Supplier Selection in Grey Environment: A Grey, AHP, Bulls-Eye and ELECTRE Approach

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ABSTRACT
In recent years, the problem of selecting and evaluating the suppliers in supply chain management has aroused considerable interest in business firms. Owing to the development of information systems, reaching an appropriate decision for adopting discrete methods is a need. The researchers intend to present a new model in this paper as a contributing factor in the grey environment in which the risk factor is evaluated high. The model decreases uncertainty in terms of two phases: A phase in parameter in terms of three -parameter interval grey numbers (the numbers are elicited from grey theory) instead of linguistic variables; in the other phase, we use a combination of AHP method and Bulls-eye method. A new method is used to rank suppliers that are due to generalization of ELECTRE I for three-parameter interval grey numbers named Grey-ELECTRE. Finally, a case study is brought to show application of the model in practical situation.

Keywords
Supply Chain management (SCM), AHP, Bulls-eye, Grey system, Grey ELECTRE, Three parameter interval grey numbers

1. INTRODUCTION
Nowadays, supply chain management (SCM) is propounded greatly in competitive environments. With the globalization of the economic markets and the development of information technology, many companies find that an implemented supply chain management (SCM) system is an important tool for increasing the competitive advantage [1]. The supplier selection problem is one of the most important components in SCM [2,3,4]. Supplier selection is a multiple-attribute decision-making (MADM) problem [5]. In Figure 1, a simple supply chain is shown.

The problem of supplier selection has emerged as an active research field in which numerous pertinent research papers have been published within the last few years [6]. For example, Liu and his colleagues used data envelopment analysis (DEA) to solve supplier selection problem [7].

Besides, Pi & Low presented a supplier evaluation method using Taguchi loss functions and AHP method [8]. Among these methods, linear weighting methods (LW) [9,10], the analytic hierarchy process (AHP) [11,12], the analytic network process [13], total cost approaches [14,15], and mathematical programming (MP) techniques [16,17] are more frequently used. Also, artificial intelligence techniques such as genetic algorithm [18,19] and artificial neural network [20] were used in this area.

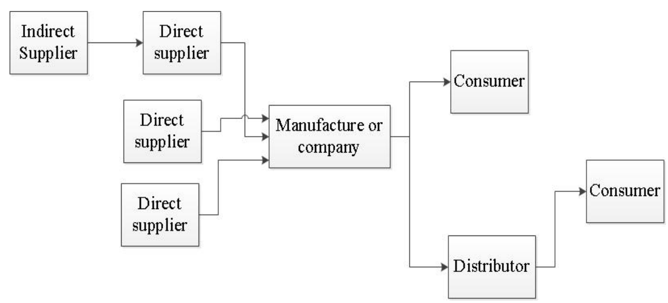

Figure 1. Supply chain

The fact that the problem of selecting suppliers has many uncertainties and troubles is irrefutable. In recent years, the methods such as the use of Fuzzy numbers and grey numbers were proposed for solving the uncertain problem. It is justifiably claimed that the advantage of grey numbers over fuzzy numbers [21,22] is its flexibility in terms of the condition of fuzziness [23].

The researchers have conducted a study on the challenge with respect to three- parameter interval Grey numbers derived from grey theory concepts. In other stage, namely preliminaries, AHP and Bulls-eye weighting methods as well as grey theory are presented. The mentioned methods are used in combination with criterion's weight in order to eliminate uncertainty. Moreover, Grey-ELECTRE method, which is an extension of ELECTRE-I for three- parameter interval grey numbers, is introduced. Accordingly, research methodology is discussed and a sample case study is presented to illuminate the approach further.

2. PRELIMINARIES
2.1. Three-Parameter Interval Gray Number
Grey system theory was first proposed by Deng [23] and extended by others [24]. Provided that black represents complete unknown information and white represents the quite clear one, gray can be representative of something go between. Accordingly, the system

containing gray information is called gray system (Fig. 2 shows the concept of gray systems).

A three-parameter interval gray number like $a(\otimes)$ can be shown within $a(\otimes) \in [\underline{a}, \tilde{a}, \bar{a}]$ where $\underline{a}$ is the lower bound, $\tilde{a}$ the center of gravity (the number with the highest possibility) and $\bar{a}$ as the upper bound. When the center of gravity is not determined, we will face typical gray numbers [25].

