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Research Article

A DEA Method to Measure the Capacity Utilization of Dynamic Supply Chain

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Abstract. The importance of performance evaluation in many complex problems of management and policies of the supply chain area is sensed more than before. One of the main researches that are still in absence in the performance of a supply chain is to improve the overall efficiency based on the dynamic performance with measure Capacity Utilization (CU). In this paper, by developing the basic Dynamic Data Evolution Analysis (DDEA) model, as an efficient tool that is a new research focus for evaluating the CU of a supplier-manufacturer dynamic supply chain is studied. Also considering the time of performance evaluation with CU measure and variable inputs utilization rate, in order to demonstrate the growth or decline inputs of the supply chain has the key role in effective evaluating of the supply chain. At the end, the result of these offered models is shown through a numeric example.

Keywords. Dynamic Data envelopment analysis (DEA); Supply chain management (SCM); Performance evaluation; Capacity Utilization (CU)

MSC. ???

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1. Introduction

Enterprises face an increasingly challenging marketplace with a growing field of competitors, complex supplier relationships, relationships among product families, higher customer expectations and other factors. On the other hands, the need to be more responsive to the market drives companies to expand their product lines and decreasing transportation costs, quickly modify product delivery rates to match changes in demand (Estampe et al., 2013). Supply chain is a hot topic for business that is processes from initial raw materials to the end user. Supply chain management (SCM) have a tremendous impact on the success of an organization and this being said creates value for subsystems, customers and stakeholders interaction throughout a supply chain. These SCM are engaged in every facet of the business process — planning, purchasing, production, transportation, inventory and distribution, customer service, and more. Hence, their performance helps organizations control expenses, boost sales, maximize profits and to provide the best high-quality products and services at the least cost (Camm et al., 1997 and Cohen and Lee 1989). Because Supply chain management is the management of the flow of goods and services and they are face to many different parts of the business, so they are in unique situations to help subsystems, (Estampe et al., 2013).

On the other hand, in the actual business world, a long time planning, engagement and investment is a subject of great concern. Therefore, one of the performances of a supply chain is measured in terms of Capacity Utilization (CU), so that inadequate or improper capacity can affect a supply chain's performance, Kamath and Roy (2007). CU provides information about short-run, such as economic incentives for investment and disinvestment. Capacity utilization is usually defined as the ration of actual output to potential output and it is depends on the ability of company to utilize their fixed factors in the short run (Klein, 1960; Friedmann, 1963 and Segerson and Squires, 1990).

Effective SCM service benefits from the support of measurement techniques. Data Envelopment Analysis (DEA) is an analytical tool and it is a nonparametric method of measuring the efficiency that can assist in the identification of best practices among a group of decision-making units (DMUs), (Cooper et al., 2006). By the same discussion, performance evaluation is an important task for a supply chain to find its strength or weakness of efficiency, output shortfalls and input excesses, (Nikfarjam et al., 2015). Performance evaluation can yield for comparison with other supply chains can be helpful in understanding situations to help improve supply chain directly identifies the benchmarking units (Yang et al., 2009).

For many cases of business, single period optimization model is not suitable for performance evaluation of supply chain. On the other hand supply chain performance evaluation in a multi-period is very important. Thus the importance of supply chain performance evaluation in dynamic situations of major management challenges, it is considered. In DEA, there are several methods for measuring efficiency changes over time and carry-over activities between two consecutive terms, (Nemoto and Goto (1999), Nemoto and Goto (2003), Emrouznejad and Thanassoulis (2005), Amirteimoori (2006)). Also Sahoo and Tone (2009) propose two methods of DEA to decompose capacity utilization.

However, the point of supply chain may be not the point of capacity utilization and dynamic supply chain. CU and DEA can provide useful information on how to improve dynamic supply chain's performance. Therefore, purpose this paper aims to analyze CU the use of dynamic data envelopment analysis (DDEA) in performance evaluation of supply chain and provide directions for improvement for SCM.

2. Data Envelopment Analysis

Since its establishment in 1973, the DEA can be a very useful analytical technique by providing and it has been responsible for use in evaluating the performances of many different kinds of entities engaged in many different activities. DEA analyzed the conversion of those resources to the wanted outputs, comparing each DMU to the best production units in terms of multiple inputs and multiple outputs (Charnes et al., 1987). Therefore, if the units produce multiple outputs using various inputs, the efficiency of DMU is defined as the ratio between a weighted sum of the outputs and a weighted sum of the inputs. We deal with N DMU_j $(j = 1,2,\ldots,N)$ with the input matrix $X \in \Re^{P\times N}$ (P number of inputs) and output matrix $Y \in \Re^{Q\times N}$ (Q number of outputs). Therefore, the efficiency of DMU_j is defined as

$$\theta_j = \frac{\sum_{q=1}^{Q} u_q y_{qj}}{\sum_{p=1}^{P} v_p x_{pj}}.$$

For weights $(u_1,u_2,\ldots,u_q)$ and $(v_1,v_2,\ldots,v_p)$ associated the outputs and inputs, respectively. In this context, the efficient frontier expresses the relationship between the inputs utilized and outputs produced. The set of feasible activities (DMUs) is called the production possibility set (PPS), and we can define the PPS by:

$$\text{PPS} = \{(x,y) \mid x \geq X\lambda,\ y \leq Y\lambda,\ \lambda \geq 0\}$$

DEA models can be input oriented and output oriented and also can address constant and variable returns to scale, Figure 1. DEA provides a number of addition opportunities for collaboration between analysis and decision-makers. Such collaborations extend to "benchmarking" behaviors of competitors and include identifying new competitors that may emerge for consideration in some of the scenarios that might be generated. And also, excesses in inputs and shortfalls in outputs are called slacks, Tone (2001).

