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A review of DEA approaches for health supply chain

J. Pourmahmoud*, M. Gholamazad

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Abstract More than 200 papers have been published in the last 20 years on the topic of health supply chains (HSC). Looking at the research methodologies employed, less than 15 papers apply data envelopment analysis (DEA) models. This is in contrast to, for example, A network data envelopment analysis (NDEA) model for supply chain performance evaluation where several reviews on respective NDEA models have already been provided. The paper summarizes research on DEA, NDEA, simulation data envelopment analysis (SI-DEA) and stochastic data envelopment analysis (S-DEA) models for health supply chains and thereby contributes to the further substantiation of the field. On the modeling side, there are four dominant approaches: Classic-DEA models, NDEA models, SI-DEA models and S-DEA models. The paper ends with suggestions for future research.

Keywords: Data Envelopment Analysis, Classic DEA Model, NDEA Model, SI-DEA Model, S-DEA Model, Health Supply Chain.

1 Introduction

Data Envelopment Analysis (DEA) was developed by Charnes, Cooper and Rhodes [1] (CCR, 1978) to evaluate the relative efficiency of peer decision making units (DMUs). DEA has been proven an effective tool for performance benchmarking when multiple performance measures exist and a priori information on the tradeoffs among these measures is completely available (see, e.g., Zhu [2], 2003). The standard DEA approach treats each DMU's operation (e.g., production process) as a black-box where inputs are transformed into outputs. There are many more complicated cases in which the whole operation is separated into more than two processes. These may have a series structure, a parallel structure, or a mixture of these. These structures are generally called network structures, and the DEA technique to measure the efficiency of systems with a network structure is called network data envelopment analysis (NDEA) (Färe& Grosskopf [3], 2000). Boloori and Pourmahmoud [4] in 2014 proposed a modified SBM-NDEA approach for the efficiency measurement in bank branches. Then in 2014 equivalent multiplier and envelopment DEA models for measuring the efficiency under general network structures proposed by Boloori et al [5]. Pourmahmoud and Zeynali [6] proposed a nonlinear model for identifying common weights set in NDEA in 2016. They [7] also in 2016 proposed a DEA network structure sensitivity to non-Archimedean epsilon. In

*Corresponding Author. (✉)
E-mail: Pourmahmoud@azaruniv.ac.ir (J. Pourmahmoud)

J. Pourmahmoud
Department of Applied Mathematics, Azarbaijan Shahid Madani University, Tabriz

M. Gholamazad
Department of Applied Mathematics, Azarbaijan Shahid Madani University, Tabriz

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2017, Sayyaditooranloo et al. [8] applied NDEA in ceramic and tile industry in Yazd province.

A supply chain (SC) is a value chain network in every industrial system. Jahani Sayyad Noveiri et al. [9] in 2017 proposed a cost efficiency of closed–loop supply chain in the presence of dual-role and undesirable factors. Then in 2018, supply chain performance with undesirable factors and reverse flows: A DEA-based approach proposed by Jahani Sayyad Noveiri et al. [10]. In healthcare industries, SCs are the most costly part of the system. Thus, evaluating of management in the healthcare supply chain (HCSC) is evident (McKone-Sweet et al [11], 2005). Human factors play an important role in SCM (Kim [12], 2005). Time and cost play an important role in the performance of the hospital and the importance of these factors on healthcare performance are expressed by some researchers such as Cheng and Whittemore [13], HaszlinnaMustaffa and Potter [14], and Kehrel [15]. It is clear that, the healthcare industry has a key role in human health and quick access to the medicine is one of the important issues with the significant impact on healthcare department. It is therefore quite essential to evaluate medicine SC to enhance performance of the healthcare department.

The aim of this paper is to summarize existing research on DEA, NDEA, simulation data envelopment analysis (SI-DEA) and stochastic data envelopment analysis (S-DEA) models for health supply chains, thereby contributes to the further substantiation of the field. This provides insights toward future research directions and needs.

The rest of this paper is organized as follows: In Section 2, a summary of papers on DEA models that were previously presented is reviewed. We review the classic DEA models on HSC in Section 3. In Section 4 we give the review of developed DEA models (NDEA models, SI-DEA models and S-DEA models) on HSC. The conclusions are discussed in Section 5.

2 The summary of previous papers on DEA

DEA is a method to evaluate the relative efficiency of comparable units called DMUs. Charnes et al. (1978) proposed a fractional programming model, commonly referred to as the CCR model.

