Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 17 (2014) 541 – 546

www.elsevier.com/locate/procedia

Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems

An Integrated Approach to Assess Manufacturing Greenness Level

Ahmed H. Salem, Ahmed M. Deif*

School of Management of Technology, Nile University, Cairo, Egypt

* Corresponding author. Tel.: +2-0100-497-2333; *E-mail address:* ahmed.hamdy@nileu.edu.eg ; deif@nileuniversity.edu.eg

Abstract

This paper proposes an integrated approach for relative greenness level assessment in selected manufacturing industries at the system level. The approach builds on existing methodologies to develop a multi-layer tool box called “Greenometer” which focus on the strategic comparison for cross industries evaluation as well as tactical comparison for intra-industries. The assessment tool captures the fundamental evaluation parameters of green manufacturing namely; Environment, Energy, Resources and Economy. In addition, the Greenometer employs geometric mean method (GMM) for the strategic layer and data envelopment analysis (DEA) for the tactical layer and will be used for different selected manufacturing disciplines. The proposed tool will have a practical impact on assessing, developing and improving environmental plans and policies of the selected industries.

© 2014 Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Selection and peer-review under responsibility of the International Scientific Committee of “The 47th CIRP Conference on Manufacturing Systems” in the person of the Conference Chair Professor Hoda ElMaraghy”

"Keywords: Green Manufacturing; Multi-Layer Modeling; DEA"

1. Introduction

Nowadays, it is mandatory for all manufacturing systems to think beyond how to profit only from manufacturing processes and products, as they have to look forward to be sustainable as well as environmental friendly systems.

Green manufacturing awareness became an important goal to all parties engaged in any manufacturing activity as it has significant influences on their social roles besides its economic benefits. There are a lot of attempts for green assessment at different manufacturing levels. Sarkar et al. [1], mentioned that National Institute of Science and Technology (NIST) categorized the manufacturing levels into different measurement units namely: product, process, facility, corporation, sector, country and world. Also Dornfeld [2], classified the green measurement units into machine, operation, process and system levels.

Assessing the greenness level at any measurement units has to stick to some clear assessment indices. According to Yang et al. [3], those indices, referred to as assessment attributes, were categorized into four main attributes namely: environment, energy, resource and economic. On the other hand, Carrel et al. [4], referred to those parameters as dimensions of sustainability and sorted them as follows: environmental stewardship, economic growth, social well-being, technological advancement and performance management.

The greenness assessment approaches include the work made by Azadeh et al. [5], assessed the energy efficiency using data envelopment analysis (DEA) as an assessment technique to ensure the utilization of energy at intensive manufacturing sectors. In addition, Driscoll et al. [6], developed an assessment framework to optimize energy performance within a complex manufacturing facility. Lean manufacturing approaches were also employed in greenness assessment, Al-Fandy [7]. Furthermore, Huang et al. [8] developed life cycle environmental performance index, however, it was limited to material selection. A fuzzy multiple attribute decision-making method to assess the risk of implementing green manufacturing projects was developed by Hui et al. [9]. In addition, Yang et al. [3], developed a non-

2212-8271 © 2014 Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Selection and peer-review under responsibility of the International Scientific Committee of “The 47th CIRP Conference on Manufacturing Systems” in the person of the Conference Chair Professor Hoda ElMaraghy”
doi:10.1016/j.procir.2014.01.127

uniform assessment method to assess the greenness of products based on DEA model. Moreover Romvall et al. [10], developed a green performance map that was integrated to the framework of ISO 14001.

Many of the green assessment methodologies use frameworks combined with life cycle assessment method (LCA). For example, Qingsong et al. [11], developed an evaluation index system for green manufacturing, based on pressure-state-response (PSR) model integrated by life cycle analysis theory. Furthermore Kassahun et al. [12], developed a framework for a software tool to evaluate the environmental compatibility of products and the associated manufacturing processes.

Unlike previous developed metrics, the proposed Greenometer aims to compare greenness level between different industries (across industry layer) and also compare greenness level for the specific selected industry within its own category (intra-industries layer). This relative assessment is achieved through integrating two different assessment techniques; GMM for the strategic comparison at across industries layer and DEA for in-depth tactical comparison used in the intra-industries layer. This multistage relative approach will help the proposed Greenometer to be considered as a generic assessment toolbox for different industrial systems.

