Routledge
Taylor & Francis Group

Edinburgh Napier UNIVERSITY

INTERNATIONAL JOURNAL OF STRATEGIC PROPERTY MANAGEMENT
ISSN 1648-715X / eISSN 1648-9179

2014 Volume 18(4): 332–343
doi:10.3846/1648715X.2014.970596

MULTI PERIOD PERFORMANCE ASSESSMENT MODEL FOR THE SITE PROPERTY MANAGEMENT

Yung-Yu LIN [a], **Nai-Hsin PAN** [b,*]

[a] *Graduate School of Engineering Science and Technology, College of Engineering, National Yunlin University of Science and Technology, Douliu, Taiwan*
[b] *Department of Construction Engineering, College of Engineering, National Yunlin University of Science and Technology, Douliu, Taiwan*

Received 29 November 2012; accepted 9 July 2013

ABSTRACT. Performance assessment is an important task for the property management company to measure the performance of site, to evaluate and rank the sites, and to trace the main indices resulting in worse performance. Therefore, this study proposes a multi period performance assessment model. A performance scale with twelve indices is adopted to measure the site performance. The raw data can be transformed to be comparable by the proposed linear preprocessing method with specification limits. The priority is ranked by the integrated method with the technique for order preference by similarity to ideal solution and the signal-to-noise ratio. Finally, the main indices resulting in worse performance can be identified by the proposed tracing method. An illustrative example of real case is adopted to demonstrate the feasibility and practicability of the proposed model. Results show the proposed model can obtain a more reliable result.

KEYWORDS: Multi-attribute decision-making; Performance scale; Signal-to-noise ratio; Site property management; Technique for order preference by similarity to ideal solution

1. INTRODUCTION

Owning to the limited land resource, the proportion of new building construction is decreasing in the city, but the proportion of building maintenance and repair is increasing as the continuous development of urbanization. The market of property management is also growing. Besides, people now have more and more requirements in living quality. Not only the outer appearance or the building structure, but also the variety and convenience of service are paid attentions. Therefore, to assess the site performance is important to the property management company for its sustainable development.

Property management industry has the inherent characteristic that the company and the sites are in different locations. Every site can be regarded as a long-term project. Services are provided to residents (customers) in the site. Hence, the performance assessment of site not only can reflect the residents' satisfaction to the service but also can assist the property management company to sort the sites and to control the worse performance sites. The performance assessment is also the basic of self-evaluation and continuous improvement for the sites. Therefore, an effective assessment model is important for all the stakeholders to realize the property management performance of the sites.

For this purpose, the authors had developed a performance scale for site property management (Pan, Liu 2010). The proposed site property management performance scale focused on the residence and community. In the definition of key indicators, eleven senior experts were invited to discuss the indicators several times and nineteen indicators were collected. After that, the appropriateness of the nineteen indicators were analyzed via twice fuzzy Delphi method. Finally, the twelve key indicators were synthesized (listed in Table 1). In the definition of dimensions, the affinity diagram was used to cluster the key indicators. The clustered three dimensions were named via their characteristics, i.e., the general affair, the environment quality, and the personal quality. Besides, the analytic network process (ANP) was used to

* Corresponding author. E–mail: pannh@yuntech.edu.tw

Copyright © 2014 Vilnius Gediminas Technical University (VGTU) Press
http://www.tandfonline.com/TSPM

Table 1. Site property management performance scale

Dimension	Evaluation indicator	Weight
General affair	Contract extension fee (I1)	0.065
	Property management fee (I2)	0.063
	Grants application (I3)	0.045
	Data completeness (I4)	0.063
	Financial structure (I5)	0.083
Environment quality	Facilities maintenance and environment (I6)	0.025
	Burglar event (I7)	0.054
	Community empowerment (I8)	0.030
Personal quality	Service attitude (I9)	0.077
	Crisis management (I10)	0.189
	Dispute management (I11)	0.160
	Resident complaint (I12)	0.147

define the weight of each indicator. Table 1 shows the site property management performance scale and the indicator weight. In practice, this scale can be adopted as the inner audit criteria in the property management company.

The performance scale is often used with the integration of the multi-attribute decision making methods, e.g., the technique for order preference by similarity to ideal solution (TOPSIS). TOPSIS has been widely employed in various fields for its four advantages: (i) a sound logic that represents the rationale of human choice; (ii) a scalar value that accounts for both the best and worst alternatives simultaneously; (iii) a simple computation process that can be easily programmed into a spreadsheet; and (iv) the performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions (Kim *et al.* 1997). TOPSIS has been successfully integrated with performance scales to solve various decision making problems, e.g., the factory location analysis, the construction process evaluation, the human resource management, the transposition decision, the product design, the manufactory analysis, the water resource management, the quality control, and the critical path definition *et al.* (Yoon, Hwang 1985; Leu, Yang 1999; Kwong, Tam 2002; Janic 2003; Chen, Tzeng 2004; Srdjevic *et al.* 2004; Milani *et al.* 2005; Yang, Chou 2005; Zammori *et al.* 2009).

Although TOPSIS has demonstrated its applicability in performance scale, two problems are still encountered in practices. The first problem is the data preprocessing. Unit vector preprocessing method is used in TOPSIS, but this preprocessing method might change the linear relationship in the raw data and further influence the priority of alternatives. Besides, no matter the unit vector preprocessing method or other linear preprocessing methods can not consider the interested region of decision makers, i.e., the specification limits of indices, in the transformation functions. Take the customer satisfaction indicator for example. The score of customer satisfaction indicator ranges from 0 to 100, and higher score means higher customer satisfaction. Decision makers are interested in the region of [80, 100], meaning 80 is the lower specification limit of customer satisfaction indicator, i.e., the unacceptable level. Unit vector processing method and other methods can not consider this interested region to reflect the decision makers' real concerns.