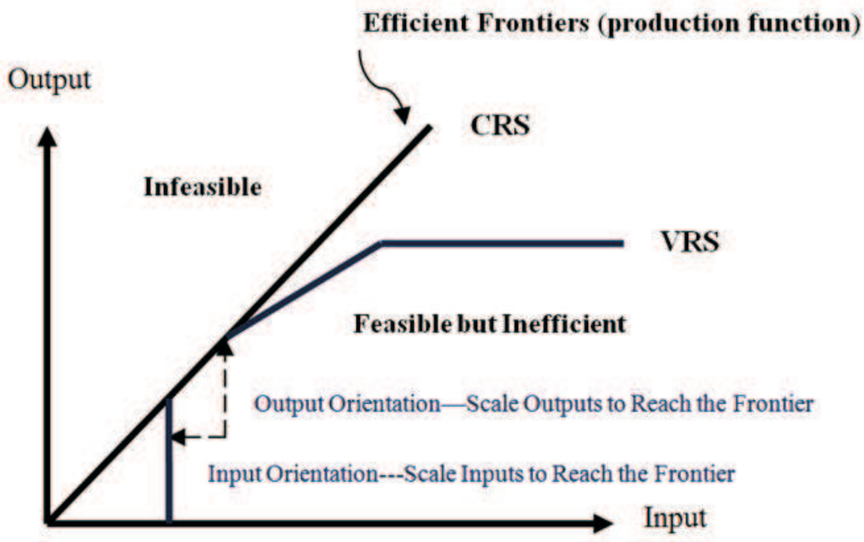


Figure 1. Choice of technology

2.1 Dynamic Data Envelopment Analysis

In fact, an important feature of DEA dynamics research efforts incorporates two different types of inputs into a framework of performance analysis (Nemoto and Goto, 1999), namely, variable inputs x^t and quasi-fixed z^{t-1} (Figure 2).

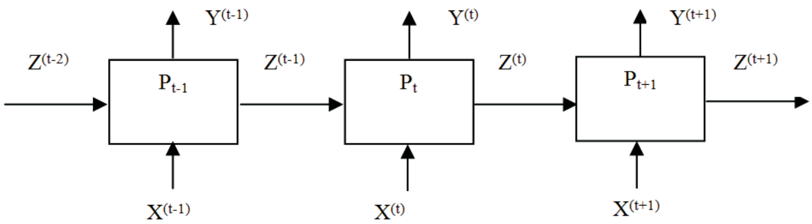


Figure 2. Dynamic DEA (Nemoto and Goto, 1999)

Consider a dynamic production process, that there are N decision making units DMU$_j$ ($j = 1,2,\dots,N$) in T periods ($t = 1,2,\dots,T$). Therefore, a PPS in the period t specified as follows:

$$PPS_t = \{(x^t, z^{t-1}, y^t, z^t) \mid X^t\lambda^t \le x^t, Z^{t-1}\lambda^t \le z^{t-1}, Y^t\lambda^t \ge y^t, Z^t\lambda^t \ge z^t, \lambda^t \ge 0\}$$

3. Method

We deal with n supply chains ($j = 1,2,\dots,n$) over T terms ($t = 1,2,\dots,T$), Figure 3. At each term, supply chains have common P inputs x_{pj}, ($p = 1,2,\dots,P$) and K quasi-fixed inputs (e.g., the capital and resource stocks) z_{kj}, ($k = 1,2\dots,K$) to the first subsystem (supplier) and R outputs i_{rj}, ($k = 1,2,\dots,K$) from that supplier so that referred to as intermediate products, and also these K outputs then become the inputs to the second subsystem (manufacturer). The outputs from the manufacturer are denoted y_{qj} ($q = 1,2,\dots,Q$) (Table 1).

Table 1

Inputs of supplier in time period t	Fix inputs of supplier	$x^{F(t)}_{p^F j}$, ($p^F = 1,2,\dots,P^F$)	x^t_{pj}, $(1,2,\dots,P)$, $P^v + P^F = P$
	Variable inputs of supplier	$x^{V(t)}_{p^V j}$, ($p^V = 1,2,\dots,P^V$)	
Quasi-fixed inputs of supplier in time period t	Fix Quasi-fixed inputs of supplier	$\bar{z}^{S(t-1)}_{k^{S(F)} j}$, ($k^{S(F)} = 1,2,\dots,K^{S(F)}$)	$z^{S(t-1)}_{k^S j}$, $(1,2,\dots,K^S)$, $K^{S(F)} + K^{S(V)} = K^S$
	Variable Quasi-fixed inputs of supplier	$\hat{z}^{S(t-1)}_{k^{S(V)} j}$, ($k^{S(V)} = 1,2,\dots,K^{S(V)}$)	
Output of supplier $z^{S(t)}_{k^S j}$, $(1,2,\dots,K^S)$			
Output of supplier (Intermediate products) i^t_{rj}, $(1,2,\dots,R)$			

(Contd.)