2. Greenometer Analytical Techniques

In this section geometric mean method GMM and data envelopment analysis DEA techniques are introduced as they will be used to measure across industries layer and intra-industries layer respectively. Generic indicators are normalized using GMM technique to get the ranked attributes at cross industries layer. Specific indicators used to assess the greenness within a manufacturing industry will employ DEA method at the intra-industries layer.

2.1. Geometric Mean Method (GMM) =

GMM is introduced as an aggregation approach of individual stakeholder preferences. This aggregation approach comes in participatory multiple criteria decision making (MCDM) process. GMM is an extended and improved technique of analytical hierarchy process (AHP). Subsequently, the criteria weights of GMM are derived through the AHP eigenvalue technique which involves the decision makers in pairwise comparison of both alternatives and criterion.

Based on the findings by Nordström et al. [13], the geometric mean of the judgments of all stakeholders for each element in the pairwise comparison matrices is calculated in equation 1 as follows:

$$\left(\prod_{t=1}^{k} m_{ij}^{t}\right) \forall\, i,j \quad , \qquad (1)$$

Where m_{ij}^{t} is the element in the pairwise comparison matrix for stakeholder t =when criterion =i =($i=1,2,...q$) =is compared with criterion j. Similarly, the geometric means of the judgment of all stakeholders are calculated from the matrices, where alternatives are compared for each criterion as shown in equation 2:

$$\left(\prod_{t=1}^{k} m_{sv}^{ti}\right) \forall\, s,v \quad , \qquad (2)$$

Where m_{sv}^{ti} is the element in the pairwise comparison matrix for stakeholder t when alternative s is compared with alternative v for criterion i.

This will result in one matrix aggregated preferences for the criteria and q matrices with aggregated preferences for the alternatives in terms of each criterion. Weights for criteria and alternatives are then determined from these matrices, shown in figure 1.

It should be noted that Saaty, [14] [15], criticized GMM as there is no conceptual justification for working on a logarithmic scale, the calculation is made with a row and the indirect estimations are not considered. However, Ishizaka et al. [16], used Monte Carlo simulation to prove that the geometric means of the columns and the geometric means of the rows always give the same ranking, since GMM uses only the direct comparisons. Results also showed the GMM is optimal when the judge s errors are multiplicative with a lognormal distribution.

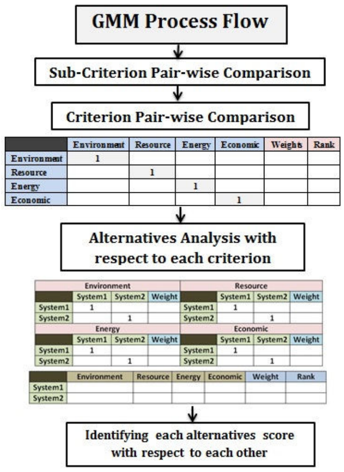

Fig. 1: GMM process sequence

2.2. Data Envelopment Analysis =

DEA, as an extreme point method, compares each decision making unit (DMU) with only the "best" supposed DMU, Crawford et al. [17], DEA does not require prescribing the functional forms that are needed in statistical regression approaches to find efficiency of alternatives. Charnes et al. [18], showed that for the given multi attributes decision making (MADM) problem, the alternatives (A_1, =A_2... =A_N) affecting the selection of an alternative are identified. However, these attributes are separated into two groups; (1) outputs: attributes of higher values representing desirable or beneficial attributes, and (2) inputs: lower values of attributes desirable or non-beneficial attributes. After building inputs and outputs matrices, the basic Charnes-Cooper-Rhodes (CCR) model, is used to find the efficiency and the comparative results.

DEA approach is widely used in assessing greenness level at different manufacturing layers, You [19]. Also, DEA offers some advantages as it aggregates the attributes of different

layers of management to be assessed. DEA can also assess the impacts of policy initiatives on productivity, then measure the change of productivity over time.

In the developed Greenometer, DEA will be used as an assessment approach for the intra-industries layer, as it is the most convenient method for identifying the relative weights of multi-attributes in different systems. Figure 2 illustrates the basic mechanism of DEA approach.