The second problem is the number of evaluation periods. Single period is commonly used in the traditional performance evaluation, but only one period might be not enough to obtain a reliable result. Besides, the multi period evaluation result can provide information not only for decision-making but also for tracing worse indices resulting in worse performance. Therefore, to obtain a reliable and useful result, multi period evaluation ought to be considered.

Hence, this study proposes a multi period assessment model for site property management. The performance of site can be measure by the performance scale. The measured values are preprocessed by the proposed linear transformation with specification limits, and the determination of specification limit is defined by the fuzzy Delphi questionnaires of senior managers. Then, the closeness to ideal solution is calculated by the TOPSIS. The closeness of multi period can be used to rank the site performance and trace the main indices resulting in worse performance.

In evaluating the comprehensive performance, arithmetic mean or geometric mean are the commonly used methods. However, in addition to the mean, the variance of multi period closeness ought to be concerned. Therefore, this study uses the signal-to-noise ratio (SN ratio) to both consider the mean and the variance of multi period closeness.

The remaining sections are organized as follows. In section 2, the TOPSIS, the fuzzy Delphi method, and the SN ratio are discussed. Based on the discussions in Section 2, the multi period assessment model is proposed in Section 3. Then, an illustrative example of real case is used to demonstrate the feasibility and practicability of the proposed model in Section 4. Finally, Section 5 concludes this study.

2. LITERATURE SURVEY

2.1. TOPSIS

TOPSIS is a widely used method to deal with multi attribute decision making (MADM) problems. TOPSIS can rank a finite number of feasible alternatives in order of preference and select a suitable alternative that conforms to the decision makers' ideal. The selected alternative will have the shortest Euclidean distance from the ideal solution and the farthest Euclidean distance from the anti-ideal solution. Assume the multi attribute decision making data, D, to be:

$$D = \begin{bmatrix} x_1(1) & x_1(2) & \dots & x_1(m) \\ x_2(1) & x_2(2) & \dots & x_2(m) \\ \dots & \dots & \dots & \dots \\ x_n(1) & x_n(2) & \dots & x_n(m) \end{bmatrix},$$

where: D is composed of n alternatives and m attributes; $x_i(j)$ denotes the value of the i-th alternative in the j-th attribute. The procedure of TOPSIS can be expressed in the following six steps (Hwang, Yoon 1981).

Step 1: Preprocess the raw data.

To make the attributes be comparable, the raw data has to be preprocessed (normalized). The unit vector method is used in TOPSIS as:

$$r_i(j) = \frac{x_i(j)}{\sqrt{\sum_{j=1}^{m} \left[x_i(j) \right]^2}}. \quad (1)$$

In Equation (1), r_{ij}. is the preprocessed value of x_{ij}.

Step 2: Weight the preprocessed data.

The weighted preprocessed data can be denoted as $v_i(j) = w(j) r_i(j)$, where: $w(j)$ is the weight of the j-th attribute and $\sum_{j=1}^{m} w(j) = 1$. The analytic hierarchy process (AHP) and the analytic network process (ANP) methods are commonly used to determine the weights in the TOPSIS (Wang *et al.* 2009; J. K. Chen, I. S. Chen 2010; Torfi *et al.* 2010; Wu *et al.* 2010).

Step 3: Determine the ideal and the anti-ideal solutions.

The ideal solution is a hypothetical alternative in which all attribute values correspond to the best level. If the ideal solution is exactly one of the feasible alternatives, there is no need for decision making. However, this situation is rarely seen in the real problems. The values of alternatives are often found to be higher in some attributes and lower in the other attributes. Thus, decision makers should consider and calculate cautiously all the attributes in order to select a suitable compromise alternative. On the contrary, the anti-ideal alternative is also a hypothetical alternative in which all attribute values correspond to the worst level. Denote the ideal solution (A^+) and the anti-ideal solution (A^-) as:

$$A^+ = \left\{ (\max_{\forall i} v_i(j) \middle| j \in J^+), (\min_{\forall i} v_i(j) \middle| j \in J^-) \middle| \ i \in n \right\} = \left(v_1^+, v_2^+, \dots, v_m^+ \right)$$

and

$$A^- = \left\{ (\min_{\forall i} v_i(j) \middle| j \in J^+), (\max_{\forall i} v_i(j) \middle| j \in J^-) \middle| \ i \in n \right\} = \left(v_1^-, v_2^-, \dots, v_m^- \right)$$

respectively. J^+ and J^- are the attribute sets of the larger-the-better type and the smaller-the-better type, respectively.

Step 4: Calculate the separations.

The separation of each alternative from the ideal solution, d_i^+, can be calculated by the m-dimensional Euclidean distance function as:

$$d_i^+ = \sqrt{\sum_{j=1}^{m} \left[v_i(j) - v_j^+ \right]^2}. \quad (2)$$

Similarly, the separation from the anti-ideal solution, d_i^-, is given as:

$$d_i^- = \sqrt{\sum_{j=1}^{m} \left[v_i(j) - v_j^- \right]^2}. \quad (3)$$

Step 5: Calculate the closeness to the ideal solution.