The CCR model for measuring the relative efficiency of a DMU indexed by 0 is:

$$E_o = \max . \frac{\sum_{r=1}^{s} u_r Y_{ro}}{\sum_{i=1}^{m} v_i X_{io}} \tag{1}$$

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

$$u_r, v_i \ge \varepsilon, \qquad r = 1, 2, ..., s, \qquad i = 1, 2, ..., m.$$

Model (1) is commonly called a ratio model.

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$$
\begin{aligned}
E_o = \min. \quad & \theta - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \\
s.t. \quad & \sum_{i=1}^{m} \lambda_j X_{ij} + s_i^- = \theta X_{io}, \quad i = 1,2,...,m \\
& \sum_{r=1}^{s} \lambda_j Y_{rj} - s_r^+ = Y_{ro}, \qquad r = 1,2,...,s \\
& \lambda_j \geq 0, \quad j = 1,2,...,n, \quad r = 1,2,...,s, \quad i = 1,2,...,m \\
& \theta \text{ unrestricted in sign.}
\end{aligned}
\tag{2}
$$

This model is called an envelopment model and its dual, the multiplier form of the CCR model in the input oriented case is:

$$
\begin{aligned}
& \max. \sum_{r=1}^{s} u_r Y_{ro} \\
s.t. \quad & \sum_{i=1}^{m} v_i X_{io} = 1 \\
& \sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, \quad j = 1,2,...,n, \\
& u_r, v_i \geq \varepsilon, \qquad r = 1,2,...,s, \qquad i = 1,2,...,m.
\end{aligned}
\tag{3}
$$

In year 2008, Jahanshahloo et al. [16] provided the review of ranking models in DEA. In evaluating the relative efficiency, usually more than one unit may be efficient. The problem of ranking efficient DMUs is of interest from theoretical and practical point of view. In this paper, different methods have been discussed and in some sense they are compared.

2.1 AP model

Anderson and Peterson [17] proposed the super efficiency model. They omitted the efficient *DMU* from the PPS and ran the CCR model for other units to rank it. They proposed the following model:

$$
\begin{aligned}
& \max. \sum_{r=1}^{s} u_r Y_{ro} \\
s.t. \quad & \sum_{i=1}^{m} v_i X_{io} = 1 \\
& \sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, \quad j = 1,2,...,n, j \neq 0 \\
& u_r, v_i \geq \varepsilon, \qquad r = 1,2,...,s, \qquad i = 1,2,...,m.
\end{aligned}
\tag{4}
$$

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2.2 MAJ model

To solve the important difficulties of AP model, Mehrabian et al. [18] proposed another model for ranking efficient units. Their proposed model is:

$$\begin{aligned} &\min . 1+w \\ &s.t. \quad \sum_{j=1,\, j\neq 0}^{n} \lambda_j X_{ij} \le X_{io} + w, \quad i=1,2,...,n \\ &\qquad \sum_{j=1,\, j\neq 0}^{n} \lambda_j Y_{ij} \ge Y_{ro}, \qquad r=1,2,...,s \\ &\qquad \lambda_j \ge 0, \qquad j=1,2,...,n,\ j\neq 0. \end{aligned} \tag{5}$$

2.3 Revised MAJ model

The MAJ model may be infeasible in some cases. To solve this problem, Saati et al [19], proposed the following model:

$$\begin{aligned} &\min . 1+w \\ &s.t. \quad \sum_{j=1,\, j\neq 0}^{n} \lambda_j X_{ij} \le X_{io} + w, \quad i=1,2,...,n \\ &\qquad \sum_{j=1,\, j\neq 0}^{n} \lambda_j Y_{ij} \ge Y_{ro} - w, \qquad r=1,2,...,s \\ &\qquad \lambda_j \ge 0, \qquad j=1,2,...,n,\ j\neq 0. \end{aligned} \tag{6}$$

2.4 The slack adjusted DEA model

In the CCR model, there are some difficulties to introduce ε. To solve these difficulties, Sueyoshi et al [20] proposed the slack adjusted DEA model (SADEA), and used it to rank efficient units. Their model for ranking is:

$$\begin{aligned} &\max . \sum_{r=1}^{s} u_r Y_{ro} \\ &s.t. \quad \sum_{i=1}^{m} v_i X_{io} = 1 \\ &\qquad \sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0, \quad j=1,2,...,n,\ j\neq 0 \\ &\qquad u_r \ge 1 \Big/ \left[(m+s) R_r^{+} \right] \quad r=1,2,...,s \\ &\qquad v_i \ge 1 \Big/ \left[(m+s) R_i^{-} \right] \quad i=1,2,...,m. \end{aligned} \tag{7}$$

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where $R_i^- = \max_j X_{ij}, R_r^+ = \max_j Y_{rj}$ for every *i, j*. *SA - DEA* has the same difficulties of *AP* model.

