

# Evaluation of Construction Supply Chain using Preference Restraint Cone DEA Model

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## Abstract

The internal pressure and external incentive of construction area contributed to the study of supply chain management, construction calls for the construction supply chain management's (CSC) research and practice. Combining with features of Data Envelope Analysis (DEA) and CSC, the basic framework of CSC comprehensive performance evaluation was built from the aspect of consumption and output. Under such framework, the indicator system for comprehensive evaluation was also constructed. Because traditional methods of DEA do not consider the impact of preferences of the input and output indicators for decision makers, an improved preference restraint cone DEA model was presented; an example was given for analysis. The results show that the DEA with the preferred model ommissions the pseudo-effective construction supply chain and reflects the subjective preferences of decision makers. It is an improvement from past research of the model.

*Keywords:* construction supply chain management; performance evaluation; restraint cone; data envelope analysis

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## 1. Introduction

The long chain and high-cost feature of construction management chain contribute to the complexity and difficulty of CSC [1,2]. As the disorder and disturbance are the congenital defect of construct industry, the partner, union or deeper cooperation build up an enhanced supply chain integrated mode [11]. Traditional management methods cannot achieve optimal control on the whole project, the researchers proposed to apply novel management mode to the construction industry [1,12]. The buffer management system method was used to improve uncertainty in the procurement of construction chain [14]. With the idea of Supply Chain Management (SCM), the environmental performance of CSC can be significantly improved [9].

In the SCM, the general contractor is the leader of CSC. The satisfaction of the owner can be increased by reducing costs, where the decrease of labor cost is most meaningful. Effective SCM and downstream enterprise strategic alliance can implement cost management [10]. Some scholars introduced a Terrain Scanning Methodology (TSM) to improve performance. The resource usage can be minimized and usage peak can be diagnosed, which is a critical step in the long-term development of the supply chain [3]. The CSC is to build supply network chain relationship among owners, general contractors, subcontractors and material suppliers and optimize the network to achieve integration of supply chain, namely the Construction Supply Chain Management (CSCM) mode can greatly enhance core competitiveness of enterprises.

However, some performance evaluation systems of existing CSC may not take own characteristics into account and the indicator system is relatively simple. The specific algorithms for performance evaluation may not suitable for the construction supply chain. To address the performance evaluation indicator system and devaluation method of CSC, a comprehensive indicator system was built and improved DEA model was presented. The following part of the paper is organized as follows: section 2 builds the performance evaluation indicator system of CSC; section 3 gives improved

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preference restraint cone DEA model; section 4 analyzes and verifies the proposed DEA model with computation example; section 5 concludes our work.

## 2. CSC Performance Evaluation Indicator System

The CSC initiates from effective demands of owners and treats general contractor as core business. By controlling information flow, logistics and capital flow, it integrates subcontractors, material suppliers, engineering equipment suppliers and owners into a project-based functional network chain mode from bid to construction, completion and after-sales service. As a workable and hierarchical comprehensive CSC evaluation framework, it should not only define which aspects to evaluate CSC performance, but also determine corresponding target and tasks included by the above aspects [4,15]. From the business processes and value-added perspective, the paper divides CSC into three core subsystems, namely the material supply subsystem, construction subsystem and transfer service subsystem, so that the performance evaluation serves CSC better.

### 2.1. Indicator Design

The evaluation indicator selection directly affects the accuracy of evaluation result and complexity of practical evaluation work. In case of evaluation indicator selection, it should reflect the actual situation of existing construction industry. The content of indicator should relate to problems concerning about most construction companies. The selected indicators should not repeat in the content covering and match to each other on the interpretation function.

The supply chain performance evaluation system consists of several linked, supplementary, hierarchical and structural indicators. These indicators include not only basic indicators from original data to reflect the feature of subsystems, but also abstract and integrated indicators to indicate correlation among subsystems. In the case of evaluation indicator selection, it should be noted that selection can be affected by management measures directly or indirectly. The indicators should also have time and dynamic characteristics. Open indicators that reflect relationship among variables and exchange with the external environment should be selected.

