\ \tilde{e}_k = \sum_{r=1}^{s} u_{rt}[y_{rkt}^L, y_{rkt}^U] \tag{18}$$

s.t.

$$\sum_{i=1}^{m} v_{it}[x_{ikt}^L, x_{ikt}^U] = 1 \tag{19}$$

$$\sum_{p=1}^{q} w_{pt}[z_{pjt}^L, z_{dj}^U] \sum_{i=1}^{m} v_{it}[x_{ijt}^L, x_{ijt}^U] \leq 0\ , j = 1,2, \dots, n \tag{20}$$

$$\sum_{r=1}^{s} u_{rt}\left[y_{rjt}^L, y_{rj}^U\right] - \sum_{p=1}^{q} w_{pt}[z_{pjt}^L, z_{pjt}^U] \leq 0\ , j = 1,2, \dots, n \tag{21}$$

$$u_{rt}, w_{pt}, v_{it} \geq \varepsilon > 0 \tag{22}$$

Here, $y^L{}_{rjt}$ and $y^U{}_{rjt}$ are the lower and upper limits of network outputs, respectively, obtained from the calculation of the rough number. Moreover, $z^L{}_{pjt}$ and $z^U{}_{pjt}$ are the lower and upper limits of the input of the second sub-system. $x^L{}_{ijt}$ and $x^U{}_{ijt}$ are lower and upper limits of inputs of the first sub-system in the network series. u_{rt}, w_{pt}, and v_{it} are the weights of the network's inputs and outputs. In this model, the p index indicated the p-th decision-making unit. Furthermore, all weights are considered greater than a very small positive number (ε).

The method of modeling in pessimistic state is as follows:

$$Max\ e_p^L = \sum_r u_{rt} y_{rkt}^L \tag{23}$$

s.t.

$$\sum_i v_{it} x_{ikt}^U = 1 \tag{24}$$

$$\sum_r u_{rt} y_{rjt}^L - \sum_p w_{pt} z_{pjt}^U \leq 0 \tag{25}$$

$$\sum_r u_{rt} y_{rjt}^U - \sum_p w_{pt} z_{pjt}^L \leq 0, j = 1,2, \dots, n, j \neq p \tag{26}$$

$$\sum_p w_{pt} z_{pjt}^L - \sum_i v_{it} x_{ijt}^U \leq 0 \tag{27}$$

$$\sum_p w_{pt} z_{pjt}^U - \sum_i v_{it} x_{ijt}^L \leq 0, j = 1,2, \dots, n, j \neq p \tag{28}$$

$$u_r, w_d, v_i \geq \varepsilon > 0 \tag{29}$$

The method of modeling in optimistic state is as follows:

$$Max\ e_p^U = \sum_r u_{rt} y_{rkt}^U \tag{30}$$

s.t.

$$\sum_i v_{it} x_{ikt}^L = 1 \tag{31}$$

$$\sum_r u_{rt} y_{rjt}^U - \sum_p w_{pt} Z z_{pjt}^L \leq 0 \tag{32}$$

$$\sum_r u_{rt} y_{rjt}^L - \sum_p w_{pt} z_{pjt}^U \leq 0, j = 1,2, \dots, n, j \neq p \tag{33}$$

$$\sum_p w_{pt} z_{pjt}^U - \sum_i v_{it} x_{ijt}^L \leq 0 \tag{34}$$

$$\sum_p w_{pt} z_{pjt}^L - \sum_i v_{it} x_{ijt}^U \leq 0, j = 1,2, \dots, n, j \neq p \tag{35}$$