2.5 The gradient line method

Jahanshahloo et al [21] used the gradient line to rank extreme efficient units. In this way, they defined the plan P_o which contains the point (X_o, Y_o) and the set S_o as follows:

$$\begin{aligned} P_o &= \{(X,Y): X = \alpha X_o, Y = \beta Y_o\} \\ S_o &= \{(X,Y) \in P_o : X = \alpha X_o, Y = \beta Y_o, \alpha \geq 0, \beta \geq 0\} \end{aligned} \tag{8}$$

The corresponding gradient equation to DMU_o in P_o with center (0, 0) is: $\frac{\alpha^2}{K_\alpha^2} + \frac{\beta^2}{K_\beta^2} = 1$.

where:

$$K_\alpha = \sqrt{\frac{\sum_{i=1}^{m} X_{io}^2 + \sum_{r=1}^{s} Y_{ro}^2}{\sum_{i=1}^{m} X_{io}^2}}, \quad K_\beta = \sqrt{\frac{\sum_{i=1}^{m} X_{io}^2 + \sum_{r=1}^{s} Y_{ro}^2}{\sum_{r=1}^{s} Y_{ro}^2}} \tag{9}$$

Later they made this model:

$$\begin{aligned} &\max . \ H_o = \sum_{r=1}^{s} u_r Y_{ro} - \sum_{i=1}^{m} v_i X_{io} \\ &s.t. \quad \sum_{i=1}^{m} v_i + \sum_{r=1}^{s} u_r = 1 \\ &\sum_{r=1}^{s} u_r Y_{rj} + \sum_{i=1}^{m} v_i X_{ij} \leq 0, \quad j = 1,2,...,n, \ j \neq 0 \\ &u_r, v_i \geq \varepsilon, \qquad r = 1,2,...,s, \qquad i = 1,2,...,m. \end{aligned} \tag{10}$$

2.6 Ranking by common set of weights

Hosseinzadeh Lotfi et al. [22] proposed a common set of weight (CSW) model which evaluates all DMUs with a set of weight. They based it on this fact that the feasible region of *n* problems is the same. Their suggested model for ranking extreme efficient units is:

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$$\max. \left\{ \frac{\sum_{r=1}^{s} u_r Y_{r1}}{\sum_{i=1}^{m} v_i X_{i1}}, ..., \frac{\sum_{r=1}^{s} u_r Y_{rn}}{\sum_{i=1}^{m} v_i X_{in}} \right\} \tag{11}$$

$$s.t. \quad \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \le 1, \qquad j = 1, 2, ..., n, \quad j \ne 0$$

$$u_r, v_i \ge \varepsilon, \qquad r = 1, 2, ..., s, \qquad i = 1, 2, ..., m.$$

2.7 Ranking by l_1 norm

Jahanshahloo et al. [23], used norm l_1 for ranking extreme efficient units. Consider the following model to obtain the ranking score of DMU_o:

$$\begin{aligned} \min. \ & \Gamma_c^o(X, Y) = \sum_{i=1}^{m} |X_i - X_{io}| + \sum_{r=1}^{s} |Y_r - Y_{ro}| \\ s.t. \ & \sum_{j=1, j\ne 0}^{n} \lambda_j X_{ij} \le X_i, \quad i = 1, 2, ..., m \\ & \sum_{j=1, j\ne 0}^{n} \lambda_j Y_{rj} \ge Y_r, \qquad r = 1, 2, ..., s \\ & X_i \ge 0, \qquad i = 1, 2, ..., m \\ & Y_r \ge 0, \qquad r = 1, 2, ..., s \\ & \lambda_j \ge 0, \qquad j = 1, 2, ..., n, \quad j \ne 0. \end{aligned} \tag{12}$$

An organizational theoretic review of green supply chain management literature is presented by Sarkis et al [24] in 2011. In this paper, they reviewed the literature on GSCM with a focus on identifying applicable and explanatory organizational theories that have been utilized to expand understanding and knowledge of this research field. They found that researchers in GSCM have started to apply a number of organizational theories in explicit ways. Some of the research has also helped to further understand and strengthen some of these theories. They also expound on future possibilities for organizational theory development and linkages.