### 2.2. Indicator Source

The paper builds CSC comprehensive performance evaluation indicator from aspects of consumption and production after indication primary selection and improvement processes. In the indicator selection process, the theory analyzing method and frequency analyzing method were combined. Therefore, the evaluation indicator should be first analyzed from a large number of collected indicators combined with selected steps and flow. Secondly, select indicators with larger frequency and stronger target using the frequency analysis method.

In the indicator improvement process, the expert consultation method was used in the construction site for interviews with a number of project managers and construction experts. Thus, indicators concerned by construction enterprises or reflect construction process can be obtained, such as project change handle capability, owner complain capability, rework rate, enter assert return rate, net profit growth, construction profitability, supply chain response time, time control capability, risk control capability, construction project cost level, inventory turnover rate, supplier product qualified rate, supplier on-time-delivery rate, proportion of general contractor account for supplier business, material procurement cost, employee number, labor productivity and etc. Then, indicators are verified one by one, namely, the correctness and feasibility of each indicator are checked [8,5,7,17,16]. The feasibility indicates whether the value of an indicator can be obtained. Indicators whose accurate information is impossible or difficult to get, or cost a lot are not feasible. The correctness is to determine whether the computation method, scope and content are correct. Then, the remaining indicators go through necessity verification, which checks whether all indicators are essential to the global system. Generally, the correlation coefficient method can be used.

Finally, the traditional DEA and network DEA methods are used for CSC performance evaluation on the basis of the evolution framework from aspects of consumption and production. Thus, the selected indicator should not only meet the feature of CSC, but also match DEA. The indication system selection based on DEA should note the following problems. DEA method regards the decision unit as a black box. The input or output factor may be full or partial control factors of Decision Making Unit (DMU), the environment cannot be controlled, or quantitative or qualitative factors. However, the introduction of a large number of factors may blur most difference among DMU. It may lead to an excessive DMU assessed as effective, resulting in meaningless assessment. Generally, the result is ideal when the number of decision units is twice of the total number of input and output indicators.

### 2.3. Indicator Building

#### 1. Consumption Indicators

The determined consumption contains two aspects of cost and human.

(1) **Cost.** The construction supply chain is the consumed resource value to achieve normal operation of whole supply chain, including necessary capital, human, equipment and material. The CSC is a collection of enterprises. The cost is generated accompanying CSC operation directly or indirectly. The cost includes construction material procurement cost  $X_{j11}$  of material supplier subsystem. When using the construction subsystem, there are input value  $M_{j121}$  of construction material and construction cost  $X_{j21}$ . As far as transfer service subsystem, there is building product value  $M_{j231}$  in the construction process, Maintenance Repair Overhaul (MRO) cost  $X_{j31}$ . The cost of the whole CSC system is  $X_1$  which is the summation of material procurement cost  $X_{j11}$ , construction cost  $X_{j21}$  and MRO cost  $X_{j31}$ .

(2) **Human.** The human resource should include many indicators of employee number, employee composition and others. Considering the operability of data collection and DEA evaluation method, there should only be a few indicators. The paper uses employee number as the lower indicator of human resource, which can reflect the labor productivity of CSC. When using the material procurement subsystem, the indicator is procurement personnel number  $X_{j12}$ . The indicator of construction subsystem is construction personnel number  $X_{j22}$ . When using the transfer service subsystem, there is service personnel number  $X_{j32}$ . When using the whole CSC system, the personnel number  $X_2$  is the summation of procurement personnel number  $X_{j12}$ , construction personnel number  $X_{j22}$  and service personnel number  $X_{j32}$ .

#### 2. Output Indicator

According to determined evaluation factors as financial situation and service level, the specific evaluation indicators contained in each factor are as follows.