Quasi-fixed inputs of manufacturer in time period t	Fix Quasi-fixed inputs of manufacturer	$\bar{z}^{M(t-1)}_{k^{M(F)}j}$, $(k^{M(F)} = 1,2,\dots,K^{M(F)})$	$z^{M(t-1)}_{k^M j}$, $(1,2,\dots,K^M)$, $K^{M(F)} + K^{M(V)} = K^M$
	Variable Quasi-fixed inputs of manufacturer	$\hat{z}^{M(t-1)}_{k^{M(V)}j}$, $(k^{M(V)} = 1,2,\dots,K^{M(V)})$	
Inputs of manufacturer (Intermediate products)	Fixed	$i^{F(t)}_{r^F j}$, $(r^F = 1,2,\dots,R^F)$	i^t_{rj}, $(1,2,\dots,R)$, $R^V + R^F = R$
	Variable	$i^{V(t)}_{r^V j}$, $(r^V = 1,2,\dots,R^V)$	
Output of supplier $z^{M(t)}_{k^M j}$, $(1,2,\dots,K^M)$			
Output of manufacturer $y^{(t)}_{qj}$, $(q = 1,2,\dots,Q)$			

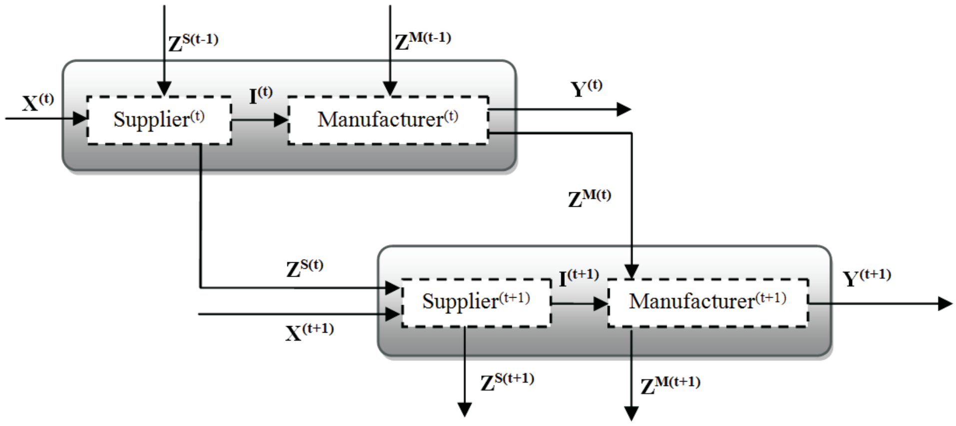


Figure 3. A dynamic supply chain simulation ($t = 1,2,\dots,T$)

3.1 Dynamic DEA

In this section, we first propose a performance evaluation of supply chain by developing the Dynamic DEA method. So that, the dynamic DEA introduce by Nemoto and Goto (1999) and Slack based measure (SBM) of efficiency model proposed by Tone (2001), incorporated into the performance of supply chains. Therefore, We propose the output-oriented dynamic efficiency of d^{th} supply chain ($d = 1,2,\dots,n$) with all inputs by solving the following linear program:

$$\textbf{Model A}: \quad SC^* = \max\left(\frac{1}{T}\right)\sum_{t=1}^{T}\left(1 + \frac{1}{Q+K^S+K^M+R}\left(\sum_{q=1}^{Q}\frac{\Delta^t_q}{y^t_{qd}} + \sum_{k^S=1}^{K^S}\frac{\Delta^t_{k^S}}{z^t_{k^S d}} + \sum_{k^M=1}^{K^M}\frac{\Delta^t_{k^M}}{z^t_{k^M d}} + \sum_{r=1}^{R}\frac{\Delta^t_r}{i^t_{rd}}\right)\right)$$

$s.t$

$$A1: \sum_{j=1}^{N}\lambda^t_j x^t_{pj} \le x^t_{pd}, \quad t = 1,2,\dots,T, p = 1,2,\dots,P$$

$$A2: \sum_{j=1}^{N}\lambda^t_j z^{S(t-1)}_{k^S j} \le z^{S(t-1)}_{k^S d}, \quad t = 1,2,\dots,T, k^S = 1,2,\dots,K^S$$

$$A3: \sum_{j=1}^{N}\lambda^t_j z^{S(t)}_{k^S j} - \Delta^t_{k^S} = z^{S(t)}_{k^S d}, \quad t = 1,2,\dots,T, k^S = 1,2,\dots,K^S$$

$$A4: \sum_{j=1}^{N} \lambda_j^t i_{rj}^t - \Delta_r^t = i_{rd}^t, \quad t = 1,2,\ldots,T, r = 1,2,\ldots,R$$

$$A5: \sum_{j=1}^{N} \mu_j^t i_{rj}^t \le i_{rd}^t, \quad t = 1,2,\ldots,T, r = 1,2,\ldots,R$$

$$A6: \sum_{j=1}^{N} \mu_j^t z_{k^M j}^{M(t-1)} \le z_{k^M d}^{M(t-1)}, \quad t = 1,2,\ldots,T, k^M = 1,2,\ldots,K^M$$

$$A7: \sum_{j=1}^{N} \mu_j^t z_{k^M j}^{M(t)} - \Delta_{k^M}^t = z_{k^M d}^{M(t)}, \quad t = 1,2,\ldots,T, k^M = 1,2,\ldots,K^M$$

$$A8: \sum_{j=1}^{N} \mu_j^t y_{qj}^t - \Delta_q^t = y_{qd}^t, \quad t = 1,2,\ldots,T, q = 1,2,\ldots,Q$$

$$A9, A10: \lambda_j^t \ge 0, \quad \mu_j^t \ge 0, t = 1,2,\ldots,T, j = 1,2,\ldots,N$$