The closeness to the ideal solution of the i-th alternative, C_i^+, is defined as:

$$C_i^+ = \frac{d_i^-}{d_i^+ + d_i^-}. \quad (4)$$

Since $d_i^+ \geq 0$ and $d_i^- \geq 0$, then, clearly, $C_i^+ \in [0,1]$.

Step 6: Rank the preference order.

A set of alternatives then can be ranked by preference according to the descending order of C_i^+; in other words, larger C_i^+ means better alternative.

Although the TOPSIS has demonstrated well applicability in various studies, it's performance still can be improved, especially the preprocessing method. As shown in Equation (1), the unit vector method is not a linear transformation method. The linear relationship in the raw data will be changed and that will influence the final priority. Therefore, the linear transformation ought to be considered in the applications of TOPSIS.

2.2. Fuzzy Delphi method

Fuzzy Delphi Method was proposed by Ishikawa *et al.* (1993), and it was integrated with the traditional Delphi technique and fuzzy set theory. Fuzzy Delphi method is an useful and commonly used tool to conclude the experts' opinions, especially in the group decision making. Therefore, this study adopts the fuzzy Delphi method to determine the specification limits. In the procedure of the fuzzy Delphi method, experts are allowed to provide interval evaluations, $\otimes x = \left[\underline{x}, \overline{x}\right]$, and then the fuzzy numbers of maximum value and minimum value are used to aggregate the evaluation result.

Figure 1 shows the function of fuzzy Delphi method. In Figure 1, the triangular fuzzy numbers $\tilde{N}$ and $\tilde{n}$ are composed of the maximum values and the minimum values of experts' interval evaluations, respectively. $\overline{x}_i$ and $\underline{x}_i$ are the maximum value and the minimum value of the *i*-th expert. $\tilde{N} = \left(L, M, U\right)$, where: $L = \min\limits_{\forall i}\left(\overline{x}_i\right)$, $U = \max\limits_{\forall i}\left(\overline{x}_i\right)$ and M is the geometric mean of $\overline{x}_i$. Similarly, $\tilde{n} = \left(l, m, u\right)$, where $l = \min\limits_{\forall i}\left(\underline{x}_i\right)$, $u = \max\limits_{\forall i}\left(\underline{x}_i\right)$, and m is the geometric mean of $\underline{x}_i$.

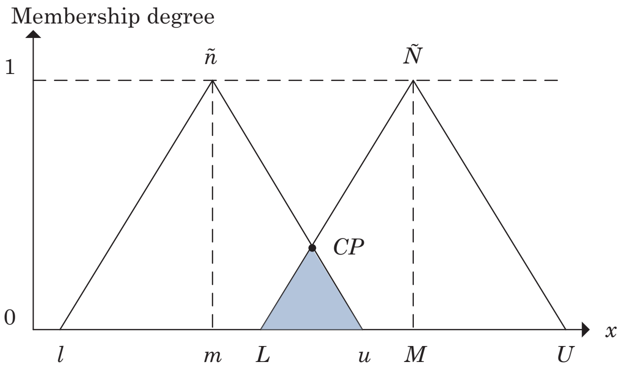

Fig. 1. Fuzzy Delphi method function

Two tests ought to be conducted before determining the cross point (CP) in Figure 1 and are described as follows.

(1) Test whether the overlap region exists, i.e., $L < u$.

(2) Test whether the overlap region is reasonable, i.e., $(u - L) < (M - m)$.

Therefore, if $L < u$ and $(u - L) < (M - m)$, the cross point can be calculated and regarded as the evaluation.

Noorderhaben (1995) pointed that the fuzzy Delphi method can be used to solve the fuzziness of common understanding of expert opinions in group decision. Owing to the applicability of the fuzzy Delphi method, it has been used in many studies and demonstrated well applications (Hsu *et al.* 2010; Kuo, Chen 2008; Liu, Wang 2009).

2.3. Signal-to-noise ratio

The signal-to-noise ratio is an important measure in the Taguchi method and is developed from the quality loss function (Y. G. Cho, K. T. Cho 2008; Chen, Kao 2009; Liao, Kao 2010). In the definition of quality loss function, it has the minimum loss when the measured value is equal to the ideal value. The loss increases with the separation from the ideal value. If $L(y)$ is the quality loss function of the measured value (y) separated from the ideal value (m), then $L(y)$ can be described by the Taylor series as:

$$L(y) = L(m) + \frac{L'(m)}{1!}(y - m) + \frac{L''(m)}{2!}(y - m)^2 + ...$$

According to the definition of the quality loss function, $L(m) = 0$ and $L'(m) = 0$ when $y = m$ and the high-order polynomials are ignored, $L(y)$ can be further described as:

$$L(y) \approx \frac{L''(m)}{2!}(y - m)^2 = k(y - m)^2,$$

where: k is the quality loss coefficient and $k = \frac{L''(m)}{2!}$. $L(y)$ is named the nominal-the-best (NTB) quality loss function and is shown as Figure 2.