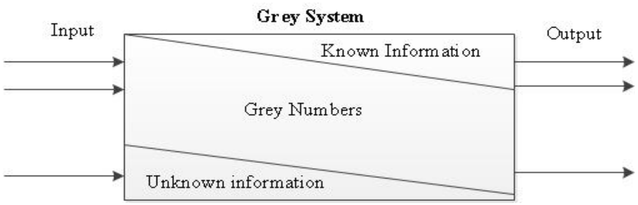

Figure 2.Concept of grey system

2.1.1 Operators of Three Parameter Interval Grey Numbers

If $a(\otimes) \in [\underline{a}, \tilde{a}, \bar{a}]$ and $b(\otimes) \in [\underline{b}, \tilde{b}, \bar{b}]$ are two/three-parameter interval grey numbers, then:

$$a(\otimes) + b(\otimes) \in [\underline{a} + \underline{b}, \tilde{a} + \tilde{b}, \bar{a} + \bar{b}]$$

$$a(\otimes)/b(\otimes) \in [\min\{\underline{a}/\underline{b}, \underline{a}/\bar{b}, \bar{a}/\underline{b}, \bar{a}/\bar{b}\}, \tilde{a}/\tilde{b}, \max\{\underline{a}/\underline{b}, \underline{a}/\bar{b}, \bar{a}/\underline{b}, \bar{a}/\bar{b}\}]$$

2.1.2 Distance Between Three-Parameter Interval Grey Numbers

Distance between two/ three-parameter interval grey numbers like $a(\otimes)$ & $b(\otimes)$ is shown with $d(a(\otimes), b(\otimes))$. In fact d is a mapping defined as $d: F \times F \to R$. For any three-parameter interval grey number like $c(\otimes)$, d has the following properties:

- $d(a(\otimes), b(\otimes)) \geq 0$
- $d(a(\otimes), b(\otimes)) = d(b(\otimes), a(\otimes))$
- $d(a(\otimes), b(\otimes)) \leq d(a(\otimes), c(\otimes)) + d(c(\otimes), b(\otimes))$

L is defined as the distance of the three-parameter interval grey numbers:

$$L(a(\otimes), b(\otimes)) = 3^{-1/2} \sqrt{(\underline{a} - \underline{b})^2 + (\tilde{a} - \tilde{b})^2 + (\bar{a} - \bar{b})^2}$$

It is easy to prove that L satisfies all above three properties.

2.1.3 Decision Making Matrix Normalization

Assume our decision making matrix is as below:

$$S = \{u_{ij}(\otimes) \mid u_{ij}(\otimes) \in (\underline{u}_{ij}, \tilde{u}_{ij}, \bar{u}_{ij}), 0 \leq \underline{u}_{ij} \leq \tilde{u}_{ij} \leq \bar{u}_{ij}, i = 1, 2, ..., n, j = 1, 2, ..., m\}$$

We use the following method for matrix normalization named poor transform method.

Desired value for efficiency:

$$\bar{x}_{ij} = \frac{\bar{u}_{ij} - \underline{u}_j^{\nabla}}{\bar{u}_j^* - \underline{u}_j^{\nabla}} \quad \tilde{x}_{ij} = \frac{\tilde{u}_{ij} - \underline{u}_j^{\nabla}}{\bar{u}_j^* - \underline{u}_j^{\nabla}} \quad \underline{x}_{ij} = \frac{\underline{u}_{ij} - \underline{u}_j^{\nabla}}{\bar{u}_j^* - \underline{u}_j^{\nabla}}$$

Desired value for costing:

$$\bar{x}_{ij} = \frac{\bar{u}_j^* - \underline{u}_{ij}}{\bar{u}_j^* - \underline{u}_j^{\nabla}} \quad \tilde{x}_{ij} = \frac{\bar{u}_j^* - \tilde{u}_{ij}}{\bar{u}_j^* - \underline{u}_j^{\nabla}} \quad \underline{x}_{ij} = \frac{\bar{u}_j^* - \bar{u}_{ij}}{\bar{u}_j^* - \underline{u}_j^{\nabla}}$$

In the above equations,

$\bar{u}_j^* = \max_{1 \leq i \leq n}\{\bar{u}_{ij}\}, \underline{u}_j^{\nabla} = \min_{1 \leq i \leq n}\{\underline{u}_{ij}\}$

When $\bar{u}_j^* - \underline{u}_j^{\nabla} = 0$, then we can eliminate this atribute from the decision making matrix,because it is an effectless parameter.