$$A11: \Delta_{k^S}^t \ge 0, \quad t = 1,2,\ldots,T, k^S = 1,2,\ldots,K^S$$

$$A12: \Delta_{k^M}^t \ge 0, \quad t = 1,2,\ldots,T, k^M = 1,2,\ldots,K^M$$

$$A13: \Delta_r^t \ge 0, \quad t = 1,2,\ldots,T, r = 1,2,\ldots,R$$

$$A14: \Delta_q^t \ge 0, \quad t = 1,2,\ldots,T, q = 1,2,\ldots,Q.$$

The objective function of Model A is introduced as the average of time of the performance by slack based measure and seeks to maximize the outputs. Expressions A1-A14 are considered as the model formulation for performance evaluation of overall supply chain. A1 and A2 are input and qusi-fixed input constraints of supplier respectively. Expression A3 and A4 indicates the output of supplier. Similar to the expressions of supplier, the A5-A8 are input, quasi-fixed input and output of manufacturer. And also A4 and A5 are intermediate products constraint. $\Delta_{k^S}^t$, $\Delta_{k^M}^t$, Δ_r^t and Δ_q^t denote the outputs shortfalls in supplier and manufacturer. The Model A is dimension free and units invariant i.e. relaxes the proportionate change assumption and aims at obtaining maximum rate of increase in outputs of supplier and manufacturer. The most important reason non-radial method was introduced that is satisfying the fundamental condition and reflects the empirical realities more. The non-negative property of the variables are indicates in A9-A14. λ_j^t and μ_j^t are intensity variable of period t of j^{th} supplier and j^{th} manufacture of j^{th} supply chain.

Definition 1. The d^{th} supply chain ($d = 1,2,\ldots,n$) is efficient if and only if $\Delta_q^t = \Delta_{k^S}^t = \Delta_{k^M}^t = \Delta_r^t = 0$, for all t, q, k^S, k^M, r or $\text{SC}^* = 1$ in Model A.

We propose the output-oriented dynamic efficiency of d^{th} supply chain ($d = 1,2,\ldots,n$) with fix inputs by solving the following linear program:

Model B: $$\text{SC}^{F*} = \max\left(\frac{1}{T}\right)\sum_{t=1}^{T}\Bigg(1 + \frac{1}{Q + K^S + K^M + R} \left(\sum_{q=1}^{Q} \frac{\bar{\Delta}_q^t}{y_{qd}^t} + \sum_{k^S=1}^{K^S} \frac{\bar{\Delta}_{k^S}^t}{z_{k^S d}^t} + \sum_{k^M=1}^{K^M} \frac{\bar{\Delta}_{k^M}^t}{z_{k^M d}^t} + \sum_{r^F=1}^{R^F} \frac{\bar{\Delta}_{r^F}^t}{i_{r^F d}^t} + \sum_{r^V=1}^{R^V} \frac{\bar{\Delta}_{r^V}^t}{i_{r^V d}^t}\right)\Bigg)$$

$s.t$

$$B1: \sum_{j=1}^{N} \lambda_j^t x_{p^F j}^{F(t)} \le x_{p^F d}^{F(t)}, \quad t = 1,2,\dots,T, p^F = 1,2,\dots,P^F$$

$$B2: \sum_{j=1}^{N} \lambda_j^t \bar{z}_{k^{S(F)} j}^{S(t-1)} \le \bar{z}_{k^{S(F)} d}^{S(t-1)}, \quad t = 1,2,\dots,T, k^{S(F)} = 1,2,\dots,K^{S(F)}$$

$$B3: \sum_{j=1}^{N} \lambda_j^t z_{k^S j}^{S(t)} - \bar{\Delta}_{k^S}^t = z_{k^S d}^{S(t)}, \quad t = 1,2,\dots,T, k^S = 1,2,\dots,K^S$$

$$B4: \sum_{j=1}^{N} (\lambda_j^t - \mu_j^t)\, i_{r^F j}^{F(t)} \ge \bar{\Delta}_{r^F}^t, \quad t = 1,2,\dots,T, r^F = 1,2,\dots,R^F$$

$$B5: \sum_{j=1}^{N} \lambda_j^t i_{r^V j}^{V(t)} - \bar{\Delta}_{r^V}^t = i_{r^V d}^{V(t)}, \quad t = 1,2,\dots,T, r^V = 1,2,\dots,R^V$$

$$B6: \sum_{j=1}^{N} \mu_j^t \bar{z}_{k^{M(F)} j}^{M(t-1)} \le \bar{z}_{k^{M(F)} d}^{M(t-1)}, \quad t = 1,2,\dots,T, k^{M(F)} = 1,2,\dots,K^{M(F)}$$

$$B7: \sum_{j=1}^{N} \mu_j^t z_{k^M j}^{M(t)} - \bar{\Delta}_{k^M}^t = z_{k^M d}^{M(t)}, \quad t = 1,2,\dots,T, k^M = 1,2,\dots,K^M$$

$$B8: \sum_{j=1}^{N} \mu_j^t y_{qj}^t - \bar{\Delta}_q^t = y_{qd}^t, \quad t = 1,2,\dots,T, q = 1,2,\dots,Q$$

$$B9, B10: \lambda_j^t \ge 0, \mu_j^t \ge 0, \quad t = 1,2,\dots,T, j = 1,2,\dots,N$$

$$B11: \bar{\Delta}_{k^S}^t \ge 0, \quad t = 1,2,\dots,T, k^S = 1,2,\dots,K^S$$

$$B12: \bar{\Delta}_{k^M}^t \ge 0, \quad t = 1,2,\dots,T, k^M = 1,2,\dots,K^M$$

$$B13: \bar{\Delta}_q^t \ge 0, t = 1,2,\dots,T, q = 1,2,\dots,Q$$

$$B14: \bar{\Delta}_{r^F}^t \ge 0, \quad t = 1,2,\dots,T, r^F = 1,2,\dots,R^F$$

$$B15: \bar{\Delta}_{r^V}^t \ge 0, \quad t = 1,2,\dots,T, r^V = 1,2,\dots,R^V.$$

Definition 2. The d^{th} supply chain ($d = 1,2,\dots,n$) is efficient if and only if $\bar{\Delta}_q^t = \bar{\Delta}_{k^S}^t = \bar{\Delta}_{k^M}^t = \bar{\Delta}_{r^F}^t = \bar{\Delta}_{r^V}^t = 0$, for all t, q, k^S, k^M, r or $\text{SC}^{F*} = 1$ in Model A.