$$u_r, w_d, v_i \geq \varepsilon > 0 \tag{36}$$

4. Numerical Implementation

The employment rate is critical among the policymakers in various countries, given the population growth, the unskillfulness of many people (even academic graduates), and eventually the unemployment of mass ranges of society. By reviewing the researches conducted in the field of designing education supply chains, it was observed that the supply chain for higher education and post-graduate education had been established, but so far there was no supply chain for skill training in the literature. It is due to the more or less encountering of most countries (from industrial societies to third world developing countries) with unemployment problems in different ways. Skill training can be considered the main priority of the educational system as an essential tool for cultivating and enhancing the efficiency and productivity of human forces to reform and solve unemployment and economic development. There are two steps in the supply chain of skill training. Generally, it can be mentioned that the outputs of a process step are considered the inputs of the next step, and it has intermediate status. Therefore, the structure of the present study is a two-step network. Only three main levels are considered to evaluate this chain as follows: First level (suppliers), Second level (training process), and Third level (consumers).

The components of the first level: higher education graduates, educational and educational aids equipment, supplies equipment, training workshop, training course, the cost of center overhead, training support force, training content, training portal, welfare;

The components of the second level: Consultation and guidance of career, training scheduling, designing of training model, training forms, and theoretical and operational evaluation;

The components of the third level): results of employment, final products.

This research was carried out for five popular standards in the industry cluster and skill training field. For this purpose, five influential provinces in Iran with higher amount of population, including Alborz, East Azerbaijan, Isfahan, Razavi Khorasan, and Tehran are investigated. Initially, the collected data in five provinces were converted to rough data using related input data to factors' performance in different layers in the first period. The summary is given in Tables 2, 3, and 4.

Table 2 Rough output related to the first layer

DMU	x_1		x_2		x_3		x_4	
	L	*U*	*L*	*U*	*L*	*U*	*L*	*U*
Motoring	40.02	42.56	147.16	152	334.06	343.85	31.97	35.43
Electricity	22.5	25.5	246.14	251.25	278.75	286.25	22.04	25.95
Turning	16.43	18.97	156.14	165.93	237.5	252.5	16.02	18.56
Welding	26.70	29.12	123.75	131.25	157.16	162	24.62	28.02
Cartography	8.75	10.25	56.77	60.81	31.70	35.29	10.22	12.18

DMU	x_5		x_6		x_7		x_8	
	L	*U*	*L*	*U*	*L*	*U*	*L*	*U*
Motoring	34.5	37.5	133.75	138.64	207.5	222.5	3.75	4.72
Electricity	22.04	25.95	89.56	93.02	128.62	135.20	3.75	4.72
Turning	18.29	20.70	59.85	63.56	133.75	141.25	5.27	6.25
Welding	33.38	28.56	93.27	97.97	137.72	140.64	3.75	5.25
Cartography	9.29	11.70	41.43	43.97	64.41	67.75	4.75	6.25

DMU	x_9		x_{10}	
	L	*U*	*L*	*U*
Motoring	31.62	36.70	31.62	36.70
Electricity	21.29	23.70	21.97	25.43
Turning	16.16	18.83	17.29	19.70
Welding	21.89	26.85	23.52	27.89
Cartography	11.29	13.70	10.08333	13.08

Uncertainty of data and conditions determines the need for a method that can apply uncertainty in evaluation. As a result, the design of a multi-period network is done with raw data to embed suitable factors in different layers and levels. Evaluation of supply chain performance is done through the rough network data envelopment analysis method. Rough Network Data Envelopment Analysis (RNDEA) is a suitable method because it analyzes all factors in the evaluation.

Considering that employment is one of the important and discussed issues of policy makers in different countries of the world and most of the countries are more or less facing the issue of unemployment. On the other hand, due to the fact that there is a deep and inferable link between education and employment, and education is considered an important factor in economic growth and employment, addressing the issue of education, especially skill training, which has not been addressed so far, is an inevitable necessity. This is why one of the important priorities in educational investments is the development and expansion of skill-based education.