$x_{ij} \in (\underline{x}_{ij}, \tilde{x}_{ij}, \bar{x}_{ij})$ is a three-parameter interval grey number in $[0,1]$. Now, we have a standard decision making matrix like below:

$$R = \begin{pmatrix} x_{11} & x_{12} \cdots & x_{1n} \\ x_{21} & \ddots & \vdots \\ \vdots & & \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}$$

2.2. AHP Method

The analytic hierarchy process (AHP) was first proposed by Saaty in 1971. It is one of the most commonly used methods for solving multiple-criteria decision-making (MCDM) problems in political, economical, social and management fields [26]. Through AHP, opinions and evaluations of decision makers can be integrated, and a complex problem can be devised into a simple hierarchy system with higher levels to lower ones [27]. The qualitative and quantitative factors can then be evaluated in a systematic manner. The application of AHP to a complex problem involves the following essential steps [28,29]:

- Define the unstructured problem and state the objectives and outcomes clearly.
- Decompose the complex problem into a hierarchical structure with decision elements (criteria and alternatives).
- Employ pairwise comparisons among decision elements and form comparison matrices.
- Use the Eigen value method to estimate the relative weights of decision elements.
- Check the consistency property of matrices to ensure that the judgments of decision makers are consistent.
- Aggregate the relative weights of decision elements to obtain an overall rating for the alternatives.

Here, we obtain weights of every attributes by AHP and implement them as subjective weights in Entropy method.

2.3. Bulls-eye Weighting Method

Bulls-eye weighting method is used for three-parameter interval grey numbers by Lou & Wang [30].Here, we show this method in a step by step approach.

Step 1: Standardizing the decision matrix of the three parameter using normalization method that is described in 2.1.3.

Step 2: Obtaining the negative bull's-eye by:

$$Z^+ = (z_1^+, z_2^+, ..., z_n^+)$$

that

$$z_j^+ \in (\underline{x}_j^+, \tilde{x}_j^+, \overline{x}_j^+) \mid \underline{x}_j^+ = \max_{1\le i\le m}\{\underline{x}_{ij}\}, \tilde{x}_j^+ = \max_{1\le i\le m}\{\tilde{x}_{ij}\}, \overline{x}_j^+ = \max_{1\le i\le m}\{\overline{x}_{ij}\}$$

Step 3: Getting the weight w_j^* by:

$$w_j^* = b_j[\alpha w_j^0 - (\sum_{j=1}^{n} \alpha w_j^0 b_j - 1) / \sum_{j=1}^{n} b_j]$$

where

$$b_j = \frac{1}{\alpha + \beta \sum_{i=1}^{m} \left[(\underline{x}_{ij} - \underline{x}_{ij}^+)^2 + (\tilde{x}_{ij} - \tilde{x}_{ij}^+)^2 + (\overline{x}_{ij} - \overline{x}_{ij}^+)^2 \right]}$$

and objective weights that are allocated by decision maker is $W^0 = (w_1^0, w_2^0, ..., w_n^0)$ and also parameters α and β indicate relative importance, and they satisfy $\alpha + \beta = 1$, $\alpha \,\&\, \beta > 0$

2.4. Grey-ELECTERE Method

The ELECTRE method (Elimination & Choice Translating Reality) was introduced and developed by Benayoun et. al for the first time [31, 32,33,34], The researchers utilized the method in terms of three-parameter interval grey numbers (Grey-ELECTRE). Grey-ELECTRE consists of the following steps:

Step 1: Calculating the normalized decision matrix.