3.2 Technological Measure of Capacity Utilization

CU provides information about short-run. Technological measure (TM) of capacity utilization is importance for effective supply chain management. In this section we show how the TM of capacity utilization in terms of output can be used in supply chain. Initially, we evaluate the Model A and Model B scores for all of the time and for all supply chain and then we set in equivalent (C). The capacity utilization of d^{th} supply chain as follows:

$$\text{CU}_d^{TM(\text{Supply.Chain})} = \frac{\text{SC}^*}{\text{SC}^{F*}} \tag{C}$$

The fraction of this capacity used within of time is called the capacity utilization of the supply chain.

It is clear that $\mathrm{SC}^* \le \mathrm{SC}^{F*}$. Therefore applying the equivalent of TM capacity utilization; we have $\mathrm{CU}_d^{TM(\text{Supply.Chain})} \le 1$ for each of n supply chains and cannot exceed one in value. According to the equivalent of TM capacity utilization, we classify them into two categories:

Case I. $\mathrm{CU}_d^{TM(\text{Supply.Chain})} < 1$:
Interpretation of this case is a tendency to classify producing supply chains as having excess capacity and some of the capital stock is not fully utilized. That supply chain has the potential for greater production without having to incur major expenditures for new capital or facilities. We have inefficient supply chain both of the two positions of Model A and Model B.

Case II. $\mathrm{CU}_d^{TM(\text{Supply.Chain}} = 1$:
Supply chain ability in adjusting their fixed factors in the short run.

Theorem 1. $\mathrm{CU}_d^{TM(\text{Supply.Chain})} = 1$ *if and only if each time* $\mathrm{CU}_d^{TM(t)} = 1$, $t = 1,2,\ldots,T$.

Proof. Consider the Model A, Model B and equation (C) and then the proof of this theorem is clear. □

Theorem 2. *Consider the Model A and Model B and also suppose that* d^{th} *supply chain is a dynamic efficient unit. Then we have* $\mathrm{CU}_d^{TM(\text{Supply.Chain})} = 1$.

Proof. The proof of this theorem is clear. □

3.3 Economic Measure of Capacity Utilization

The economic measure of CU the state of performance that all variable factors necessary to achieve an economic optimal such as minimum cost or maximum profit. In contract, the previously discussed TM capacity utilization definition of capacity equates with maximum potential output in the short run without any economic optimization. The economic measure of CU to give a measure based on the ratio of optimal use of a variable input to observed use input. Therefore, using optimal $\lambda_j^{t(*)}$ in Model B, CU of variable inputs of supplier can be obtained as:

$$\mathrm{CU}_{p^V d}^{EM} = \frac{\sum_{j=1}^{N} \lambda_j^{t(*)} x_{p^V j}^t}{x_{p^V d}^t}, \quad t = 1,2,\ldots,T,\ p^V = 1,2,\ldots,P^V. \tag{D1}$$

And also using optimal $\mu_j^{t(*)}$ in Model B, CU of variable inputs of manufacturer can be obtained as:

$$\mathrm{CU}_{r^V d}^{EM} = \frac{\sum_{j=1}^{N} \mu_j^{t(*)} i_{r^V j}^t}{i_{r^V d}^t}, \quad t = 1,2,\ldots,T,\ r^V = 1,2,\ldots,R^V. \tag{E1}$$

And CU of overall time of inputs of supplier and manufacturer, respectively D2 and E2:

$$\mathrm{CU}_{p^V d}^{EM(\text{Supplier})} = \frac{\sum_{t=1}^{T}\sum_{j=1}^{N} \lambda_j^{t(*)} x_{p^V j}^t}{\sum_{t=1}^{T} x_{p^V d}^t}, \quad p^V = 1,2,\ldots,P^V. \tag{D2}$$

$$\mathrm{CU}_{r^V d}^{EM(\text{Manufacturer})} = \frac{\sum_{t=1}^{T}\sum_{j=1}^{N} \mu_j^{t(*)} i_{r^V j}^t}{\sum_{t=1}^{T} i_{r^V d}^t}, \quad r^V = 1,2,\dots,R^V. \tag{E2}$$

Also the rate of capacity utilization of supplier and manufacturer when there are quasi-fixed:

$$\mathrm{CU}_{k^{S(V)} d}^{EM} = \frac{\sum_{j=1}^{N} \lambda_j^{t(*)} \hat{z}_{k^{S(V)} j}^{S(t-1)}}{\hat{z}_{k^{S(V)} d}^{S(t-1)}}, \quad t = 1,2,\dots,T,\ k^{S(V)} = 1,2,\dots,K^{S(V)}. \tag{F}$$

$$\mathrm{CU}_{k^{M(V)} d}^{EM} = \frac{\sum_{j=1}^{N} \lambda_j^{t(*)} \hat{z}_{k^{M(V)} j}^{M(t-1)}}{\hat{z}_{k^{M(V)} d}^{M(t-1)}}, \quad t = 1,2,\dots,T,\ k^{M(V)} = 1,2,\dots,K^{M(V)}. \tag{G}$$

Numerical Example

We apply our method to a data set consisting 7 supply chains and three observation periods (Table 2, Table 3 and Table 4). The columns 2^{th}, 3^{th} and 4^{th} of Table 2, Table 3 and Table 4 report the three inputs scores, note that the columns 2^{th} and 3^{th} are fix inputs and the column 4^{th} is variable input, and also the columns 7^{th} and 8^{th} of each table are outputs. There are also two intermediate products between the supplier and manufacturer, reported as the columns 5^{th} and 6^{th} of each table.