However, $L(y)$ is the quality loss function of a product, but the quality loss function of a batch of products ought to be more considered in practice. L_{NTB} denotes the quality loss function of n products and is defined as:

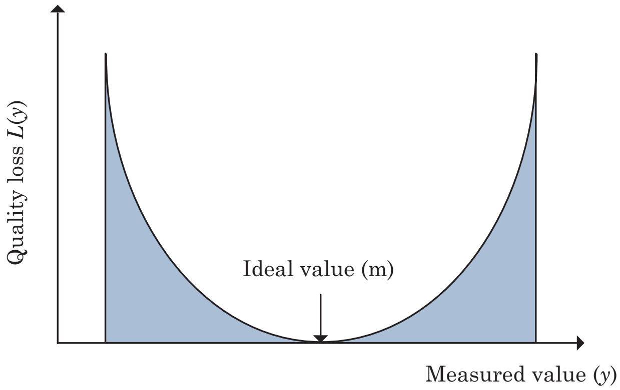

Fig. 2. The nominal-the-best quality loss function

$$L_{NTB} = \frac{k}{n}\sum_{i=1}^{n}(y-m)^2 = k\left[(\bar{y}-m)^2 + s_n^2\right] = k\left[MSD_{NTB}\right].$$

As shown in the definition, the mean square deviation (MSD) is the core of L_{NTB}. In the Taguchi method, MSD is transformed as the SN ratio to evaluate the quality loss in the Taguchi method. The nominal-the-best SN ratio is denoted as:

$$SN_{NTB} = -10\log_{10}(MSD_{NTB}) = -10\log_{10}((\bar{y}-m)^2 + s_n^2). \quad (5)$$

As shown in Equation (5), SN_{NTB} considers both the average ($\bar{y}$) and the variance (s_n^2) of the measured values. Therefore, in the multi period evaluations, a more stable and reliable result can be obtained by applying the SN ratio. In the real application of performance evaluation, the larger-the-better SN ratio and the smaller-the-better SN ratio are more commonly used. The larger-the-better SN ratio and the smaller-the-better SN ratio are denoted as Equation (6) and Equation (7), respectively:

$$SN_{LTB} = -10\log_{10}\left(\frac{\sum_{i=1}^{n}\frac{1}{y_i^2}}{n}\right), \quad (6)$$

$$SN_{STB} = -10\log_{10}\left(\bar{y}^2 + s_n^2\right). \quad (7)$$

2.4. Analytic network process

Determining the weights of the indicators is important in the decision making problems. The AHP and the ANP are two commonly used methods (Saaty 1980, 1996). Although the AHP method has been widely used, the AHP method assumes that the indicators listed in the hierarchical structure are independent. However, this is not always a reasonable assumption. Therefore, the AHP method and the ANP method are suggested to solve the problem of independence among indicators and the problem of dependence among indicators (Lee, Kim 2000).

The ANP method is constructed via the pairwise comparison matrices and the priority vectors. The pairwise comparison matrices and the priority vectors in the ANP method can be derived as an estimate of the relative importance associated with the indicators (or dimensions) being compared by solving the following equation (Chung *et al.* 2005; Tseng *et al.* 2009):

$$A \times w = \lambda_{\max} \times w. \quad (8)$$

In Equation (8), A is the matrix of pairwise comparison, w is the eigenvector, and $\lambda_{\max}$ is the largest eigenvalue of A.

To obtain the global priorities with interdependent indicators, the local priority vectors are entered in the appropriate columns of a matrix. As a result, a supermatrix is developed, where each matrix segment represents a relationship between two dimensions. A standard supermatrix is denoted as:

$$W = \begin{array}{cc} & \begin{array}{cccc} D_1 & D_2 & & D_n \\ e_{11}\,e_{12}\ldots e_{1m1} & e_{21}\,e_{22}\ldots e_{2m2} & \ldots & e_{n1}\,e_{n2}\ldots e_{nmn} \end{array} \\ \begin{array}{c} D_1 \begin{array}{c} e_{11} \\ e_{12} \\ \ldots \\ e_{1m1} \end{array} \\ D_2 \begin{array}{c} e_{21} \\ e_{22} \\ \ldots \\ e_{2m2} \end{array} \\ \ldots \\ D_n \begin{array}{c} e_{n1} \\ e_{n2} \\ \ldots \\ e_{nmn} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \ldots & W_{1n} \\ W_{21} & W_{22} & \ldots & W_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ W_{n1} & W_{n2} & \ldots & W_{nn} \end{bmatrix} \end{array}.$$

In the standard supermatrix, there are n dimensions, $D_1, D_2, \ldots, D_k, \ldots, D_n$, and each dimension has mk indicators, denoted by $e_{k1}, e_{k2}, \ldots, e_{kmk}$. The local priority vectors are grouped and placed in the appropriate positions in the supermatrix based on the flow of influence from one dimension to another (or itself).

To achieve convergence on the importance weights, the weighted supermatrix is raised to the power of an arbitrarily large number. The final matrix is called the limit supermatrix. The final priorities of all indicators can be obtained by normalizing each dimension of this supermatrix.

3. METHODOLOGY

For the purposes of effectively (i) measuring the property site performance, (ii) defining the specification limits of indices, (iii) considering the multi period evaluations, and (iv) tracing the main factors of worse sites, this study proposes a multi period evaluation model for site property management performance (as shown in Figure 3). First, the site performance for every period is measured by Table 1. Then, the raw data will be transformed by the proposed linear preprocessing method with specification limits. The closeness of site is calculated by TOPSIS, and the comprehensive evaluation result is determined by the SN ratio. Also, the SN ratio is used to trace the main factors causing worse performance.