(1) **Financial situation.** The profit is the main indicator to reflect investment efficiency, so as to the construction industry. Thus, net profit and Return on Investment (RIO) are used to reflect the financial condition of the CSC. When using the material supply subsystem, there is construction material value as intermediate variable  $M_{j121}$ . As far as construction subsystem, the indicator is the value of completed construction product as intermediate variable  $M_{j231}$ . When using the transfer service subsystem, there are net profit  $Y_{j31}$  and project ROI  $Y_{j33}$ . So, the financial situation of whole CSC is net profit  $Y_3 = Y_{j31}$  and ROI  $Y_5 = Y_{j33}$ .

(2) **Service level.** The service level includes the following factors. When using the material supply subsystem, there is a timely delivery rate  $Y_{j11}$ . When using the construction subsystem, there is the satisfaction of the owner on the project  $Y_{j21}$ . The indicator of transfer service subsystem is after-sales service quality  $Y_{j32}$ . As far as the whole CSC system as concerned, the evaluation is conducted with timely delivery rate  $Y_1 = Y_{j11}$ , owner satisfaction  $Y_2 = Y_{j21}$  and after-sales service quality  $Y_4 = Y_{j32}$ .

### 3. Application of DEA in Supply Chain Evaluation

#### 3.1. Network DEA

Supply chain system is a complicated system. The CSC performance evaluation should not only consider overall performance and horizontal comparison, but also that of internal subsystems. Although traditional DEA method is able to evaluate the relative efficiency of the supply chain, it only regards the supply chain as a big system with input and output. The conversion system between input and output is processed as a black box. That is to say, the traditional DEA method does not consider coordination among subsystems within the supply chain and impact of performance change on the whole supply chain in the evaluation on relative performance.

We argue that the entire system should be divided into a series of core subsystems on the basis of evaluating on overall performance with traditional DEA method. The paper builds a supply chain relative performance evaluation model based on network DEA to thoroughly investigate the supply chain.

Divide the decision unit into  $K$  sub-processes and each one has corresponding input variable and output variable. Meanwhile, there is also an intermediate variable, which is both the output variable of one subsystem and the input variable

of an adjacent subsystem. Arrange each sub-process in accordance with the business process. The outputted intermediate variable from former sub-process can only be consumed by the next one. Through these intermediate variables, each subsystem of the decision unit can be tightly connected. Based on the DEA model [6,13], the general form of single network DEA based on flow is as follows.

The decision unit is represented by  $j$  and decision of target as  $j_0, j=1, 2, \dots, n$ . As mentioned above, each unit can be divided into  $K$  sub-processes, which is represented by  $k$  in it and  $k=1, 2, \dots, K$ . The paper set  $x_{jki}$  as the consumed amount of the  $i$ -th input in the  $k$ -th sub-process of the  $j$ -th decision unit,  $i=1, 2, \dots, I$ . The  $m_{jk(k+1)}$  is the consumed amount of intermediate product 1 by the  $(k+1)$ -th sub-process produced by the  $k$ -th sub-process of the  $j$ -th decision unit,  $l=1, 2, \dots, L$ . The  $y_{jkg}$  is output amount of  $g$  in the  $k$ -th sub-process of the  $j$ -th decision unit,  $g=1, 2, \dots, G$ . The  $\lambda_{jkj_0}$  is the relative efficiency of the  $k$ -th sub-process of the  $j_0$ -th decision unit.

As known from above definition, the problem is to solve the linear programming model to the  $k$ -th sub-process of the  $j_0$ -th decision unit.

$$\left\{ \begin{array}{l} \min \theta_{kj_0} \\ \sum_{j=1}^n \lambda_{jkj_0} x_{jki} \leq \theta_{kj_0} x_{j_0ki}; i=1, 2, \dots, I; \\ \sum_{j=1}^n \lambda_{jkj_0} x_{j(k-1)kl} \leq \theta_{kj_0} x_{j_0(k-1)kl}; l=1, 2, \dots, L; \\ \sum_{j=1}^n \lambda_{jkj_0} m_{j(k+1)kl} \geq m_{j_0(k+1)kl}; l=1, 2, \dots, L; \\ \sum_{j=1}^n \lambda_{jkj_0} y_{jkg} \geq y_{j_0kg}; g=1, 2, \dots, G; \\ \lambda_{jkj_0} \geq 0, j=1, 2, \dots, n. \end{array} \right. \quad (1)$$