Table 2. Data-Time (1)

No.	$x_{1j}^{F(1)}$	$x_{2j}^{F(1)}$	$x_{1j}^{V(1)}$	$i_{1j}^{F(1)}$	$i_{1j}^{V(1)}$	$y_{1j}^{(1)}$	$y_{2j}^{(1)}$
SC1	12481	13418	23	12215	14036	13772	18130
SC2	7050	5150	17	4758	4012	1453	961
SC3	446	4775	5	6061	13709	3614	6085
SC4	7239	20125	90	3763	555	10928	19803
SC5	10538	17911	11	3848	2334	2002	2348
SC6	3363	2363	30	13407	13471	57	5326
SC7	10678	19460	25	4407	1594	20825	63138

Table 3. Data-Time (2)

No.	$x_{1j}^{F(2)}$	$x_{2j}^{F(2)}$	$x_{1j}^{V(2)}$	$i_{1j}^{F(2)}$	$i_{1j}^{V(2)}$	$y_{1j}^{(2)}$	$y_{2j}^{(2)}$
SC1	10168	1526	20	5277	9130	17394	26617
SC2	5915	5407	25	4064	385	7782	5464
SC3	7237	1708	10	17782	12656	9415	7287
SC4	5150	2713	85	1415	5658	6134	4038
SC5	14775	1443	20	6134	4614	17324	16186
SC6	6125	638	32	17324	13408	5191	7309
SC7	17911	1975	30	5191	8819	49907	28250

Table 4. Data-Time (3)

No.	$x_{1j}^{F(3)}$	$x_{2j}^{F(3)}$	$x_{1j}^{V(3)}$	$i_{1j}^{F(3)}$	$i_{1j}^{V(3)}$	$y_{1j}^{(3)}$	$y_{2j}^{(3)}$
SC1	10213	10372	19	5516	5690	10322	10164
SC2	9385	5516	26	3555	3570	6271	7782
SC3	2656	13555	11	1811	5915	6280	9415
SC4	105658	1811	86	19852	19370	11389	16134
SC5	14614	19852	22	5262	2558	4516	7324
SC6	3408	5262	30	4786	177	14598	15191
SC7	18819	14786	24	7394	4870	54120	71110

In Tables 5 and 6 we assume one fix input and one variable input regarding seven supplier-manufacturer supply chains.

Table 5. Data-Quasi-fixed (supplier)

No.	$\bar{z}_{1j}^{S(0)}$	$\hat{z}_{1j}^{S(0)}$	$\bar{z}_{1j}^{S(1)}$	$\hat{z}_{1j}^{S(1)}$	$\bar{z}_{1j}^{S(2)}$	$\hat{z}_{1j}^{S(2)}$	$\bar{z}_{1j}^{S(3)}$	$\hat{z}_{1j}^{S(3)}$
SC1	1713	25	19662	14	17945	28	18902	10
SC2	443	3	8261	20	8419	17	6873	9
SC3	638	14	9169	16	6131	8	4119	17
SC4	575	16	6223	7	9416	15	5972	22
SC5	1432	12	18813	15	14477	11	11789	16
SC6	510	20	8876	12	7639	23	3959	24
SC7	442	13	5412	11	1870	12	3239	14

Table 6. Data-Quasi-fixed (manufacturer)

No.	$\bar{z}_{1j}^{M(0)}$	$\hat{z}_{1j}^{M(0)}$	$\bar{z}_{1j}^{M(1)}$	$\hat{z}_{1j}^{M(1)}$	$\bar{z}_{1j}^{M(2)}$	$\hat{z}_{1j}^{M(2)}$	$\bar{z}_{1j}^{M(3)}$	$\hat{z}_{1j}^{M(3)}$
SC1	1413	205	19662	104	27945	208	10002	100
SC2	443	32	8261	200	8419	107	18073	92
SC3	638	104	29169	106	6131	85	9119	107
SC4	1575	106	16223	72	19416	105	5442	202
SC5	2432	102	18813	105	24477	101	17789	106
SC6	2510	200	8876	102	439	203	5559	214
SC7	1442	103	15412	101	10870	102	1239	104

Table 7 lists the overall efficiencies obtained by the Model A and Model B in 2^{th} and 3^{th} columns. Based on the structure of this three-time dynamic supply chain shown in Figure 3, the SC2 is efficient by Model A. Also the period CU obtained by the Model A and Model B reports as the 4^{th}, 5^{th} and 6^{th} column of Table 7. The propose method offers the CU for dynamic supply chain, as shown in the 8^{th} column of Table 7. Then, whatever CU value closes to zero more, then the importance of variables indicators will be more in the assessment of performance, reported as the 8th column of Table 7. In other words, variable indicators have more affect on the efficiency of supply chain. These critical indicators make to criticize in critical assessment system if these be or not too, that is, have direct affect on efficiency measurement and the manger has to more focus on these indicators, that in, this supply chain has not self capacity properly. Therefore, the SC6 is the optimal CU and the SC5 is the end of level ranking based on the CU, while Figure 4. Gives a graphical interpretation of the same results.