Assume the site performance measurement data at the *t-th* period, $X^{(t)}$, to be:

$$X^{(t)} = \begin{bmatrix} x_1^{(t)}(1) & x_1^{(t)}(2) & \dots & x_1^{(t)}(m) \\ x_2^{(t)}(1) & x_2^{(t)}(2) & \dots & x_2^{(t)}(m) \\ \dots & \dots & \dots & \dots \\ x_n^{(t)}(1) & x_n^{(t)}(2) & \dots & x_n^{(t)}(m) \end{bmatrix}.$$

$X^{(t)}$ is composed of n sites and m performance indices (m = 12 in this study). The proposed linear preprocessing method with specification limits and the evaluation model are stated as follows.

3.1. Linear preprocessing method with specification limits

This study takes the comprehensive grey generating method (Chang 2000) as the basic and integrates the specification limits in it to propose the linear preprocessing method. In the comprehensive grey generating method, the larger-the-better preprocessing and the smaller-the-better preprocessing are defined as Equation (9) and Equation (10), respectively:

$$r_i(j) = \frac{x_i(j) - x_{\min}}{x_{\max} - x_{\min}}(1 - \alpha_l) + \alpha_l. \quad (9)$$

$$r_i(j) = 1 - \frac{x_i(j) - x_{\min}}{x_{\max} - x_{\min}}(1 - \alpha_s). \quad (10)$$

$$x_{\min} = \min_{\forall i}\left(x_i(j)\right) \text{ and } x_{\max} = \max_{\forall i}\left(x_i(j)\right).$$

Besides, $\alpha_l = \frac{x_{\min}}{x_{\max}}$ and $\alpha_s = -\frac{x_{\max}}{x_{\min}} + 2$. In practical applications of the comprehensive grey generating method, $x_{\min}$ is commonly defined as 0, and then α_l is equal to 0. Hence, $r_i(j) = \frac{x_i(j)}{x_{\max}}$ in the larger-the-better preprocessing. Similarly, in the smaller-the-better preprocessing, $r_i(j) = -\frac{x_i(j)}{x_{\min}} + 2$ when substituting $\alpha_s = -\frac{x_{\max}}{x_{\min}} + 2$ into Equation (10) (Lin *et al.* 2009; Zhang, Liu 2011).

This study integrates the lower limit (LL) and the upper limit (UL) in the larger-the-better preprocessing and the smaller-the-better preprocessing, respectively. The structures of the proposed larger-the-better preprocessing and the smaller-the-better preprocessing are shown in Figure 4(a) and 4(b), respectively. Equation (11) and Equation (12) define the larger-the-better preprocessing and the smaller-the-better preprocessing.

