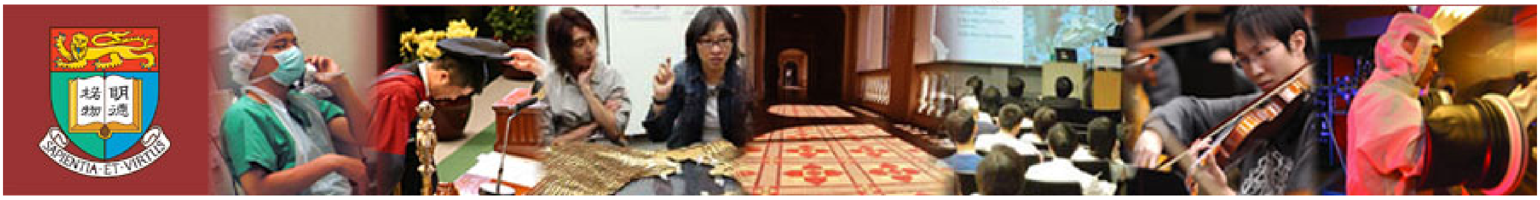

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Using Data Envelopment Analysis for Supplier Evaluation with Environmental Considerations

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***Abstract*—With the proliferation of outsourcing in global market place, supplier selection has become a key strategic consideration in forming a competitive supply chain. Supplier selection has been recognized as a multi-criteria decision making problem in which suppliers are evaluated according to multiple criteria such as price, quality, delivery and service simultaneously. Facing with excessive pressures from government and customers, increasing number of companies are beginning to consider environmental issues in the procurement and supplier selection process to practice the sustainable development. It is therefore necessary to measure a supplier's environmental performance. This paper aims to find out what kind of environmental criteria can be applied to assess suppliers overall performances. The multi-criteria decision making approach data envelopment analysis (DEA) is applied to help companies to evaluate suppliers' various environmental performance and other capabilities simultaneously.** *(Abstract)*

Keywords—Supplier selection, DEA, Environmental Consideration*(key words)*

I. INTRODUCTION

Due to the fierce competition arising from globalization, companies have been forced to seek every possible way to make more profit and lower the cost. Many companies have increased the level of outsourcing substantially to gain competitive advantages from supply chain partners and focus on their core businesses. Supplier selection has become a key strategic consideration in forming a competitive supply chain. Supplier selection has been recognized as a multi-criteria decision making problem in which suppliers are evaluated according to multiple criteria such as price, quality, delivery and service simultaneously.

Recently, facing with excessive pressures from government and customers, increasing number of companies are beginning to consider environmental issues in the procurement and supplier selection process to practice the sustainable development. For example, IBM sets a lot of environmental requirements including compliance with restriction of the use of certain Hazardous Substances (RoHS) in electrical and electronic equipment, Energy efficiency grades, Electronic Industry Citizenship Coalition (EICC) Code of Conduct (CoC), greenhouse gas emissions, waste management, recycling and setting voluntary environmental goals to its suppliers. It is therefore necessary to measure a supplier's environmental performance. However, existing supplier evaluation methods considering the environmental criteria rely too much on subjective judgments. Weights or even scores of different criteria are assigned according to decision makers' subjective opinions.

This paper is on the development of a decision support system to select suppliers with the incorporation of environmental consideration. The corresponding system will be implemented in multi-agent architecture since it is competent in modeling and facilitating interactions between various parties involved in the supplier selection process. The multi-criteria decision making approach data envelopment analysis (DEA) is adopted to help companies to evaluate suppliers' various environmental performance and other capabilities simultaneously. DEA was firstly introduced by Charnes [1] to assess the relative performance of decision-making units (DMUs), such as schools, hospitals, or sales outlets. In this paper, different suppliers are represented as different DMUs. In typical DEA, each DMU will obtain an efficiency score that ranges from 0 to 1, and a higher efficiency score is more preferable. An efficiency score is obtained from the weighed sum of output divided by the weighted some of input. That means the supplier who can generate more outputs (outcomes) with less inputs (resources) is better. In conventional DEA, each DMU gets its own set of weights to maximize its efficiency score while keeping other DMUs efficiency scores no more than 1. If there are n suppliers to evaluate, n different sets of weights will be assigned to each DMU. When there is no explicit preference towards weights of inputs and outputs, conventional DEA can be applicable. Each DMU can highlight its own advantage by adopting the weights set that maximizes its efficiency score while keeping other DMUs' efficiency score less than or equal 1. However, common weights DEA is more suitable for this application since it can offers uniform standard to evaluate candidate suppliers by introducing a common set of weights. This set of common weights can represent buyer's interests towards some preferred criteria. Also, the stronger discriminating power of common weights DEA can differentiate the DMUs' efficiency score more explicitly. In this paper, a common set of weights is identified so that each supplier's efficiency score is calculated based on the same set of weights. After the computation, all of the suppliers get a ranking according to respective efficiency scores and a supplier that has the highest efficiency score will be selected as the final supplier.