After slack variables  $s^-$  and  $s^+$  been introduced, we get:

$$\left\{ \begin{array}{l} \min \theta_{kj_0} \\ \sum_{j=1}^n \lambda_{jkj_0} x_{jki} + s_i^- = \theta_{kj_0} x_{j_0ki}; i=1, 2, \dots, I; \\ \sum_{j=1}^n \lambda_{jkj_0} x_{j(k-1)kl} + s_l^- = \theta_{kj_0} x_{j_0(k-1)kl}; l=1, 2, \dots, L; \\ \sum_{j=1}^n \lambda_{jkj_0} m_{j(k+1)l} - s_l^+ = m_{j_0(k+1)l}; l=1, 2, \dots, L; \\ \sum_{j=1}^n \lambda_{jkj_0} y_{jkg} - s_g^+ = y_{j_0kg}; g=1, 2, \dots, G; \\ \lambda_{jkj_0} \geq 0, j=1, 2, \dots, n; \\ s^- \geq 0, s^+ \geq 0. \end{array} \right. \quad (2)$$

In fact, the linear programming model represented by (1) and (2) is the C2R model of the  $k$ -th sub-process. Its principle and solving process have no difference with traditional DEA except for regarding intermediate variables as the input-output indicators if it has the intermediate variable. In addition, constraints should be set. Therefore, we can also arrive at the C2R model, BC2 model and extreme efficiency DEA model of each sub-process. Similarly, the slack variable can be also introduced into the model for problem-solving.

### 3.2. Match of DEA Evaluation to Supply Chain

DEA method is mostly used for effectiveness evaluation on complicated systems with multi-input and multi-output. It does not focus on the specific operation within the system, but mainly on efficiency ratio of system input and output to evaluate system performance by comparing relativity. The CSC is a complicated system consisting of different subsystems of contractors, suppliers, subcontractors and owners. These systems share information and coordinate to ensure normal operation of logistics, information and capital flow. Its overall performance is affected and constrained by each subsystem. For its complexity, it is not suitable to simply performance evaluation on each subsystem and then totaling. It needs to regard the CSC as an integrated one for investigation. The CSC is an integration enterprise set. As the system, it also has input and output, namely investment and output, which is consistent with the feature of DEA.

In addition, the relative effectiveness measurement on the evaluated object of DEA method is consistent with the benchmarking standard of CSC. DEA uses relative effectiveness evaluation standard, namely comparison among decision units in performance evaluation. There is at least one DEA is effective in all decision units, which is equivalent to benchmarking in the CSC. It has the best comprehensive performance. Other non-effective and weak DEA effective CSCs compare with it to seek for own inadequacies. The above two methods are consistent in evaluation standard with strong compatibility.

In summary, the paper research on comprehensive CSC performance evaluation system based on DEA, including building evaluation framework and indicator system from consumption and output as well as evaluating it with DEA.

### 3.3. Preference Restraint Cone DEA Model

Since the first of DEA, many scholars realized that it determines the most favorable weight for DMU to be evaluated by the way of self-assessment without other assumptions. However, the evaluation method also has its shortcoming. For example, in case of evaluation with C2R model, sometimes a DMU is relatively effective, while some indicator has extremely big weight, while may lead to determining an unrealistic weight as DMU valid. Under the other status, if a general C2R model is used for comprehensive CSC performance evaluation, all indicators are equal. Although the method can avoid the influence of subjective on indicator weight, it cannot reflect characteristics of the supply chain, such as the emphasis of the supply chain on input-output indicators as cost, personnel is different. Therefore, the paper introduces preference restraint cone to represent the different importance of input and output indicators in accordance with decision makers' preference based on CSC performance evaluation with general DEA model, which is an improvement on existing model itself.