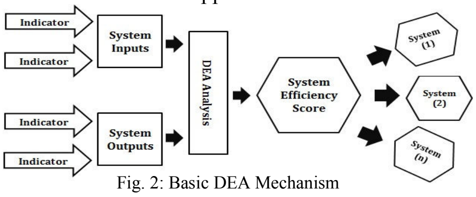

Fig. 2: Basic DEA Mechanism

3. The Greenometer Structure

The proposed Greenometer is an assessment tool box designed to evaluate the greenness level for any manufacturing system and is composed of two main layers. The first layer is dedicated to evaluate the general considerations of greenness between different industrial systems. This layer aims at assisting and directing the top management towards positioning their industry relative to others as well as strategic decision concerning the required level of green transformation. This cross industries layer includes four main general attributes which are compared with a reference datum system. GMM is introduced in this layer as an assessment technique to evaluate the actual system with respect to the reference virtual system. The virtual reference has fixed pairwise alternatives. When a system is assessed by the Greenometer, the first output result will be the relative weight between the datum virtual system and the system under assessment. In that respect, the cross industries layer positions the general greenness level of any industrial system relative to a generic benchmark.

The second layer contains the specific assessment model that compares tactically intra-industries greenness level to one another. It has three different industrial classes: heavy industrial class, intermediate industrial class and light industrial class. These classes are classified based on different parameters such as number of indicators in each attribute. Example of these classes include metal and mining industries and petroleum sectors as heavy industries in the first class, automotive and textile industries in the second class and electronics and plastic industries in the third class. Figure 3 shows the framework of the proposed Greenometer with its two layers while figure 4 focuses on the second layer of the intra-industry relative assessment.

3.1. Cross Industries Layer

The first assessment layer, cross industries layer (CIL), will be used to compare different industry in a generic normalized manner. The comparison at the CIL is carried out using four of the previously mentioned main attributes; each attribute includes most generic environmental indicators. The aim of this layer is to find a final relative assessment with respect to a datum virtual system as a benchmark with the optimal scores in each indicator. These scores will be calculated with respect to the best indicator conditions, and then the indicators of the assessed systems will be compared with regards to the indicators of the datum virtual system. The optimal values of the indicators in the datum system are derived from different sources including ISO 14000 families of environmental management system (EMS), United States environmental protection agency (U.S. EPA) and other different international environmental standards, to ensure the high accuracy of these values.

Using GMM ranking method, the main four attributes; environment, resources, energy and economy, for both the considered system and the datum virtual system, are aggregated to get a final ranking weights for each system relative to the other one. Multiple systems could also be introduced to this tool box to be relatively compared with each other. The main goal of the first layer is to find the relative weights of both assessed and datum systems which are the decision alternatives of the model while attributes and indicators represent the criterion and sub-criterion respectively of the GMM model as shown in figure 5.

The proposed Greenometer adopts the general attributes and indicators presented by Qingsong et al. [12], in which they collected 39 general indicators on pressure-state-response assessment mechanism, including 17 indicators for environment attributes, 8 indicators of energy attributes, 7 indicators of resource attributes and finally 7 indicators of economic attribute. However, some of these generic indicators are adapted to better fit the generic objective of the Greenometer indicators. These indicators have to be comparable and measurable to help in driving the strategic decisions and plans. Table (1) shows the most generic indicators used in each attribute. It is important to note that since these indicators directly influence their attributes' weights, the aggregation process of these indicators is very important in order to come up with the accurate weights.

Table (1): The most generic indicators of the first layer.

Attribute	Indicators
1- **Environment**	solid waste, water waste, air quality, water quality, disposal rate, greenhouse gas (GHG), industrial emissions,… etc.
2- **Resource**	material scrap rate, utilization of raw material, natural resources consumption, resources productivity, the RE's rates (Reuse, Reduce, Repair, Recycle, Recover, Remanufacture), .. etc.
3- **Energy**	fuel productivity, electricity efficiency, energy utilization rate, solar energy usage, .. etc.
4- **Economy**	return on environmental investment, environmental penalties cost rate, environmental taxation rate, environmental expenses, … etc.

3.2. Intra-Industries Layer

The intra-industries layer (IIL), in the proposed Greenometer, uses the DEA approach to compare the considered specific industry with respect to the ideal reference industry in the field. Figure 6 represents how the Greenometer uses the DEA approach as an assessment approach in the second layer.