Step 2: Calculating the weighted normalized decision matrix:

$$V = [v_{ij}]$$
$$v_{ij} = x_{ij} * w_j$$

Step 3: Determining the concordance and discordance set:

The concordance set C_{kl} of A_k and A_l is composed of all criteria while A_k is preferred to A_l . In other words,

$$C_{kl} = \{ j \mid x_{kj} \ge x_{lj} \}$$

The complementary subset is called the discordance set, including

$$D_{kl} = \{ j \mid x_{kj} < x_{lj} \}$$

Step 4: Calculating the concordance matrix. Member of this matrix is obtained through:

$$I_{kl} = \sum w_j ; j \in A_{k,l}$$

Then this matrix is like:

$$I = \begin{bmatrix} - & I_{12} & I_{13} \dots & I_{1m} \\ I_{21} & - & I_{23} & \dots & I_{2m} \\ . \\ . \\ . \\ I_{m1} & I_{m2} & \dots I_{m(m-1)} & - \end{bmatrix}$$

Step 5: Calculating the discordance matrix. The member of this matrix is obtained by

$$NI_{kl} = \frac{Max\left\{\sqrt{(\underline{v}_{kj} - \underline{v}_{lj})^2 + (\tilde{v}_{kj} - \tilde{v}_{lj})^2 + (\overline{v}_{kj} - \overline{v}_{lj})^2}\right\}, j \in D_{k,l}}{Max\left\{\sqrt{(\underline{v}_{kj} - \underline{v}_{lj})^2 + (\tilde{v}_{kj} - \tilde{v}_{lj})^2 + (\overline{v}_{kj} - \overline{v}_{lj})^2}\right\}, j \in \left(all \cdot of \cdot criterias\right)}$$

Then this matrix is like the following:

$$NI = \begin{bmatrix} - & NI_{12} & NI_{13} \dots & NI_{1m} \\ NI_{21} & - & NI_{23} & \dots NI_{2m} \\ . \\ . \\ . \\ NI_{m1} & NI_{m2} & \dots & NI_{m(m-1)} & - \end{bmatrix}$$

Step 6: Determining the concordance dominance matrix. The threshold value is calculated through:

$$\overline{I} = \sum_{l=1}^{m} \sum_{k=1}^{m} I_{kl} \,/\, m(m-1)$$

Also, The concordance dominance matrix H is structured by:

$$I_{kl} \ge \overline{I} \rightarrow H_{kl} = 1$$
$$I_{kl} < \overline{I} \rightarrow H_{kl} = 0$$

Step 7: Determining the discordance dominance matrix. the threshold value is calculated through:

$$\overline{NI} = \sum_{l=1}^{m} \sum_{k=1}^{m} NI_{kl} \,/\, m(m-1)$$

Also, The discordance dominance matrix G is structured by:

$$NI_{kl} \ge \overline{NI} \rightarrow G_{kl} = 0$$
$$NI_{kl} < \overline{NI} \rightarrow G_{kl} = 1$$

Step 8: Determining the aggregate dominance matrix. the member of the aggregate dominance matrix F is obtained by:

$$F_{kl} = H_{kl}.G_{kl}$$

Step 9: Eliminating the less favorable alternatives. It is more favorable if A_k is preferred to A_l for both the concordance and discordance criteria.

3. RESEARCH METHODOLOGY

In this section, we show that how the proposed model works in a step by step manner.

Step 1: Constructing the decision making matrix.

Step 2: Changing the linguistic variables to three parameter interval grey numbers.

Step 3: Constructing pair wise comparison matrix.

Step 4: Obtaining subjective weights of each criteria by AHP method.

Step 5: Obtaining the weight of each criteria using Bulls-eye method.

Step 6: Ranking alternatives by Grey-ELECTRE (Fig 3. depicts the entire steps)

4. CASE STUDY

To satisfy the requirements of the Iranian company called Sadra Stone The authorities decided to select a supplier in terms of five factors. They formed a committee consists of four professors major in industrial engineering and management sciences. The committee specified the following five factors to evaluate suppliers:

- Price/Cost
- Transformation costs
- Technological capability
- Delay on delivery
- Products quality