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II. Literature Review

With increasing level of outsourcing, supplier selection problem has attracted great attentions from researchers in supply chain management. Even though price is a major concern in selecting suppliers, other criteria like product quality and delivery are considered to be other important indicators to assess suppliers overall capability. Therefore, supplier selection is a multiple attribute decision making (MADM) problem in which several criteria are considered simultaneously. With increasing public awareness and stringent regulations companies have to find ways to balance between economic gains and environmental issues.

A. General Criteria

Dickson's [2] works that considers supplier selection criteria is one of the most cited studies. He identified 23 criteria and it shows that quality, delivery and performance history are considered to be 3 most important factors.

According to subsequent research on supplier selection criteria by Weber [3] and Cheraghi [4] quality, delivery and price are three most important supplier selection criteria.

B. Environmental Criteria

Noci [5] proposed a green vendor rating system in which four factors were identified to measure suppliers' environmental performances. These four factors are Green competencies, Current environmental efficiency, supplier's green image and Net Life Cycle Cost, and under each factor, there are several detailed indicators. AHP was adopted to deal with both qualitative and quantitative indicators.

Virginia W. Gerde and Jeanne M. Logsdon [6] examined four major databases that measures US corporate environmental performance. These include US Environmental Protection Agency's Toxics Release Inventory (TRI) and another 3 databases maintained respectively by Kinder, Lydenberg, Domini, and Co., (KLD) the Council on Economic Priorities (CEP) and the Investor Responsibility Research Center (IRRC). After comparison between different databases, the author suggested that the most comprehensive environmental performance measurement should be useful for communicating to all stakeholders – financial community and investors, governments and local communities, business organizations and various interest groups as well as consumers and employees.

Handfield [7] identified 5 requirements that environmental criteria should meet and according to these requirements, the environmental criteria are categorized into six attributes, namely packing/reverse logistics, environmental programs, product attributes, labeling/ certification, government regulation and waste management.

Humphreys [8] identified seven environmental categories and they are environmental costs (pollutant effects), environmental costs (improvement), management competencies, green image, design for environment, environmental management systems and environmental competencies.

Lu [9] identified the material, energy use, solid residue liquid residue and gaseous residue are important environmental criteria in different lifecycle stages.

Lee proposed a green supplier selection model for high tech industry [10]. In his model, criteria are identified with Delphi method. Weights or criteria and Ratings of alternatives are given according to fuzzy method.

Awasthi [11] proposed a fuzzy multi-criteria approach for evaluating the environmental performance of suppliers. In her model, 3 steps for supplier selection are identified. Firstly, 12 environmental criteria are identified according to experts' opinion, and then linguistic assessments are used to rate the criteria and the alternatives. Fuzzy TOPSIS is adopted to generate the overall performance score for each alternative. Lastly, sensitivity analysis is conducted to evaluate the influence of criteria weights on the environmental performance evaluation of suppliers.

C. Supplier Selection Method

Weber proposed a vendor selection model that combines multi-objective programing (MOP) and Data Envelopment Analysis (DEA) [12]. In this model, buyer will negotiate will non-selected vendor by suggesting the vendor to make improvements on some performances so that the vendor can become competitive again. Quality, price and delivery are considered. The qualitative criterion-Quality is converted into percentage of rejected units for vendor for calculation.

Aslı Aksoy [13] proposed neural network based system to select proper suppliers in JIT production environments. After trained by 200 previous supplier selection cases, the system was verified by results taken from automotive factory data. The shortcoming of this system is that it needs a number of previous cases to train the neural network. However, green supplier selection is a relatively new problem and there will not be so many cases for training.