### 3.4. Group Preference Information Aggregation

Assume there are  $n$  supply chains engaged in competition. The evaluation indicators have  $m$  inputs and  $s$  outputs, which are marked as  $I = (X_1, X_2, \dots, X_m)$  and  $R = (Y_1, Y_2, \dots, Y_m)$  respectively. Set the supply chain  $j (j=1, 2, \dots, n)$  as decision unit  $DMU_j$ . The preference information of decision makers on each evaluation indicate can be represented by preference order, reciprocal judgment matrix or complementary judgment matrix. Where the preference order means the importance of decision makers of each indicator is sorted as  $O^{(k)} = \{O^{(k)}_1, O^{(k)}_2, \dots, O^{(k)}_m\}$ . The  $O^{(k)}_1$  is importance order of indicator  $X_i$  determined by decision maker  $d_k (k=1, 2, \dots, N)$ . If the decision maker compares indicators in pairwise, the  $a^{(k)}_{iz}$  is relative importance of indicator  $X_i$  to indicator  $X_z$  determined by decision maker  $dk$ . Using 9 scale method, the reciprocal judgment matrix is  $A^{(k)} = (a^{(k)}_{iz})_{m \times m}$ . When the decision makers compare indicators pairwise, the  $b^{(k)}_{iz}$  shows importance of indicator  $X_i$  than  $X_z$  by  $d_k$ , meeting  $0 \leq b^{(k)}_{iz} \leq 1$ ,  $b^{(k)}_{iz} + b^{(k)}_{zi} = 1$  and  $b^{(k)}_{ii} = 0.5$ ; then, the complementary judgment matrix is  $B^{(k)} = (b^{(k)}_{iz})_{m \times m}$ .

In order to aggregate preference information from  $N$  decision makers, the group decision Geometric Mean Judgment (GMJ) matrix method is used to integrate  $N$  judgment matrix  $A^{(k)}$  into group judgment matrix  $C_m = (c_{iz})_{m \times m}$ . Where.

$$c_{iz} = \prod_{k=1}^N (a^{(k)}_{iz})^{1/N} \quad (3)$$

According to the above methods, build DEA model preference restraint cone of input indicator  $I$  and indicator  $R$  of CSC. The specific steps are as follows.

Step 1. Uniformed the preference information of  $N$  decision makers to build  $2N$  judgment matrixes  $A^{(k)}$  and  $D^{(k)}$  for input and output indicators.

Step 2. Aggregate the  $A^{(k)}$  and  $D^{(k)}$  to group judgment matrix  $\bar{C} = (c_{iz})_{m \times m}$  and  $\bar{S}_s = (b_{rz})_{s \times s}$  in accordance with (3), meeting  $c_{iz} = 1/c_{zi}$ ,  $c_{iz} > 0$ ,  $c_{ii} = 1$  and  $b_{rz} = 1/b_{zr}$ ,  $b_{rz} > 0$ ,  $b_{rr} = 1$ .

Step 3. Conduct consistency verification on judgment matrix  $\bar{C}_m$  and  $\bar{S}_s$  with AHP method. Generally, the consistency of judgment matrix is acceptable in case of  $C.R. < 0.1$ . Let  $\lambda_c$  and  $\lambda_b$  as the maximum eigenvalues of matrix  $\bar{C}_m$  and  $\bar{S}_s$  respectively. Set  $C = \bar{C}_m - \lambda_c E_m$  and  $B = \bar{S}_s - \lambda_b E_s$ . Where,  $E_m$  and  $E_s$  are  $m$ -order and  $s$ -order unit matrixes. Build multi-faceted closes convex cone  $CV \geq 0$ ,  $V = (v_1, v_2, \dots, v_m)^T \geq 0$ ,  $BU \geq 0$ ,  $U = (u_1, u_2, \dots, u_s)^T \geq 0$  as the preference restrain cone.