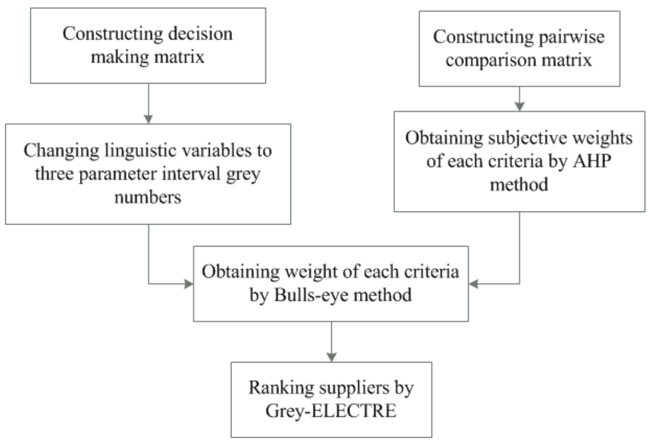

Figure 3. Research methodology

An expert committee evaluated each supplier based on the aforementioned factors (Table 1. shows the result).

Table 1.Suppliers evaluation

	Price	Transformation Costs	Technological Capability	Delay on Delivery	Products Quality
Supplier 1	VG	MG	MG	MB	G
Supplier 2	MG	VB	MG	B	MG
Supplier 3	MB	MG	VG	G	MB
Supplier 4	MB	G	G	B	MG
Supplier 5	B	MB	MG	VB	B

The next step is to change the linguistic variables to numerical values. The committee used three parameter interval grey numbers in lieu of linguistic values (Table 2).

Table 2. Linguistic variables and their three parameter interval numbers equivalent

Linguistic variable	Equivalent three parameter interval grey number
Very Bad (VB)	(0.0,0.075,0.15)
Bad (B)	(0.15,0.25,0.35)
Medium Bad (MB)	(0.35,0.4,0.45)
Medium (M)	(0.45,0.5,0.55)
Medium Good (MG)	(0.55,0.6,0.65)
Good (G)	(0.65,0.75,0.85)
Very Good (VG)	(0.85,0.925,1)

Then they weighted each criterion by AHP method. They formed pair wise comparison matrix for each criteria (Table 3).

Table3. Pair wise comparison matrix of criteria

	Price	Transformation Costs	Technological capability	Delay on delivery	Products quality
Price	1	1.8	1.6	2	1.5
Transformation Costs		1	0.83	0.9	0.55
Technological capability			1	0.8	0.67
Delay on delivery				1	0.67
Products quality					1

They used AHP weights as subjective weights in Bulls-eye weighting method (alpha=0.5) shown in Table 4.

Table4. Weights of criteria by AHP and Bulls-eye methods

	Price	Transformation cost	Technological capability	Delay on delivery	Products quality
AHP weight	0.3	0.14	0.16	0.17	0.23
Bulls-eye weight	0.16	0.18	0.26	0.13	0.27

Finally, they obtained F matrix of alternatives shown in Table 5. F matrix is also shown in Figure 4.

Table5. F matrix by Grey-ELECTRE

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Supplier 1	0	1	0	0	1
Supplier 2	0	0	0	0	1
Supplier 3	0	0	0	0	1
Supplier 4	0	1	0	0	1

Supplier 5	0	0	0	0	0

5. CONCLUSION

Pursuing today's strict competitive business environment, companies and manufacturers are to struggle to gain overwhelming competitive advantages over their rivals. Supply chain management (SCM) is one of the most important scopes affecting the firms' performances. Many researchers have focused on companies' SCM. Consequently, they have deployed many types of scientific techniques to enhance productivity and efficiency of the supply networks. Supplier selection as an MCDM problem has recently attracted many researchers.

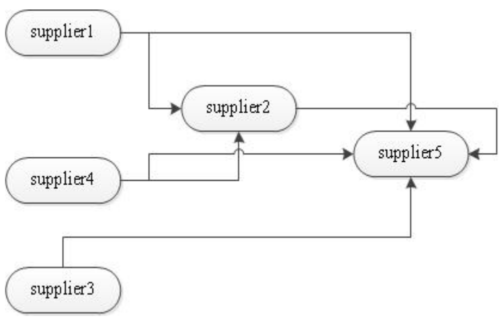

Figure 4. Preference graph

The investigators attempted to show a very effective method in risk conditions. The method enhances certainty adopting a combination of AHP and Bulls-eye weighting methods. Using three-parameter interval grey numbers instead of linguistic variables can also mitigates uncertainty. A Grey-MCDM method is also used for three-parameter interval grey numbers posited as a generalization of ELECTRE I. The method named Grey ELECTRE can contribute to evaluation and ranking each supplier in terms of the pre-defined criteria. A case study was eventually discussed to show the application of this actual model.