Dudek [14] proposed a negotiation based scheme to synchronize plans between independent supply chain partners to reduce the total supply chain costs. Once the buyer/supplier received the proposal which has conflicts with its locally optimal plan, modification was made according to two goals as maximize the cost savings and minimize the amount of modifications. Total deviation measure was defined to compute the amount of modifications or "harm" that follow from counter-proposal suggested by the negotiation partner.

Talluri [15] adopted DEA to evaluate suppliers according to ideal targets set by the buyer. In DEA method, efficiency score derives from weighted sum of output divided by weighted sum of input. In his model, efficiency score of ideal target is maintained as 1, while other suppliers' efficiency scores are kept no more than 1. Objective functions differ in whether it minimizes sum of efficiency score or individual efficiency score. Each efficiency score is calculated based on weights derived from these objective functions. In individual objective function case, each supplier's weights set that minimizes its efficiency score was calculated separately. Then for n suppliers, the calculation of weight sets iterate for n times. While in simultaneous objective function case, the weight set was calculated only once, and suppliers' respective efficiency scores were obtained according to this same set of weight. The supplier who has largest minimum efficiency score will be selected.

III. DEA MODEL

DEA was developed to assess the comparative efficiency of organizational units. The decision making problem can be expressed as evaluating n DMUs according to m inputs and s outputs indices for each DMU. For *j*th DMU, $DMU_j\,(j=1,2,...,n)$ the values of inputs and outputs are $(x_{1j},x_{2j},...,x_{mj})$ and $(y_{1j},y_{2j},...,y_{sj})$ respectively. Solving the following fractional programming problem P1 will derive DMU_o's $(j=o)$ efficiency score and a set of weights for each input ($v_{io}, i=1,2,...,m$) and output ($u_{ro}, r=1,2,...,s$).The n fractional constraints mean all DMUs efficiency scores are kept equal to or less than 1. The symbol ε is a positive Archimedean infinitesimal constant and all of the weights should be larger then ε. These constraints ensure that values of weights are kept bigger than 0, so that all indices are considered in the computation. To rank all *n* DMUs, n rounds of optimization should be conducted for each DMU.

(P1) DEA-Fractional Programming

$$\theta_o^* = \max \frac{\sum_{r=1}^{s} y_{ro}u_{ro}}{\sum_{i=1}^{m} x_{io}v_{io}}$$

$$s.t. \quad \frac{\sum_{r=1}^{s} y_{ro}u_{ro}}{\sum_{i=1}^{m} x_{io}v_{io}} \le 1, \quad j=1,2,...,n,$$

$$u_{ro} \ge \varepsilon > 0, \quad r=1,2,....,s,$$

$$v_{io} \ge \varepsilon > 0, \quad i=1,2,....,m.$$

If the efficiency score θ_o^* equals to 1, then this DMU is called efficient one. It should be noted that, each DMU will obtain an efficiency score base on its own weight set, and that means *n* DMUs have n different sets of weights. In conventional DEA application, number of DMU is at least 2 times larger than number of input and output variables. However, in this application number of DMU is less than number of input and output variables. If conventional DEA is adopted here, all ten suppliers will be identified as DEA efficient which means conventional DEA is not suitable for this application. Therefore, the Common Weights DEA which offers stronger discriminating power is suitable. At the same times, it can represent buyer's preference for some criteria.

(P2) Common Weights DEA- Fractional Programming

By solving the following common weights DEA-fractional programing problem P2, a set of common weights $U_r(r=1,2,...,s)$ and $V_i(i=1,2,...,m)$ for respective *s* outputs and m inputs will be obtained so that sum of all DMUs' virtual gaps towards benchmark line can be minimized. Then efficiency score for all DMUs are calculated according to this set of common weights. Δ_j^O and Δ_j^I denotes that DMU_j's virtual gaps of outputs and inputs respectively towards the benchmark line. Detailed development of common weight DEA can be found in Liu [16].