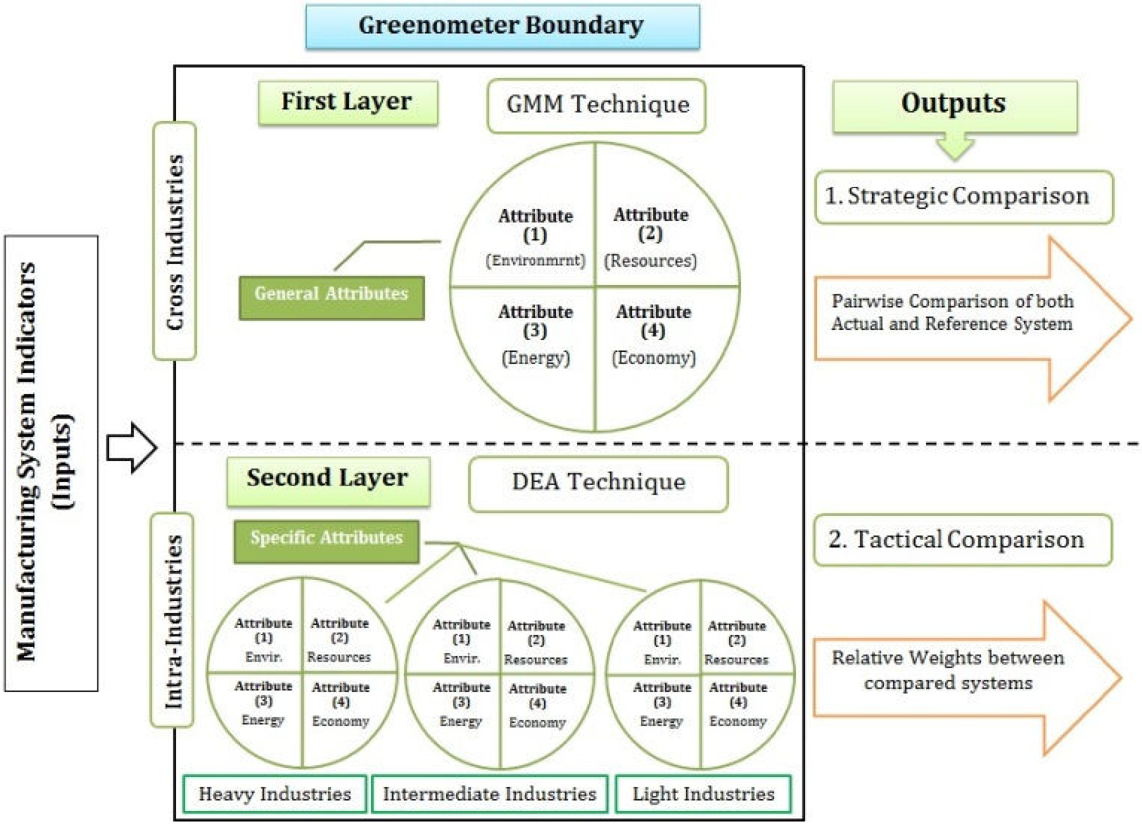

Fig. 3: Greenometer framework and components

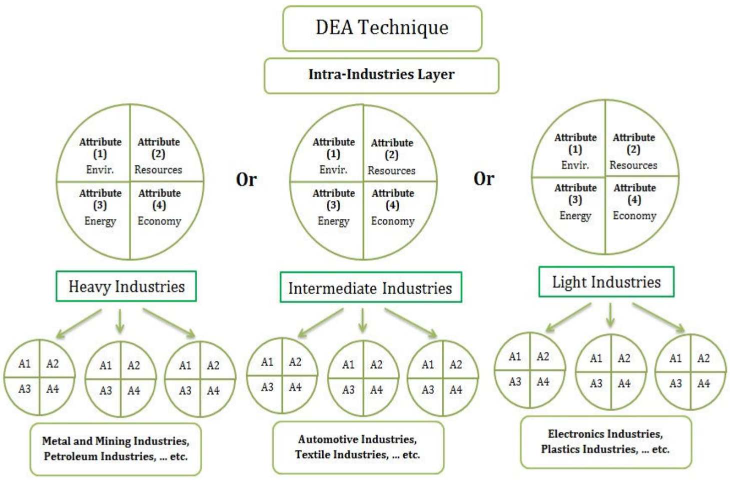

Fig. 4: Intra-Industries Layer framework

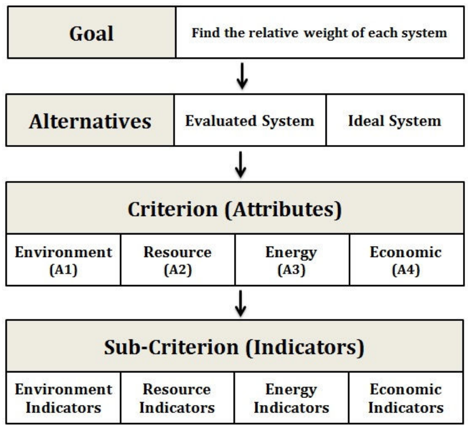

Fig. 5: GMM Model Structure.

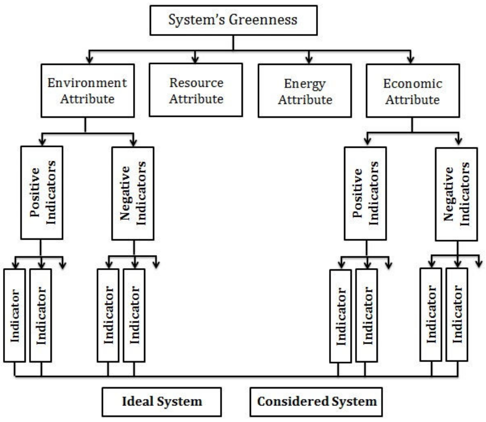

Fig. (6): Second layer assessment flow diagram.

Since the attributes of the second layer consist of many indicators, the DMU matrix of the multiple inputs and multiple outputs has to be constructed for each attribute. For this purpose, the CCR model mentioned earlier is adopted to develop this matrix using linear programming, Sarkis et al. [20] & Cooper et al. [21]. If m input items of indicators and s output items of indicators are selected for each attribute, then let the inputs and outputs data for each attribute (DMU_j) be ($x_{1j}, x_{2j}, x_{3j}, \ldots, x_{mj}$) and ($y_{1j}, y_{2j}, y_{3j}, \ldots, y_{sj}$) respectively. So, the matrix of the inputs and outputs can be arranged as shown in equations 3 and 4.

$$Inputs\ ,X \quad \begin{pmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ . & . & \ldots & . \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{pmatrix} \quad (3)$$

$$Outputs\ ,Y \quad \begin{pmatrix} y_{11} & y_{12} & \ldots & y_{1n} \\ y_{21} & y_{22} & \ldots & y_{2n} \\ . & . & \ldots & . \\ y_{s1} & y_{s2} & \ldots & y_{sn} \end{pmatrix} \quad (4)$$