Table 7. Performance evaluation and CU

No.	SC^*	SC^{F*}	$CU_d^{TM(\text{time-1})}$	$CU_d^{TM(\text{time-2})}$	$CU_d^{TM(\text{time-3})}$	$CU_d^{TM(\text{Supply.Chain})}$	Rank of CU
SC1	1.4837	1.7168	0.7753	1.0000	0.9022	0.8642	3
SC2	1.0000	2.2401	1.0000	0.2119	1.0000	0.4464	6
SC3	1.3647	1.8898	1.0000	0.5707	1.0000	0.7221	4
SC4	2.0736	3.0997	0.8675	1.0000	0.2912	0.6690	5
SC5	1.1223	3.2716	0.2384	0.4633	0.3745	0.3430	7
SC6	28.0000	28.0000	1.0000	1.0000	1.0000	1.0000	1
SC7	1.2790	1.3329	0.9191	1.0000	1.0000	0.9596	2

It is clear that, disruption within supply chains can have a significant impact on efficiency, leading to them falling efficiency of SC2, SC4. Figure 4 show this point.

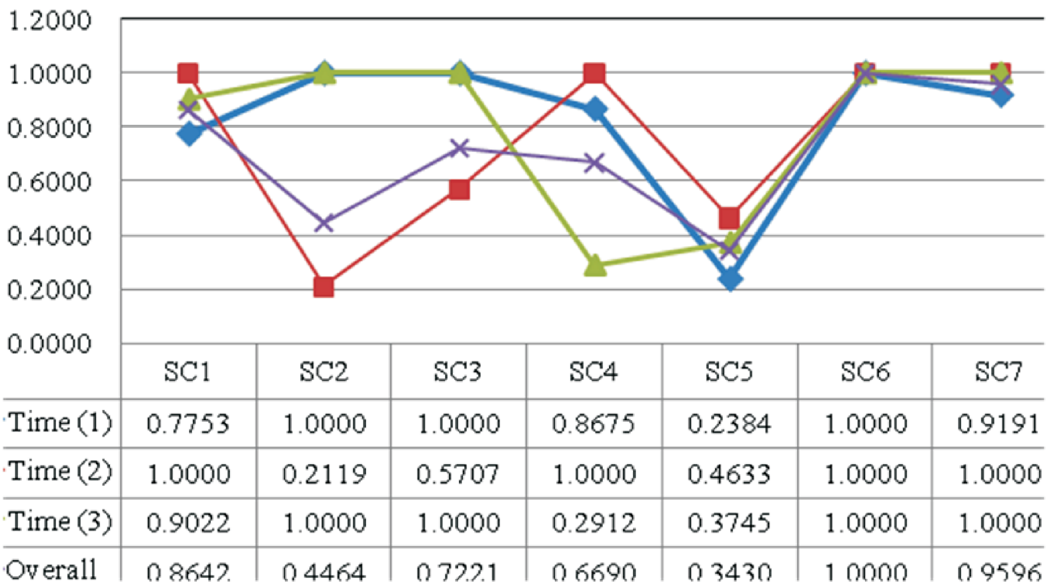
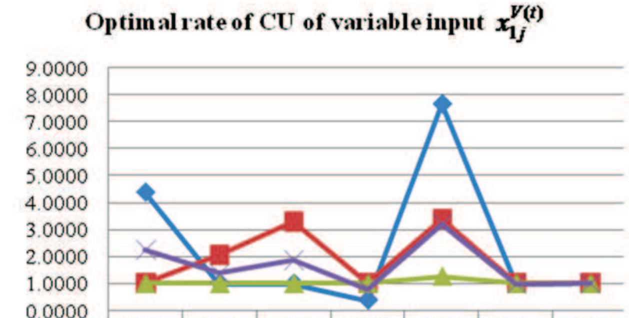


Figure 4. Compare CU of supply chain

We solved the CU of variable input $x_{p^V j}^{V(t)}$ of supplier by equation (D1) and (D2). For the convenience for comparison, Figure 5 shows solutions and decomposed part of times. The CU of variable input of SC1, SC2, SC3, SC5 and SC7 must be growth. The CU of variable input

$x^{V(t)}_{p^V j}$ of SC4 must be decline and SC6 unchanged. We observe that, for SC5 of variable input $x^{V(t)}_{p^V j}$ disruption seems to be increasing. Therefore, supply chain management should be able to growth or decline variable input and rapidly take action to minimize the impact of a disruption. The best mange a variable input disruption is to prepare for SC6.

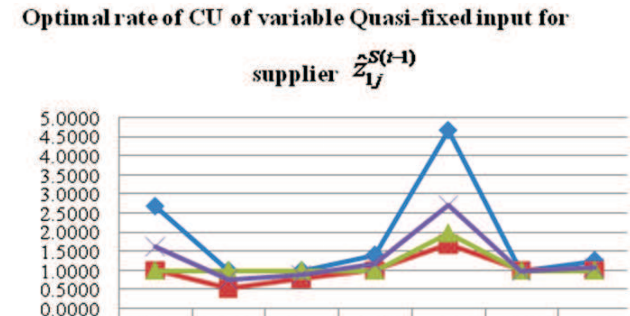


	SC1	SC2	SC3	SC4	SC5	SC6	SC7
Time (1)	4.3813	1.0000	1.0000	0.3757	7.6582	1.0000	1.0172
Time (2)	1.0000	2.0476	3.2960	1.0000	3.3920	1.0000	1.0000
Time (3)	1.0000	1.0000	1.0000	1.0000	1.2800	1.0000	1.0000
Overall	2.2544	1.3851	1.8831	0.7847	3.2249	1.0000	1.0055

No.	State
SC1	CU of variable input must be growth
SC2	CU of variable input must be growth
SC3	CU of variable input must be growth
SC4	CU of variable input must be decline
SC5	CU of variable input must be growth
SC6	unchanged
SC7	CU of variable input must be growth

Figure 5. Optimal rate of CU of variable input

Figure 6 corresponds to the $\hat{z}^{S(t-1)}_{1j}$ factor, where SC5 with highly disruption input. That is, the measures of CU are conditional on the available quasi-fixed factors, for example capital stock and resource stock.