### 3.5. Supply Chain Evaluation DEA Model

As to supply chain  $j_0$ , its DEA performance evaluation preference restraint cone mode  $C^2WH$  is:

$$\begin{cases} \max \frac{U^T Y_{j_0}}{V^T X_{j_0}} \\ \frac{U^T Y_j}{V^T X_j} \leq 1, j = 1, 2, \dots, n \\ V_{ahp} = \{V \mid CV \geq 0, V \geq 0\} \\ U_{ahp} = \{U \mid BU \geq 0, U \geq 0\} \\ V \in V_{ahp}, U \in U_{ahp} \\ \text{int } V_{ahp} \neq \emptyset, \text{int } U_{ahp} \neq \emptyset \end{cases} \quad (4)$$

Conduct Charnes-Cooper transformation on fractional programming model of (4) to arrive at the dual model as:

$$\begin{aligned} & \max u^T Y_{j_0} \\ (p)_{C^2WH} \text{ s.t. } & \begin{cases} w^T X_j - u^T Y_j \geq 0, j = 1, 2, \dots, n \\ w^T X_{j_0} = 1 \\ w = (w_1, w_2, \dots, w_m)^T \geq 0, \\ u = (u_1, u_2, \dots, u_s)^T \geq 0, \\ w \in V_{ahp} = \{V \mid CV \geq 0, w \geq 0\}, \\ u \in U_{ahp} = \{U \mid BU \geq 0, u \geq 0\} \end{cases} \end{aligned} \quad (5)$$

### 3.6. Validity Analysis

If the model  $(p)_{C^2WH}$  has optimal solution  $w^*$  and  $u^*$  meeting the condition  $u^{*T} Y_{j_0} = 1$ , regard the supply chain  $j_0$  as weak DEA effective. If the optimal solution meets  $u^{*T} Y_{j_0} = 1$  and  $w^* \in \text{int } V_{ahp}$ ,  $u^* \in \text{int } U_{ahp}$ , we call the supply chain  $j_0$  as DEA effective.

It can be proven that when the AHP judgment matrix  $\bar{C}_m$  and  $\bar{S}_s$  meet completely consistent conditions, the relative efficiency  $p^*_{j_0} = u^{*T} Y_{j_0}$  of each supply chain obtained by  $(p)_{C^2WH}$  evaluation model is same with weighted average input output ratio of each supply chain with AHP method. However, the judgment matrix  $\bar{C}_m$  is not always consistent with  $\bar{S}_s$ , when the solution domain  $CV \geq 0$  and  $BU \geq 0$  contain the domain  $CV > 0$ ,  $BU > 0$ . The smaller  $C.R.$  means  $\bar{C}_m$  and  $\bar{S}_s$  are closing to complete consistency. The solution domain is smaller, so is the restraint scope of input and output indicator weight. Within the restraint scope, solve the weight  $w^*$  and  $u^*$  with DEA method to be favorable for evaluating supply chain  $j_0$ , so that the evaluation result can better reflect subjective preferences of decision makers. On the contrary, the bigger  $C.R.$  indicates that the evaluation result means evaluation result emphasizes on objective data. Therefore, it can adjust and balance the importance of subjective and objective factors of supply chain evaluation result by appropriately regulating acceptable scope of consistency indicator  $C.R.$

### 3.7. CSC Sorted DEA Model

Based on result of  $(p)_{C^2WH}$ , we can sort the orders of non-DEA-effective and weak-DEA-effective supply chain. When there are multiple DEA effective supply chains, it is necessary to compare relative efficiency for preferable supply chain selection. The paper introduces the ideal decision unit to solve a group of fair and reasonable public weight to build relative efficiency index, so as to complete sorting and preferable selection on DEA effective supply chains.