Table 3 Rough output related to the second layer

DMU	z_1		z_2		z_3	
	L	*U*	*L*	*U*	*L*	*U*
Motoring	979.58	994.58	4.58	5.41	986.77	1001.14
Electricity	338	342.83	5.27	6.25	338.31	345.43
Turning	258.5	264.16	5.12	5.87	262.85	267.68
Welding	455.43	474.14	9.70	13.29	465.85	475.39
Cartography	172.18	184.89	3.75	5.25	179.06	188.85
DMU	z_4		z_5			
	L	*U*	*L*	*U*		
Motoring	33	37.83	986.14	995.93		
Electricity	21.29	23.70	334.04	341.79		
Turning	14.56	18.02	257.64	266.93		
Welding	24.70	28.29	468.45	475.70		
Cartography	11.29	13.70	184.06	193.85		

Table 4 Rough output related to the third layer

DMU	y_1		y_2		y_3		y_4	
	L	*U*	*L*	*U*	*L*	*U*	*L*	*U*
Motoring	83	87.83	104.18	108.22	64.06	73.85	168.60	175.97
Electricity	27.43	32.14	40.12	44.87	22.72	27.68	53.60	60.97
Turning	22.66	13.83	25.60	31.81	17.60	21.64	42.04	47.12
Welding	37.18	43.29	53.37	57.62	33.77	37.81	83	87.83
Cartography	22.39	27.02	29.97	33.43	17.12	20.70	42.45	47.54

By providing informal skill training along with high formal training, a very effective step can be taken in the development of human resource employment. Therefore, due to increasing the efficiency and effectiveness of training in skill-oriented organizations, checking the progress towards the set educational goals, correct formulation of educational policies, identifying the components that need more attention and obtaining information in order to make the right decisions, it is necessary to enforce the training performance evaluation.

Having a chain of training for this type of training can help a lot in training a capable and trained workforce ready to work in the society. Designing a performance evaluation model for skill training that leads to sustainable political, economic, social, cultural and environmental development is an undeniable necessity. Considering the special and important role of skill training in increasing people's skills and employment, designing and evaluating the supply chain of these trainings is considered very important. The need to evaluate the performance of the education supply chain is important because it increases the efficiency and effectiveness of education. The findings of the research show the efficiency of various factors in the stages of the designed network. In addition, it provides efficiency scores for inefficient decision-making units and boundary prediction for these units in an efficient boundary. Then, performance evaluation is carried out using input data and the proposed RNDEA model. The outputs of each step of efficiency evaluation in the rough form in the first period are indicated in Table 5.

Table 5 Output for period 1

NO	DMU	Rough	Rank
1	Motoring	[0.285,0.571]	5
2	Electricity	[0.639,1]	1
3	Turning	[0.450,0.767]	3
4	Welding	[0.346,0.648]	4
5	Cartography	[0.633,0.855]	2

Notably, the mentioned process is repeated; performance evaluation is performed in different periods, and an improvement solution is provided. The results of this study show the effectiveness of different factors in the stages of network design. By designing the performance evaluation model of the skill training supply chain network, we tried to identify the best performance for the supply chain.

5. CONCLUSION

Based on the outputs table, the best efficiency is related to the electrical field due to having the maximum efficiency in the first, second, and third layers. Besides, the lowest efficiency is related to motoring. Thereby: Electricity > Cartography > Turning > Welding > Motoring; It can be described that these results were obtained given the supply chain components of skill training that are used in this research and declared in the numerical example section. Moreover, the following reasons can be pointed out for the low efficiency of debated fields: lack of updated proper workshop equipment based on the requirement of the labor market, no existence of sufficient consumer goods due to the budget deficit, not the proportion of knowledge and experience of instructors with skill artisan and updated changes of technology, lack of insurance of employed skill learners in the repair shop, also skill learners that established their considered business, and lack of providing accurate information in employment tracking to the staff of career monitoring. Another point is that most skill courses in electrical, building cartography, order-oriented turning and welding, and proportion to work market requirements. In contrast, the most presented periods in the motoring field are supply-oriented. Thereby, most of the skilled learners participate in four required fields in the market, leading to employment.

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