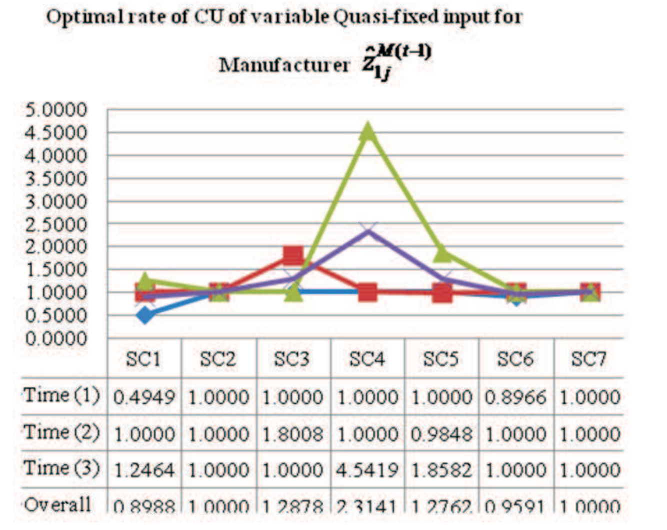


	SC1	SC2	SC3	SC4	SC5	SC6	SC7
Time (1)	2.6872	1.0000	1.0000	1.4087	4.6800	1.0000	1.2638
Time (2)	1.0000	0.5245	0.7725	1.0000	1.6960	1.0000	1.0000
Time (3)	1.0000	1.0000	1.0000	1.0000	1.9836	1.0000	1.0000
Overall	1.6296	0.7623	0.9042	1.1721	2.7216	1.0000	1.0953

No.	State
SC1	CU of variable input must be growth
SC2	CU of variable input must be decline
SC3	CU of variable input must be decline
SC4	CU of variable input must be growth
SC5	CU of variable input must be growth
SC6	unchanged
SC7	CU of variable input must be growth

Figure 6. Optimal rate of CU of variable Quasi-fixed input for supplier

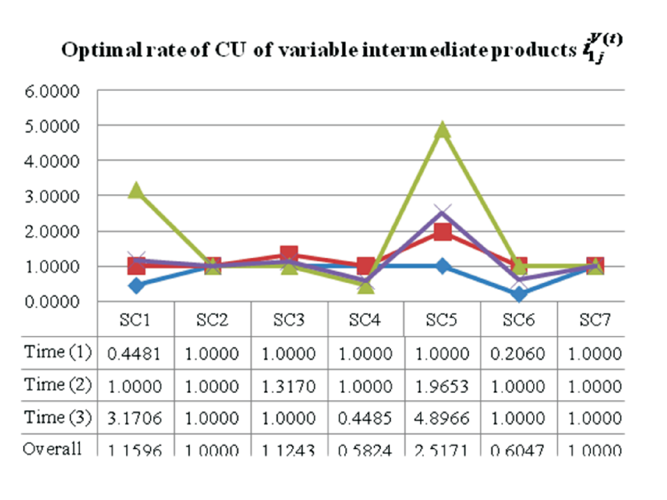
Figure 7 shows $CU^{EM}_{kM(V)d}$ degree of each manufacturer. In terms of CU scores, SC3, SC4 and SC5 must be growth.



No.	State
SC1	CU of variable input must be decline
SC2	unchanged
SC3	CU of variable input must be growth
SC4	CU of variable input must be growth
SC5	CU of variable input must be growth
SC6	CU of variable input must be decline
SC7	unchanged

Figure 7. Optimal rate of CU of variable Quasi-fixed input for manufacturer

Figure 8 displays the results graphically of rate of CU for intermediate products.



No.	State
SC1	CU of variable input must be growth
SC2	unchanged
SC3	CU of variable input must be growth
SC4	CU of variable input must be decline
SC5	CU of variable input must be growth
SC6	CU of variable input must be decline
SC7	unchanged

Figure 8. Optimal rate of CU of variable intermediate products

To describe one variable factor, we can show that (B) delete one constraint corresponding to variable factor in the model and then sensitivity analysis of CU.

4. Conclusions

Organizations and companies know that to survive, keeping customers and more profit requires the use of new technologies are every company in today' s society that operate smarter and better use of existing opportunities to win in this competitive environment will so today, implementing supply chain management major concern of managers is present. But before implementing any new idea must first identify its challenges and problems to be run over when they were overcome. To overcome this problem, in this paper, by developing the basic Dynamic

Data Evolution Analysis (DDEA) model, as an efficient tool that is a new research focus for evaluating the CU of a supplier-manufacturer dynamic supply chain is studied. Also considering the time of performance evaluation with CU measure and variable inputs utilization rate, in order to demonstrate the growth or decline inputs of the supply chain has the key role in effective evaluating of the supply chain. Therefore, in this paper we show that conventional DEA approaches could lead to biased results due to the dynamic effect in performance evaluation of supply chain. The presented models have important applications in areas of supply chain network. However, the utilization of performance evaluation is still at a relatively low level in Producing operation management and supply chain management. Applications to negative data model are potential subjects for future research.

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Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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