REFERENCES

[1] Choi, J. S., Bai, G. J., & Romeijn, H. (2007). Manufacturing Delivery Performance for Supply Chain Management, *Mathematical and Computer Modelling,* Vol. 45, pp. 11-20.

[2] Hong, W., Lyes, B., & Xie, X. (2005). A Simulation Optimization Methodology for Supplier Selection Problem, *International Journal of Computer Integrated Manufacturing,* Vol. 18, No. no. 2-3, pp. 210-224.

[3] Ndubisi, N., Jantan, M., King, L., & Ayub, M. (2005). Supplier Selection and Management Strategies and Manufacturing Flexibility, *Journal of Enterprise Information Management,* Vol. 18, No. 3, pp. 330-349.

[4] Lasch, R., & Janker, C. (2005). Supplier Selection and Controlling Using Multivariate Analysis, *International Journal of Physical Distribution and Logistics Management,* Vol. 35, No. 6, pp. 409–425.

[5] Weber, C., Current, J., & Benton, W. (2001). Vendor Selection Criteria and Methods, *European Journal of Operational Research,* Vol. 50, No. 1, pp. 2-18.

[6] Shemshadi, A., Shirazi, H., Toreihi, M., & Tarokh, M. (2011). A Fuzzy VIKOR Method for Supplier Selection Based on Entropy Measure for Objective Weighting, *Expert Systems with Applications,* Vol. 38, No. 10, pp. 12160–12167.

[7] Liu, J., Ding, F., & Lall, V. (2000). Using Data Envelopment Analysis to Compare Suppliers for Supplier Selection and Performance Improvement, *The Journal of Supply Chain Management,* Vol. 5, No. 3, pp. 143-150.

[8] Pi, W., & Low, C. (2006). Supplier Evaluation and Selection via Taguchi Loss Functions and an AHP, *International Journal of Advance Manufacturing Technology,* Vol. 27, No. 5-6, pp. 625-630.

[9] Thompson, K. (1990). Vendor Profile Analysis, *Journal of Purchasing and Materials Management*, Vol. 26, No. 1, pp. 11-18.

[10] Timmerman, E. (1986). An Approach to Vendor Performance Evaluation, *Journal of Purchasing and Supply Management,* Vol. 1, pp. 27-32.

[11] Barbarosoglu, G., & Yazgac, T. (1997). An Application of the Analytic Hierarchy Process to the Supplier Selection Problem, *Production and Inventory Management Journal 1st quarter* , Vol. 38, pp. 14-21.

[12] Narasimhan, R. (1983). An Analytic Approach to Supplier Selection, *Journal of Purchasing and Supply Management,* Vol. 1, pp. 27-32.

[13] Sarkis, J., & Talluri, S. (2006). A Model for Strategic Supplier Selection, Journal of Supply Chain Management, Vol. 38, No. 1, pp. 18-28..

[14] Monezka, R., & Trecha, S. (1998). Cost-based Supplier Performance Evaluation, *Journal of Purchasing and Materials Management,* Vol. 24, No. 2, pp. 2-7.

[15] Smytka, D., & Clemens, M. (1993). Total Cost Supplier Selection Model: A Case Study, *International Journal of Purchasing and Materials Management,* Vol. 29, No. 1, pp. 42-49.

[16] Buffa, F., & Jackson, W. (1983). A Goal Programming Model for Purchase Planning, *Journal of Purchasing and Materials Management,* Vol. 19, No. 3, pp. 27–34.

[17] Chaudhry, S., Forst, F., & Zydiak, J. (1993). Vendor Selection with Price Breaks, *European Journal of Operational Research,* Vol. 70, No. 1, pp. 52-66.

[18] Chen, Z. H., & Wang, H. S. (2008). Supplier Selection and Supply Quantity Allocation of Common and Non-common Parts with Multiple Criteria under Multiple Products, *Computers & Industrial Engineering,* Vol. 55, No. 1, pp. 110–133.