$$r_i^{(t)}(j) = \frac{x_i^t(j) - LL(j)}{x_{\max} - LL(j)}, \quad (11)$$

$$r_i^{(t)}(j) = \frac{UL(j) - x_i^{(t)}(j)}{UL(j) - x_{\min}}. \quad (12)$$

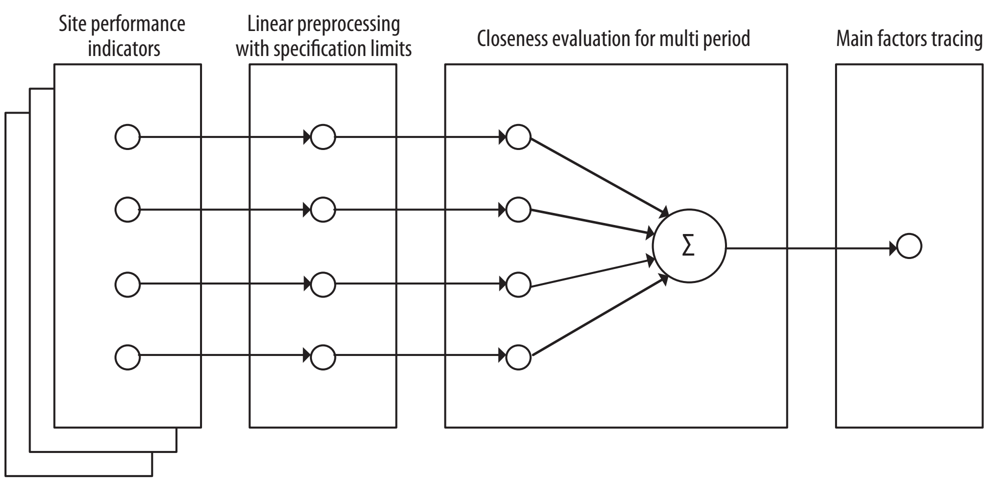

Fig. 3. The structure of the propose multi period evaluation model

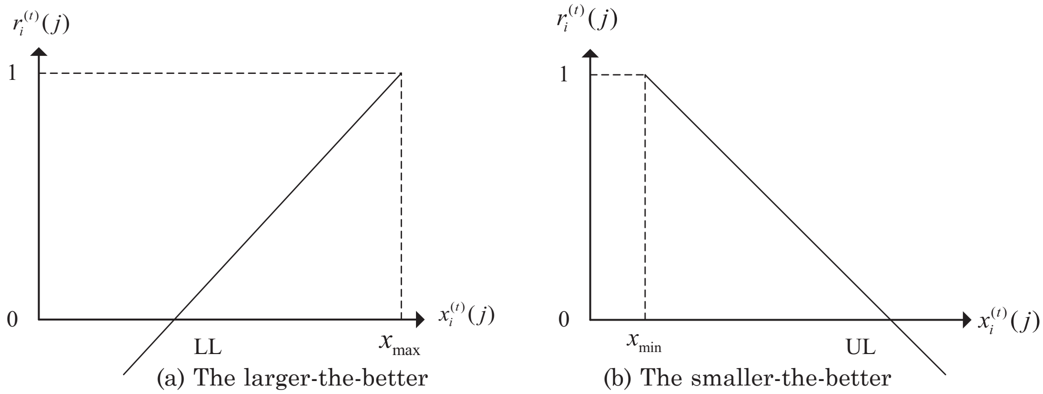

Fig. 4. Linear preprocessing method with specification limits

In Equations (11) and (12), $LL(j)$ and $UL(j)$ are the lower limit and the upper limit of the *j-th* performance indicator, respectively. As shown in Figure 4, the negative value might exist after preprocessing the raw datum. The negative value does not influence the following calculations and the final priority. Furthermore, the negative value can point out whether the measured value is out of the specification limit. The fuzzy Delphi method is used in this paper to calculate the cross points of lower limit or upper limit.

3.2. Site performance evaluation and tracing

After preprocessing $X^{(t)}$, the TOPSIS is used to calculate the closeness of site at the t-th period, $C_i^{(t)+}$. Then, the closeness of site at each period can be collected and the comprehensive evaluation result can be determined by using SN ratio. The number of periods depends on the control requirements. In this study, the current period is defined as $t = 0$, and the last period and the last two period are defined as $t = 2$ and $t = 3$, respectively.

In the evaluation of multi period performance, Equation (6) is used because the closeness $C_i^{(t)+}$ is belonged to the larger-the-better type. Therefore, the multi period performance evaluation of site, p_i, can be denoted as:

$$p_i = -10\log_{10}\left[\frac{\sum_{t=1}^{T}\frac{1}{\left(C_i^{(t)+}\right)^2}}{T}\right]. \quad (13)$$

In Equation (13), T is the considered number of periods. A stable and reliable result considering both the mean and the variance of the closeness can be obtained by Equation (13). Finally, the priority of sites can be rank by p_i, i.e., larger p_i means better performance.

This study also proposes a method to trace the main indices causing worse performance. Multi period measurements are also considered in the trace of main indices. Assume the preprocessed values of indices at each period in the worse site, R, to be:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1T} \\ r_{21} & r_{22} & \cdots & r_{2T} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mT} \end{bmatrix}.$$

R is composed of m indices and T periods. r_{jt} is the preprocessed value of the j-th evaluation indicator at the *t-th* period. However, the preprocessed value might be negative. Both the larger-the-better SN ratio and the smaller-the-better SN ratio will result in misjudgment when dealing with the negative values. Therefore, the nominal-the-best SN ratio is adopted in this study to trace the main indices. The multi period performance evaluation of indicator, p_j, can be defined as:

$$p_j = -10\log_{10}\left[\left(\bar{r}_{jt} - m\right)^2 + s_r^2\right]. \quad (14)$$

In Equation (14), the ideal of the processed value is equal to 1, i.e., $m = 1$. $\bar{r}_{jt}$ and s_r^2 are the mean and variance of r_{jt}, respectively. Similarly, larger p_j means better indicator. Therefore, the main indices resulting in worse performance are the indices with lower p_j.

4. ILLUSTRATIVE EXAMPLE

A real case of thirteen sites (S1 ~ S13) of a property company in Taiwan is adopted to demonstrate the feasibility and practicability of the proposed model. Twelve evaluation indices, shown in Table 1, were employed in the company to meas-

Table 2. Analysis of the fuzzy Delphi questionnaires

Dimension	Evaluation indicator	$\underline{x}$			$\overline{x}$			$u - L$	CP	$(M - m) - (u - L)$
		l	m	u	L	M	U			
General affair	Contract extension fee	–20%	–14.3%	–12%	–15%	–9.7%	–7%	3%	1.6%	–12.9%
	Property management fee	73%	76.5%	82%	80%	81.5%	85%	2%	2.9%	80.4%
	Grants application	6	7.7	11	10	10.8	15	1	2.2	10.2
	Data completeness	65%	67.7%	70%	67%	72.5%	75%	3%	1.7%	69.1%
	Financial structure	63%	66.6%	72%	68%	71.8%	77%	4%	1.2%	69.7%
Environment quality	Facilities maintenance and environment	75	78.1	82	80	82.6	85	2	2.4	80.8
	Burglar event	1	1.2	3	2	2.5	3	1	0.3	2.2
	Community empowerment	70	73.1	77	75	78.1	82	2	2.9	75.9
Personal quality	Service attitude	60	65.3	70	65	70.5	75	5	0.2	67.7
	Crisis management	70	75.2	80	76	80.1	85	4	0.9	77.8
	Dispute management	75	77.7	81	80	81.7	85	1	3.0	80.4
	Resident complaint	5	5.8	8	7	9.1	11	1	2.3	7.5

Table 3. Specification limits and features of indices

Dimension	Evaluation indicator	Specification limit		Feature
		LL	UL	
General affair	Contract extension fee	–12.9%	–	LTB
	Property management fee	80.4%	–	LTB
	Grants application	10.2	–	LTB
	Data completeness	69.1%	–	LTB
	Financial structure	69.7%	–	LTB
Environment quality	Facilities maintenance and environment	80.8	–	LTB
	Burglar event	–	2.2	STB
	Community empowerment	75.9	–	LTB
Personal quality	Service attitude	67.7	–	LTB
	Crisis management	77.8	–	LTB
	Dispute management	80.4	–	LTB
	Resident complaint	–	7.5	STB

ure and audit the site performance. Three period measurements (T = 3) of these thirteen sites are used in this study.