$$\Delta^* = \min \sum_{j=1}^{n} (\Delta_j^O + \Delta_j^I)$$

$$s.t. \quad \frac{\sum_{r=1}^{s} y_{rj}U_r + \Delta_j^O}{\sum_{i=1}^{m} x_{ij}V_i + \Delta_j^I} \le 1, \quad j=1,2,...,n,$$

$$\Delta_j^O, \Delta_j^I \ge 0, \quad j=1,2,...,n,$$

$$U_r \ge \varepsilon > 0, \quad r=1,2,...,s,$$

$$V_i \ge \varepsilon > 0, \quad i=1,2,...,m.$$

IV. SUPPLIER SELECTION CRITERIA

In this section, a set of supplier selection criteria with the incorporation of Environmental Responsibility will be introduced. The criteria are identified according to literature of academic publications. Finally, a set of 16 criteria are selected and they are categorized into two groups: General criteria and Environmental responsibility related criteria.

A. General Criteria

Product Price: it refers to the supplier's bidding price of the product.

Quality: it refers to the conformance and reliability of product.

Delivery: Delivery refers to the required day that the ordered product will arrive at the door of buying organization.

Warranty and claims: assurance that suppliers announced about the product.

Technique help: training or technique support.

B. Environmental Responsibility Criteria

Green market share: Supplier's green image.

Staff training: staff training about the knowledge and technologies of environmental management.

Environmental accident: capability of dealing with the environmental accidents.

Design for disassembly: refers to designing a product that is easier to be disassembled.

Green purchasing: ratio of green materials components and new energy friendly products purchased from contracted suppliers to total purchased items.

Hazard purchasing: ratio of hazard materials and components purchased suppliers to total purchased items.

TABLE I. INPUT AND OUTPUT CRITERIA

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Dummy
price	709	704	685	681.3	676.04	678.1	687	687.7	699.6	684.15	676.04
delivery	17.1	17.04	17.4	17.34	17.424	16.353	16.8	16.95	17.14	17.137	16.353
hazard purchasing	0.42	0.329	0.39	0.401	0.4265	0.3166	0.35	0.421	0.322	0.3331	0.3166
air emission	111	117.5	110	116.5	113.74	113.69	119	116.3	113.7	113.27	110
energy consume	35.3	38.51	36.2	35.4	39.314	37.907	38.3	36.53	40.13	35.778	35.3
waste water	32.5	33.51	31.4	31.22	33.02	34.811	31.8	31.85	34.08	32.878	31.22
solid waste	27.3	27.57	28.6	30.92	29.601	27.846	28.9	30.42	30.08	27.955	27.3
quality	4.06	3.205	4.05	3.411	3.0567	3.5957	3.19	3.593	3.901	3.7023	4.06
warranty and claims	3.97	4.071	4.05	4.253	3.1674	4.1214	3.25	4.702	4.724	3.0949	4.724
technique help	4.6994	3.5527	4.2446	4.1767	4.9269	3.1718	4.001	4.0432	3.1803	4.8093	4.9269
green market share	2.89	2.79	2.77	3.169	2.8799	2.7688	3.01	3.134	2.862	3.0421	3.169
staff training	3.43	3.397	3.25	3.273	3.2798	3.577	3.35	3.576	3.58	3.3727	3.577
env accident	2.61	2.595	2.72	2.645	2.6529	2.6637	2.76	2.518	2.54	2.7633	2.7633
disassembly	2.28	2.386	2.22	2.327	2.2275	2.3981	2.38	2.247	2.208	2.3158	2.3981
green purchasing	0.39	0.364	0.36	0.409	0.3657	0.4086	0.33	0.37	0.368	0.3295	0.409
reuse rate	0.4	0.42	0.34	0.327	0.375	0.3255	0.37	0.407	0.374	0.3915	0.42

TABLE II. EFFICIENCY SCORE FOR CANDIDATE SUPPLIERS

S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
0.913515	0.946736	0.912517	0.95093	0.913751	0.982497	0.960968	0.912711	0.88214	0.947935

Air emission: volume of air emission of NOx, SOx, and VOCs per SKU.

Energy consume: cost of energy per SKU.

Waste water: volume of waste water per SKU.

Solid waste: volume of solid waste per SKU.

Reuse rate: Reuse rate refers to the percentage of reused product without significant repair and refurbishment.