Seuring [25] in 2013 provided the review of modeling approaches for sustainable supply chain management. The main goal of his paper is to provide summarized research on quantitative models for forward supply chains and thereby contributes to the further substantiation of the field. While different kinds of models are applied, it is evident that the social side of sustainability is not taken into account. On the environmental side, life-cycle assessment based approaches and impact criteria clearly dominate. On the modeling side, there are three dominant approaches: equilibrium models, multi-criteria decision making and analytical hierarchy process.

According to research of Hosseinzadeh Lotfi et al. [26], there exists a variety of papers which apply different ranking methods to a real data set. These ranking methods have divided

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into seven groups. As each of the existing methods can be viewed from different aspects, it is possible that somewhat these groups have an overlapping with the others. The first group conducts the evaluation by a cross-efficiency matrix where the units are self-and peer-evaluated. On the second one, the ranking units are based on the optimal weights obtained from the multiplier model of DEA technique. In the third group, super-efficiency methods are dealt with which are based on the idea of excluding the unit under evaluation and analyzing the changes of frontier. The fourth group involves methods based on benchmarking, which adopts the idea of being a useful target for the inefficient units. The fourth group uses the multivariate statistical techniques, usually applied after conducting the DEA classification. The fifth research area ranks inefficient units through proportional measures of inefficiency. The sixth approach involves multiple-criteria decision methodologies with the DEA technique. In the last group, some different methods of ranking units are mentioned. In this section we refer to the three groups:

2.7.1 Cross-efficiency ranking techniques

Sexton et al. [27] provided a method for ranking units based on this idea that units are self- and peer-evaluated. For deriving the cross-efficiency of any DMU_j using weights chosen by DMU_o, they proposed the following equation:

$$\theta_{oj} = \frac{U_o^* Y_j}{V_o^* X_j} \tag{13}$$

Where U^*, V^* are optimal weights obtained from the following model for DMU_o under assessment:

$$\begin{aligned} &\min. \; V^t X_o \\ &s.t. \quad U^t Y_o = 1 \\ &\qquad U^t Y_j - V^t X_j \le 0 \quad j = 1,2,...,n \\ &\qquad U^t, V^t \ge 0 \end{aligned} \tag{14}$$

Now DMU_o received the average cross-efficiency score as: $\bar{\theta}_o = \frac{\sum_{j=1}^{n} \theta_{oj}}{n}$

2.7.2 Super-efficiency ranking techniques

Super efficiency models, introduced in DEA technique, are based upon the idea of leave one out and assessing this unit trough the remanding units. Jahanshahloo et al. [28] added some ratio constraints to the multiplier form of A.P. model and introduced a new method for ranking DMUs:

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$$
\begin{aligned}
&\max. \sum_{r=1}^{s} u_r Y_{ro} \\
&s.t. \quad \sum_{i=1}^{m} v_i X_{io} = 1 \\
&\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0, \quad j = 1,2,...,n,\ j \ne 0 \\
&\tilde{t}^{pq} \le \frac{v_p}{v_q} \le \bar{t}^{pq}, \qquad p,q = 1,2,...,m,\ p < q \\
&\hat{t}^{kw} \le \frac{u_k}{u_w} \le \breve{t}^{kw}, \qquad k,w = 1,2,...,s, k < w \\
&u_r, v_i \ge \varepsilon, \qquad r = 1,2,...,s, \qquad i = 1,2,...,m.
\end{aligned}
\tag{15}
$$

DMU_o is efficient if the optimal objective function of the previous model is greater than or equal to one.

2.7.3 Benchmarking ranking techniques

Sueyoshi et al. [29] proposes a "benchmark approach" for baseball evaluation. This method is the combination of DEA this index is the better rank for corresponding unit will be obtained

$$
FPI_k^{IBM} = \frac{\left(TE_k^{BCC} - STD_k^{IBM}\right)}{STD_k^{IBM}} \tag{16}
$$

where TE_k^{BCC} and STD_k^{IBM} are, respectively, the efficiency in the BCC model and normalization of TE^{IBM} of DMU_k.

A review of network data envelopment analysis has been presented by Kao [30] in 2014. In this paper, the review of the studies on network DEA was based on the network structures of the problems discussed in the focal works, and the models that were developed or applied to them. The structures of NDEA divided into six groups: The first of them is two-stage structures, the second of them is series structures, the third of them is parallel structures, the fourth of the is mixed structures, the fifth is hierarchical structure and the last group of them is dynamic structures.