In the definition of specification limits, this study used the fuzzy Delphi questionnaire to interview twelve senior experts in the company. Experts were allowed to provide a possible region of the specification limit of each indicator. Table 2 shows the cross points of indices and Table 3 shows the specification limits (lower limit or upper limit) and features (nominal-the-best, larger-the-better, or smaller-the-better) of indices.

Table 4, Table 5, and Table 6 are the preprocessed data of the current period, the last period, and the last two period, respectively, by substituting the raw measurement data of the thirteen sites into Equations (10) or (11). Parts of preprocessed values are negative, meaning they are out of the specification limits and ought to be noticed.

After that, the preprocessed values and the weights of evaluation indices are substituted into Equation (4) to calculate the closeness of site at each period. The multi period performance evaluations of the sites are then calculated by Equation (13) and are shown in Table 7. To verify the effectiveness of the proposed evaluation model, the mean of multi period is also listed and compared the priority with p_i.

As mentioned above, most multi-attribute decision making methods (e.g., TOPSIS) can only deal with one-period decision making problems. In each period, as shown in Table 7, S4, S1, and S12 are the best sites in the first, second, and third periods, respectively. Although the average values of

Table 4. The first period preprocessed data

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
S1	1.00	0.48	0.71	0.54	0.33	1.00	1.00	0.80	1.00	0.30	1.00	0.45
S2	1.00	0.69	0.26	0.27	0.18	0.05	1.00	–0.76	0.59	–0.39	0.57	0.09
S3	0.61	–0.57	–0.03	–0.01	0.18	0.52	1.00	–0.17	–0.37	–0.81	0.79	0.82
S4	1.00	0.69	–0.18	0.45	0.33	–0.90	0.10	–0.56	0.32	0.72	1.00	0.64
S5	0.46	–0.46	0.12	0.08	0.10	–1.38	1.00	0.02	0.32	0.30	–0.50	0.45
S6	1.00	0.58	0.71	0.27	0.63	0.05	1.00	0.22	0.73	0.02	0.36	1.00
S7	1.00	1.00	1.00	0.17	0.40	–0.43	0.55	–0.95	1.00	–0.12	–0.07	0.82
S8	0.61	–0.46	0.26	1.00	0.93	0.29	1.00	–0.56	0.73	–0.39	–0.50	0.09
S9	1.00	0.16	–0.18	0.91	0.55	0.52	1.00	0.61	0.59	0.30	–0.29	0.45
S10	1.00	0.27	–0.03	0.45	0.10	–0.67	0.10	–1.15	0.32	0.44	–0.07	0.64
S11	1.00	0.48	0.12	0.27	1.00	0.52	1.00	–0.17	0.04	0.58	0.14	0.27
S12	0.23	–0.04	0.26	–0.10	0.25	–0.90	1.00	1.00	0.18	1.00	0.57	0.09
S13	1.00	0.69	0.41	0.08	0.40	–1.38	0.55	0.80	0.59	0.58	0.79	–0.09

Table 5. The second period preprocessed data

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
S1	1.00	1.00	0.66	0.49	0.56	0.09	1.00	0.51	0.68	1.00	0.79	0.45
S2	0.85	0.39	0.48	0.37	0.38	–0.36	1.00	0.76	0.89	0.76	0.57	1.00
S3	1.00	–0.06	0.14	0.24	0.30	–1.72	0.55	–0.70	1.00	–0.68	0.36	0.82
S4	0.46	0.70	0.31	0.37	0.21	–1.27	1.00	–0.21	0.25	0.52	0.79	0.09
S5	1.00	–0.06	0.31	0.11	0.65	–2.63	1.00	0.03	0.57	0.76	1.00	0.45
S6	1.00	0.70	0.66	0.24	0.38	0.09	0.55	–1.19	0.46	–0.20	0.14	0.64
S7	1.00	1.00	1.00	0.37	1.00	0.55	1.00	–1.43	0.25	–0.68	0.57	0.27
S8	1.00	–1.28	0.83	1.00	0.47	1.00	1.00	1.00	0.68	–1.16	–0.07	0.82
S9	1.00	–0.06	0.48	0.87	0.21	0.09	0.55	–0.21	0.79	0.52	–0.50	0.64
S10	1.00	0.09	–0.21	0.75	1.00	–0.36	1.00	0.03	0.57	0.76	0.57	0.27
S11	1.00	0.54	0.31	0.49	0.47	–0.82	1.00	–0.70	0.68	–0.68	0.79	0.09
S12	1.00	–0.37	0.48	0.37	0.38	–1.72	1.00	–0.46	0.46	–1.16	1.00	0.82
S13	0.61	0.70	0.31	0.75	0.30	–1.27	1.00	0.27	0.36	0.04	–0.07	0.27