The virtual idea supply chain  $DMU_I$  is consisted of the minimum value  $X_{\min_i}$  of each input indicator and maximum value  $Y_{\max_r}$  ( $r=1,2,\dots,s$ ) of each output indicator in all DEA effective supply chain. Using the virtual ideal supply chain  $DMU_I$  as a reference, solve fair and reasonable public weight to all DEA effective chain  $DMU_j$ .

Define  $h' = \frac{U^T Y_{\max}}{V^T X_{\min}}$  as the efficiency index of virtual ideal supply chain  $DMU_I$ . Build model  $C^2WH$  target to maximum efficiency as:

$$(p)_{C^2WH} \text{ s.t. } \begin{cases} \max h' = \frac{U^T Y_{\max}}{V^T X_{\min}} \\ \frac{U^T Y_j}{V^T X_j} \leq 1, j = 1, 2, \dots, n \\ \frac{U^T Y_{\max}}{V^T X_{\min}} \leq 1 \\ U_{ahp} = \{U \mid BU \geq 0, U \geq 0\} \\ V_{ahp} = \{V \mid CV \geq 0, V \geq 0\} \\ V \in V_{ahp}, U \in U_{ahp} \\ U = (u_1, u_2, \dots, u_s)^T \\ V = (v_1, v_2, \dots, v_m)^T \end{cases} \quad (6)$$

The optimal solutions of the model are  $U^*$  and  $V^*$ , which are regarded as the public weight to compute relative efficiency of all DEA effective supply chains.

## 4. Numerical Computation and Result Analysis

### 4.1. Preference Restraint Cone

The input and output indicators are shown in Table 1. After consulting three experts and aggregating preference information on each evaluation indicator, build group judgment matrix  $\bar{C}_2$  and  $\bar{B}_5$  to input and output indicators.

Table 1. Overall operation data of construction supply chain

DMU	$X_1$	$X_2$	$Y_1$	$Y_2$	$Y_3$	$Y_4$	$Y_5$
A	3193	325	92.6	93.7	145	45.6	9.6
B	2613	255	92.6	95.6	78	39.6	9.5
C	1709	375	98.0	98.9	350	56.6	9.9
D	3706	321	91.0	92.0	158	40.3	9.5
E	2569	400	89.0	99.0	302	53.0	9.9
F	2807	366	95.3	94.6	145	43.6	9.6
G	1964	293	98.0	97.0	78	39.8	9.5
H	2308	332	94.0	96.0	214	45.6	9.7
I	2244	311	97.0	97.8	326	49.7	9.8
J	1929	414	93.8	88.0	201	39.0	9.4
K	3489	308	94.2	90.0	170	43.2	9.4
L	2203	296	92.8	91.7	126	39.8	9.3

Where

$$\bar{C}_2 = \begin{pmatrix} 1 & 3 \\ 1/3 & 1 \end{pmatrix} \quad \text{and} \quad \bar{B}_5 = \begin{pmatrix} 1 & 1/3 & 1/7 & 1/5 & 1/6 \\ 3 & 1 & 1/4 & 1/2 & 1/2 \\ 7 & 4 & 1 & 7 & 5 \\ 5 & 2 & 1/7 & 1 & 1/5 \\ 6 & 2 & 1/5 & 5 & 1 \end{pmatrix}$$

Conduct consistency verification of above two judgment matrix. The maximum eigenvalue of matrix  $\bar{C}_2$  is  $\lambda_{\max} = 2$ . The corresponding normalized eigenvector is  $X_c = (0.9487, 0.2163)^T$ ,  $C.R = 0 < 0.1$ . The maximum eigenvalue of matrix  $\bar{B}_5$  is  $\lambda_{\max} = 5.439$  and the corresponding normalized eigenvector is  $Y_c = (0.04, 0.09, 0.53, 0.11, 0.23)^T$ ,  $C.R = 0.098 < 0.1$ . The judgment matrixes are regarded as at the acceptable level. Set  $C = \bar{C}_2 - \lambda_c E_2$  and  $B = \bar{B}_5 - \lambda_s E_5$ , build preference restraint cone from  $Cw \geq 0$  and  $B\mu \geq 0$ .