Suppose a system is composed of p processes. Other terms, such as subunits, sub-DMUs, divisions, and components have also been used, and this paper use the term processes when there is no ambiguity. Denote $X_{ij}^{(k)}$ and $Y_{rj}^{(k)}$ as the i th input supplied from outside, $i \in I^{(k)}$, where $I^{(k)}$ is the index set of the exogenous inputs used by process k, and the r th final output of the system, $r \in O^{(k)}$, where $O^{(k)}$ is the index set of the final outputs produced by process k, $k = 1,2,...,p$, respectively, of the j th DMU. Clearly, the sums of $X_{ij}^{(k)}$ and $Y_{rj}^{(k)}$ for all

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p processes are the system input X_{ij} and system output Y_{rj}, respectively, i.e., $\sum_{k=1}^{p} X_{ij}^{(k)} = X_{ij}$ and $\sum_{k=1}^{p} Y_{rj}^{(k)} = Y_{rj}$. Further, let $Z_{fj}^{(a,k)}$ denote the f th intermediate product produced by process a, $f \in M_k$, where M_k is the index set of the intermediate products used by process k, and $Z_{gj}^{(k,b)}$ denote the g th intermediate product to be used by process $b, g \in N_k$, where N_k is the index set of the intermediate products produced by process k. The input-oriented model for measuring the system efficiency can be formulated as:

$$
\begin{aligned}
&\min.\ \theta \\
&s.t. \quad \sum_{j=1}^{n} \lambda_j^{(k)} X_{ij}^{(k)} + s_i^{-(k)} = \theta X_{io}^{(k)},\ i \in I^{(k)}, \quad k = 1,2,...,p \\
&\sum_{j=1}^{n} \lambda_j^{(k)} Y_{rj}^{(k)} - s_r^{+(k)} = Y_{ro}^{(k)},\ r \in O^{(k)}, \quad k = 1,2,...,p \\
&\sum_{j=1}^{n} \lambda_j^{(k)} Z_{fj}^{(k)} + s_f^{o(k)} = Z_{fo}^{(k)},\ f \in M^{(k)}, \quad k = 1,2,...,p \\
&\sum_{j=1}^{n} \lambda_j^{(k)} Z_{gj}^{(k)} - s_g^{o(k)} = Z_{go}^{(k)},\ g \in N^{(k)}, \quad k = 1,2,...,p \\
&s_i^{-(k)}, s_r^{+(k)}, s_f^{o(k)}, s_g^{o(k)}, \lambda_j^{(k)} \geq 0,\ i \in I^{(k)}, r \in O^{(k)}, f \in M^{(k)}, \\
&g \in N^{(k)}, j = 1,2,...,n, k = 1,2,...,p.
\end{aligned}
\tag{17}
$$

Another way to measure the efficiency of the system is to find the multipliers u, v, w and $\hat{w}$ which produce the maximum efficiency under the constraint that the aggregation of the outputs is less than or equal to that of the inputs for all processes. In symbols, this is:

$$
\begin{aligned}
&E_o = \max. \frac{\sum_{r=1}^{s} u_r Y_{ro}}{\sum_{i=1}^{m} v_i X_{io}} \\
&s.t. \quad \sum_{r \in O^{(k)}} u_r^{(k)} Y_{rj}^{(k)} + \sum_{g \in N^{(k)}} \hat{w}_g^{(k)} Z_{gj}^{(k)} \\
&\quad - \sum_{i \in I^{(k)}} v_i^{(k)} X_{ij}^{(k)} - \sum_{f \in M^{(k)}} w_f^{(k)} Z_{fj}^{(k)} \leq 0, \quad j = 1,2,...,n, \quad k = 1,2,...,p \\
&\quad u_r^{(k)}, \hat{w}_g^{(k)}, v_i^{(k)}, w_f^{(k)} \geq 0, \quad r \in O^{(k)}, g \in N^{(k)}, i \in I^{(k)}, f \in M^{(k)} \qquad k = 1,2,...,p.
\end{aligned}
\tag{18}
$$

The efficiency of process k is the ratio of the aggregation of its outputs to that of its inputs:

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$$E_o^{(k)} = \max . \frac{\sum_{r \in O^{(k)}} u_r^{(k)} Y_{ro}^{(k)} + \sum_{g \in N^{(k)}} \hat{w}_g^{(k)} Z_{go}^{(k)}}{\sum_{i \in I^{(k)}} v_i^{(k)} X_{io}^{(k)} + \sum_{f \in M^{(k)}} w_f^{(k)} Z_{fo}^{(k)}} \quad (19)$$

Models to measure the efficiency of network systems have been developed from these two basic models.