V. DEA APPLICATION

10 Suppliers are denoted as 10 different DMUs, and 16 criteria are represented as inputs and outputs. The data utilized in this model are randomly generated simulated data within specific interval. First of all, criteria identified in previous section are categorized into inputs and outputs groups. Since small values of inputs are preferred to large values, 7 criteria, namely product price, delivery, hazard purchasing, air emission, energy consume, waste water and solid waste compose inputs variables.

While large values of outputs are preferred to small values, quality, warranty claims, technique help, green market share, staff training, environmental accident, design for disassembly, green purchasing and reuse rate these 9 criteria form outputs variables. Table 1 is input and output criteria. The data filled with grey color are input criteria, and other 9 are output criteria.

Common Weights DEA model is applied here to calculate the efficiency scores. To further discriminate between different DMUs, a dummy DMU is created. Its input and output values consist of optimum values derive from other DMUs so that its efficiency score is equal to 1 while other DMUs' efficiency scores are kept no more than 1. 10 candidate suppliers' efficiency scores are shown in the table 2. Supplier 6 obtained the highest efficiency score of 0.982497 which means that supplier 6 is the most preferable supplier according to the common weights set.

VI. CONCLUSION

In this paper, 16 supplier selection criteria are identified base on literature review so that suppliers' overall capabilities can be evaluated accordingly. Common Weights DEA which enables evaluation of suppliers in the same set of weights is applied to calculate the efficiency scores. Result shows that Common weight DEA is able to give rankings to candidate suppliers considering general criteria as well as environmental criteria.

REFERENCES

[1] Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6), 429-444.

[2] Dickson, G. W. (1966). An analysis of vendor selection systems and decisions. *Journal of purchasing, 2*(1), 5-17.

[3] Weber, C. A., Current, J. R., & Benton, W. (1991). Vendor selection criteria and methods. European Journal of Operational Research, 50(1), 2-18.

[4] Cheraghi, S. H., Dadashzadeh, M., & Subramanian, M. (2011). Critical success factors for supplier selection: an update. Journal of Applied Business Research (JABR), 20(2).

[5] Noci, G. (1997). Designing [] green'vendor rating systems for the assessment of a supplier's environmental performance. European Journal of Purchasing & Supply Management, 3(2), 103-114.

[6] Gerde, V. W., & Logsdon, J. M. (2001). Measuring environmental performance: use of the toxics release inventory (TRI) and other US environmental databases. Business Strategy and the Environment, 10(5), 269-285.

[7] Handfield, R., Walton, S. V., Sroufe, R., & Melnyk, S. A. (2002). Applying environmental criteria to supplier assessment: A study in the application of the Analytical Hierarchy Process. European Journal of Operational Research, 141(1), 70-87.

[8] Humphreys, P., Wong, Y., & Chan, F. (2003). Integrating environmental criteria into the supplier selection process. Journal of Materials Processing Technology, 138(1), 349-356.

[9] Lu, L. Y. Y., Wu, C., & Kuo, T. C. (2007). Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis. International Journal of Production Research, 45(18-19), 4317-4331.

[10] Lee, A. H. I., Kang, H. Y., Hsu, C. F., & Hung, H. C. (2009). A green supplier selection model for high-tech industry. Expert Systems with Applications, 36(4), 7917-7927.

[11] Awasthi, A., Chauhan, S. S., & Goyal, S. (2010). A fuzzy multicriteria approach for evaluating environmental performance of suppliers. International Journal of Production Economics, 126(2), 370-378.

[12] Weber, C. A., Current, J. R., & Desai, A. (1998). Non-cooperative negotiation strategies for vendor selection. European Journal of Operational Research, 108(1), 208-223.

[13] Aksoy, A., & Öztürk, N. (2011). Supplier selection and performance evaluation in just-in-time production environments. Expert Systems with Applications, 38(5), 6351-6359.

[14] Dudek, G., & Stadtler, H. (2005). Negotiation-based collaborative planning between supply chains partners. European Journal of Operational Research, 163(3), 668-687.

[15] Talluri, S. (2002). A buyer–seller game model for selection and negotiation of purchasing bids. European Journal of Operational Research, 143(1), 171-180.

[16] Liu, F. H. F., & Hsuan Peng, H. (2008). Ranking of units on the DEA frontier with common weights. Computers & operations research, 35(5), 1624-1637.