In order to determine the weights, linear programming is used to maximize the ratio of outputs to inputs. Let the weights of the inputs and outputs be V_i and U_r respectively. Thus, the objective function of the linear program is to maximize θ, as found in equations 5-10.

$$LP_0\ Max\ \theta_{(U,V)} \quad \mu_1 Y_1 + ... + \mu_r Y_r \quad (5)$$

$$subjected\ to: \quad V_1 X_1 + ... + V_m X_m \quad 1 \quad (6)$$

$$\mu_{1j} Y_{1j} + ... + \mu_{rj} Y_{rj} \le V_{1j} X_{1j} + ... + V_{mj} X_{mj} \quad (7)$$

$$U_r \ge 0 \quad r \quad 1,2,...s \quad (8)$$

$$V_i \ge 0 \quad i \quad 1,2,...m \quad (9)$$

$$j \quad A, B, C\ and\ D \quad (10)$$

Where, A = Environmental attribute.
B = Resource attribute.
C = Energy attribute.
D = Economic attribute.

The output of this layer is a comparative weight of each attribute of the assessed system with respect to the attributes of the technical reference system in each industrial class.

4. Summary

This paper presented a multi-layer tool box called "Greenometer" to assist manufacturers in evaluating the current state greenness level. The Greenometer provides the decision makers with two different environmental performance indicators; one deals with general relative comparison that helps in strategic positioning and decisions, while the other takes the comparison into more details at the same intra-industry level that helps in tactical decisions for greenness transformation and benchmarking.