3 Literature review of classic DEA models on HSC

According to Parkin and Hollingsworth [31], Pereira [32], CAballer et al. [33], Kumar Mishra [34], Bin et al. [35] and Azadeh et al. [36], "Health is not only a basic need for human survival, but also a common goal of global development". They applied the CCR fractional model (1) and an envelopment model (2) in the papers.

Parkin and Hollingsworth believed that, although DEA has the potential to produce useful information concerning the efficiency of hospitals, this must be considered carefully because of the existence of some unresolved issues. The model used in their paper had a problem common to many health care production frontier analyses - whether statistical or deterministic - in that it used outputs not outcomes. They applied these results in the real study in hospitals of Scotland.

Pereira provided that, exploitation of economies of scale is often argued in favor of blood-bank consolidation into large regional centers, despite a lack of adequate empirical support. This study was aimed at testing the economies of scale hypothesis in a sample of blood centers in the USA.

The fundamental objective of the research work of Caballer et al. is to offer simple tools to measure efficiency in hospitals in the Valencian Community. The importance of analyses the operational efficiency of hospital units has been highlighted in the Introduction.

In the study of Kumar Mishar, the supply chain efficiency is measured by the application of DEA. In this paper, an attempt had been taken to measure the efficiency of the supply chain. He had taken the case of the pharmaceutical industry of India.

Bin et al. applied the DEA in evaluating the efficiency of public hospitals in Tianjin, China. They believed that, public hospitals are the most important components of health systems and account for a large proportion of health resources in China.

In the study of Azadeh et al. presented an integrated approach for analyzing the impact of macro-ergonomics factors in the healthcare supply chain (HCSC) by DEA. The case of this study is the supply chain (SC) of a real hospital.

4 Literature review of developed DEA models on HSC

4.1 NDEA model on HSC

There is one paper in the HSC field via NDEA. In this paper that worked by Azbari et al. [37], the NDEA model of Cook et al. [38] under the assumption of constant returns to scale (CRS) had been used and they had developed this model to variable returns to scale (VRS). This paper is the result of research related to supply chain of pharmaceutical companies in Tehran

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Stock Exchange and 115 experts and senior executives have been questioned as a sample. They suggested that the overall efficiency in the P stage system is:

$$\theta = \sum_{p=1}^{p}\left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j_1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j_2}\right) \Big/ \left\{\sum_{i=1}^{I_o} v_{oi} z_{oi}^{j} + \sum_{p=2}^{p}\left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j_2} + \sum_{i=1}^{I_p} v_{p-1i} z_{p-1i}^{j_g}\right)\right\} \quad (20)$$

4.2 SI-DEA and S-DEA models on HSC

Jacobs [39], Azadeh et al [40, 41] and Shwartz et al. [42] believed that, composite measures calculated from individual performance indicators increasingly are used to profile and reward health care providers. They used simulation and stochastic DEA models for evaluating the efficiency of hospitals.

Jacobs developed SDEA models to examine hospital efficiency in the UK. He suggested that, there has been increasing interest in the ability of different methods to rank efficient hospitals over their inefficient counterparts. The UK department of health had used three cost indices to benchmark NHS Trusts. His study used the same dataset and compares the efficiency rankings from the cost indices with those obtained using DEA and stochastic cost frontier analysis (SCF).

Azadeh et al. in 2013 presented that, overcrowding is common problem for emergency departments (ED) and related decision making process. Furthermore, they proposed in 2015, an integrated simulation and DEA approach to increase the quality of service in a neurosurgical intensive care unit (ICU).

In the study of Shwartz et al. the following cases have highlighted:

1- DEA is used to develop a composite measure of health care quality.
2- An empirical study is carried in US Department of Veterans Affairs nursing homes.
3- DEA identifies fewer high performers, but more highly rewards the high performers.
4- Advantages of DEA for developing composite measure make it worth pursuing further.
5- Monte Carlo resampling with replacement is applied to reflect DEA data uncertainty.

5 Conclusion

This paper provides a review of the status of research on health supply chain applying modeling of DEA. The classic DEA models, the NDEA models as well as the simulation and stochastic DEA models presented in the papers have been assessed. The findings of the paper summarize the status of research on applying modeling techniques DEA in health supply chain.

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