[19] Liao, Z., & Rittscher, J. (2007). Integration of Supplier Selection, Procurement Lot Sizing and Carrier Selection under Dynamic Demand Conditions, *International Journal of Production Economics,* Vol. 107, No. 2, pp. 502–510.

[20] Lee, C.C., & Ou-Yang, C. (2009). A Neural Networks Approach for Forecasting the Supplier's Bid Prices in Supplier Selection Negotiation Process, *Expert Systems with Applications,* Vol. 36, No. 2, pp. 2961–2970.

[21] Zadeh, L. (1965). Fuzzy Sets. *Information and Control,* Vol. 8, pp. 338-353.

[22] Bellman, R., & Zadeh, L. (1970). Decision-making in a Fuzzy Environment. *Management Science,* Vol. 17, No. 4, pp. 141-164.

[23] Deng, J. (1989). The Introduction of Grey System, *The Journal of Grey System,* Vol. 1, No. 1, pp. 1-24.

[24] Liu, S.F., Dang, Y.G., & Fang, Z.G. (2005). *Grey System Theory and Application,* Beijing: Science Press.

[25] Kamfiroozi, M., Aliahmadi, A., & Jafari, M. (2012). Application of Three Parameter Interval Grey Numbers in

Enterprise Resource Planning Selection. *International Journal of Information, Se*curity and Systems Management, Vol 1, No 2, pp. 72-77.

[26] Saaty, T.L. (1980). *The Analytic Hierarchy Process,* New York: McGraw-Hill.

[27] Lee, A.H., Kang, H.Y., Hsu, C.F., & Hung, H.C. (2009). A Green Supplier Selection Model for High-tech Industry, *Expert Systems with Applications*, Vol. 36, No. 4, pp. 7917-7927.

[28] Lee, A.H., Kang, H.Y., & Wang, W.P. (2006). Analysis of Priority Mix Planning for Semiconductor Fabrication under Uncertainty, *International Journal of Advanced Manufacturing Technology*, Vol, 28, No. 3-4, pp. 351-361.

[29] Murtaza, M.B. (2003). Fuzzy-AHP Application to Country Risk Assessment, *American Business Review,* Vol. 21, No. 2, pp. 109-116.

[30] Luo, D., & Wang, X. (2012). The Multi-attribute Grey Target Decision Method for Attribute Value within Three-parameter Interval Grey Number, *Applied Mathematical Modelling,* Vol. 36, No. 5, pp. 1957-1963.

[31] Benayoun, R., Sussman, B., & Roy, B. (1966). *Manual de Reference du Programme ELECTRE.* Paris: Direction Scientifique SEMA.

[32] Nijkamp, P. (1974). A Multicriteria Analysis for Project Evaluation: Economic-Ecological Evaluation of a land Reclamation Project. *Papers of egional Associations,* Vol. 35, No. 1, pp. 87-111.

[33] Roy, B. (1971). Problems and Methods with Multiple Objective Functions. *Mathematical Programming,* Vol. 1, No. 2, pp. 239-266.

[34] Van Delft, A., & Nijkamp, P. (1976). A Multi-Objective Decision Model for Regional Development, Environmental Quality Control and Industrial Land Use. *Papers of the Regional Science Association,* Vol. 36, No. 1, pp. 35-57.

[35] nalysis, *Journal of Purchasing and Materials Management*, Vol. 26, No. 1, pp. 11-18.

[36] Timmerman, E. (1986). An Approach to Vendor Performance Evaluation, *Journal of Purchasing and Supply Management,* Vol. 1, pp. 27-32.

[37] van Delft, A., & Nijkamp, P. (1976). A Multi-Objective Decision Model for Regional Development, Environmental Quality Control and Industrial Land Use. *Papers of the Regional Science Association*, Vol. 36, No. 1, pp. 35-57.

[38] Weber, C., Current, J., & Benton, W. (2001). Vendor Selection Criteria and Methods, *European Journal of Operational Research,* Vol. 50, No. 1, pp. 2-18.

[39] Zadeh, L. (1965). Fuzzy Sets. *Information and Control,* Vol. 8, pp. 338-353.