The advantage of the proposed Greenometer is that it offers a holistic comparative assessment as well as it quantifies this assessment through mathematical analysis using GMM and DEA techniques.

The output of the prospered green manufacturing planners and practitioners in assessing the current green level of their industry, follow the best practices of other relative systems captured by the Greenometer assessment process and finally act as a performance metric along the green transformation journey that many industries are embarking on currently.

Future work will include multiple application of the Greenometer to various industries to better develop the tool as well as to modify the considered attributes.

References

[1] Sarkar P, Joung C, Carrel J., Feng S, Sustainable manufacturing indicator repository. Proceedings of the ASME 2011 International Design Engineering Technical Conference Computer and Information in Engineering Conference; 2011.
[2] Dornfeld D, Green issues in manufacturing: Greening Processes, Systems and Products. LMAS.
[3] Yang Y, Lu G, Guo X, Yamamoto R, Greenness Assessment of Products in PLCAby DEA Approach. Materials Transactions, Vol. 44 No. (4); 2003.
[4] Carrel J, Joung C, Sarkar P, Feng S. Categorization of indicators for sustainable manufacturing. Ecological Indicators; 2012.
[5] Azadeh A, Amalnick M, Ghaderi S, Asadzadeh S, An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors. Energy Policy 35; 2007.
[6] Driscoll E, Cusack D, The development of energy performance indicators within a complex manufacturing facility. Int J Adv Manuf Technol (2013) 68:2205–2214; 2013.
[7] Al-Fandi L, A Novel Approach using LEAN and simulation modeling for effective green transformation for High-End server manufacturing. Ph.D. dissertation in industrial and system engineering, State University of New York; 2011.

[8] Huang H, Liu Z, Zhang L, Sutherland J, "Materials Selection for Environmentally Conscious Design via a Proposed Life Cycle Environmental Performance Index," International Journal of Advanced Manufacturing Technology, Vol. 44, pp. 1073-1082; 2009.

[9] Hui K, Spedding T, Bainbridge I, Taplin D, "Creating A Green Supply Chain: A Simulation and Modeling Approach," in Sarkis, J., Greening the supply chain, 1 st ed, London; 2006, pp. 341-363, Springer.

[10] Romvall K, Kurdve M., Bellgran M, Wictorsson J, Green Performance Map – An Industrial Tool for Enhancing Environmental Improvements within a Production System. Glocalized Solutions for Sustainability in Manufacturing: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Technische Universität Braunschweig, Braunschweig, Germany, May 2nd - 4th; 2011.

[11] Qingsong W, Xueliang Y, Dayong C, Chunyuan M, Kai Z, Research on Evaluation Index System for Green Manufacturing Based on PSR Model and Life Cycle. Applied Mechanics and Materials Vols. 34-35; 2010.

[12] Kassahun B, Saminathan M, Sekutowski J, "Green Design Tool" Proceedings of the 1995 IEEE International Symposium on Electronics and the Environment, Orlando, FL; 1995, pp. 118-125.

[13] Nordström E, Öhman K, Eriksson L, Approaches for Aggregating Preferences in Participatory Forest Planning - An Experimental Study. The open forest science journal; 2012.

[14] Saaty Th L, Vargas LG, (1984a) Inconsistency and Rank Preservation, Journal of Mathematical Psychology; 1984, 28: 205-214.

[15] Saaty Th L, Vargas LG. (1984b) Comparison of Eigenvalue, Logarithmic Least Squares and Least Squares Methods in Estimating Ratios, Mathematical Modelling; 1984, 5: 309-324

[16] Ishizaka, A., Lusti, M., How to derive priorities in AHP: A Comparative Study.

[17] Crawford GB, Williams C, (1985). A note on the analysis of subjective judgment matrices. The geometric mean procedure for estimating the scale of a judgment; 1985.

[18] Charnes C, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units.Eur J Oper Res 2:429–444; 1979.

[19] YOU S, Development of a green index for the textile industry: An Application in China; June 2009.

[20] Sarkis J, Comparative analysis of DEA as a discrete alternative multiple criteriadecision tool. Eur J Oper; 2000, Res 123:543–557.

[21] Cooper W, Seiford L, Tone K, Data envelopment analysis. Kluwer Academic, London; 2002.