#### 4.2. DEA Evaluation Result

With data input model  $(p)_{C^2WH}$ , solve the comprehensive DEA evaluation result of 12 CSCs, as shown in Table 2.

Table 2. Evaluation result with preference DEA

DMU	$X_1$	$X_2$	$Y_1$	$Y_2$	$Y_3$	$Y_4$	$Y_5$	Overall Value	Order
A	3193	325	92.6	93.7	145	45.6	9.6	0.2571	10
B	2613	255	92.6	95.6	78	39.6	9.5	0.1956	12
C	1709	375	98.0	98.9	350	56.6	9.9	1.0000	1
D	3706	321	91.0	92.0	158	40.3	9.5	0.2369	11
E	2569	400	89.0	99.0	302	53.0	9.9	0.5925	3
F	2807	366	95.3	94.6	145	43.6	9.6	0.2897	7
G	1964	293	98.0	97.0	78	39.8	9.5	0.2575	9
H	2308	332	94.0	96.0	214	45.6	9.7	0.5091	5
I	2244	311	97.0	97.8	326	49.7	9.8	0.7296	2
J	1929	414	93.8	88.0	201	39.0	9.4	0.5334	4
K	3489	308	94.2	90.0	170	43.2	9.4	0.2678	8
L	2203	296	92.8	91.7	126	39.8	9.3	0.3265	6

In accordance with result of  $(p)_{C^2WH}$  model, the order of non-DEA-effective and weak-DEA-effective chains can be sorted. Since the example does not have DEA effective CSC with multiple preference restraint cone, there is no need to further compare relative efficiency for preferred selection on supply chains.

#### 4.3. Result Analysis

To analyze the effectiveness, the operation efficiency of CSC evaluates with ordinary DEA model and preference DEA model to arrive at related sort. In terms of computation method, the evaluation result from preference restraint cone DEA model is more realistic in the economic sense. For its stronger subjective determined by preference, it is also questioned by users. The comparison between the above two methods is shown in Table 3.

Table 3. Evaluation result comparison between general DEA and preference DEA

DMU	A	B	C	D	E	F
General DEA	0.886	1.000	1.000	0.843	0.843	0.794
Preference DEA	0.257	0.196	1.000	0.237	0.593	0.290
DMU	G	H	I	J	K	L
General DEA	1.000	0.919	1.000	0.857	0.895	0.950
Preference DEA	0.258	0.509	0.730	0.533	0.268	0.327

As seen from the above table, the preference DEA model has fewer decision units than traditional DEA model in the evaluation result. B, G and H are effective decision units in the traditional DEA evaluation model, while they are excluded as pseudo-effective units in the preference DEA model. The preference restraint cone DEA model excludes pseudo-effective units, which reflects the subjective preference of evaluation makers to some extent. The evaluation result is more realistic, which is an improvement on traditional DEA model.



## 5. Conclusions

The feature of construction industry leads to its complexity of SCM. Its performance evaluation is not simply a summation of performance evaluation on each subsystem, but a need to investigate the CSC as a whole. It should not only consider the performance of each core subsystem, but also overall performance of CSC. DEA validity selection sorting is to evaluate optimizing on objective weight among several indicators. In case of determined decision unit, the increase of indicator number is easy to blur DMU information difference due to complementary of merits and shortcomings. As a result, the statistical result may have too many valid values. Combining with features of DEA and CSC, the comprehensive CSC performance evaluation system based on DEA was built from aspects of consumption and production. An improved DEA model with preference restraint cone was presented. The computation example result shows that the improved model excludes pseudo-effective CSC to reflect the subjective preference of decision makers, which is consistent with practical applications. It is also an improvement on model selection. However, the method has a restriction on indicator number in the application of performance evaluation, so it is difficult to consider both comprehensive and scientific. The conflict should be solved in the further researches.

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