Table 6. The third period preprocessed data

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
S1	1.00	0.85	0.47	0.32	0.47	–1.72	1.00	0.02	0.73	0.03	0.45	0.33
S2	1.00	0.09	0.74	0.55	0.65	–0.36	1.00	–0.17	1.00	0.42	0.73	0.55
S3	1.00	0.24	0.47	0.32	0.30	0.09	1.00	–0.56	0.86	–0.16	1.00	0.11
S4	1.00	1.00	1.00	0.66	0.38	1.00	–0.34	–0.95	0.45	–1.51	–1.46	0.78
S5	1.00	0.24	0.21	0.21	1.00	–3.09	1.00	–0.37	0.59	–0.35	–0.09	1.00
S6	1.00	0.39	0.74	0.32	0.47	–1.72	1.00	0.61	0.73	–0.74	–0.64	0.55
S7	0.61	0.24	0.74	0.66	0.65	–2.63	0.55	0.80	0.45	0.03	–0.37	0.11
S8	0.85	0.24	0.21	0.44	0.56	0.09	1.00	1.00	0.86	0.23	–0.92	0.78
S9	0.07	–0.52	0.47	0.66	0.38	1.00	1.00	–0.76	0.18	0.61	–0.09	0.55
S10	0.23	0.09	0.21	1.00	0.47	–3.09	0.55	0.41	0.59	0.42	0.18	0.33
S11	1.00	0.24	–0.05	0.66	0.65	0.09	1.00	0.02	0.04	0.81	–0.37	1.00
S12	1.00	0.24	0.21	0.55	0.56	–0.36	1.00	–0.37	0.86	1.00	0.18	0.78
S13	1.00	0.85	1.00	0.44	0.12	–2.63	1.00	–0.76	1.00	0.03	0.45	0.55

Table 7. Multi period evaluations of the sites

	$C_i^{(1)+}$	$C_i^{(2)+}$	$C_i^{(3)+}$	Mean	p_i	Priority by mean	Priority by p_i
S1	0.687	0.822	0.646	0.718	–3.009	1	1
S2	0.421	0.790	0.769	0.660	–4.739	2	3
S3	0.398	0.382	0.641	0.474	–7.159	12	11
S4	0.730	0.659	0.235	0.541	–8.702	9	12
S5	0.421	0.729	0.517	0.556	–5.743	8	8
S6	0.578	0.481	0.365	0.474	–6.941	11	10
S7	0.472	0.434	0.517	0.474	–6.542	10	9
S8	0.300	0.295	0.525	0.373	– 9.422	13	13
S9	0.501	0.554	0.656	0.570	–5.039	6	5
S10	0.528	0.719	0.654	0.634	–4.184	3	2
S11	0.593	0.425	0.673	0.564	–5.474	7	7
S12	0.650	0.391	0.777	0.606	-5.460	4	6
S13	0.630	0.490	0.645	0.588	–4.814	5	4

Table 8. The main indices tracing results

Dimension	Evaluation indicator	r_{j1}	r_{j2}	r_{j3}	p_j	Priority
General affair	Contract extension fee	0.040	0.065	0.055	0.475	5
	Property management fee	–0.029	–0.081	0.015	–0.280	10
	Grants application	0.012	0.037	0.009	0.170	7
	Data completeness	0.063	0.063	0.028	0.454	6
	Financial structure	0.077	0.039	0.046	0.481	4
Environment quality	Facilities maintenance and environment	0.007	0.025	0.002	0.100	9
	Burglar event	0.054	0.054	0.054	0.482	3
	Community empowerment	–0.017	0.030	0.030	0.122	8
Personal quality	Service attitude	0.056	0.052	0.066	0.521	2
	Crisis management	–0.075	–0.219	0.043	–0.759	12
	Dispute management	–0.081	–0.012	–0.146	–0.683	11
	Resident complaint	0.013	0.120	0.114	0.730	1

the three periods can be calculated, the stability of performance still can not be revealed. Take the comparison of S2 and S10 in Table 7 as an example. Although the multi period mean of S2 (0.660) is larger than that of S10 (0.634), the range of S2 (0.369) is double larger than that of S10 (0.191), meaning the performance of S2 is less stable. In the comprehensive consideration, the performance of S10 ought to be better than that of S2. In Table 7, the p_i value of S10 is larger than that of S2, demonstrating the priority by p_i is more reasonable. Also, as shown in Table 7, the worst three sites are sequentially S8, S4, and S3.

This study takes S8 as an example to trace the main indices resulting worse performance. Table 8 shows the preprocessed values of indices at three periods of S8, and the multi period performance evaluation of indicator (p_j) is also calculated by Equation (14). The priority of indices is ranked by p_j. As shown in Table 8, crisis management (I10), dispute management (I11), and property management fee (I2) have the lowest three p_j values, meaning they are the main indices needed to be improved.

5. CONCLUSIONS

From the results in this study, the following five conclusions can be drawn:

1. This study has adopted the site property management performance scale, the TOPSIS, and the SN ratio to build a multi period evaluation model. The proposed model not only can obtain a reliable result by consider-

ing the multi period evaluations, but also can trace the main indices resulting in worse performance in order to take further improvement actions.
2. The first contribution of the propose model is to consider the interested region of managers into the preprocessing method. The proposed linear preprocessing method with specification limits not only can avoid distorting the linear relationship of the raw data, but also can point out the differences of indices. The fuzzy Delphi method is used to define the reliable specification limits.
3. The second contribution is to propose a multi period evaluation method. The evaluation model is based on the larger-the-better SN ratio and the closeness of site at each period. The mean and variance of multi period closeness can be both considered to provide a more reliable result.
4. The third contribution is to propose a main indices tracing method. The tracing method is based on the nominal-the-best SN ratio and the preprocessed values of indices at periods. The nominal-the-best SN ratio is used to avoid misjudgments when using the larger-the-better SN ratio or the small-the-better SN ratio on negative values.
5. An illustrative example of real case is used to demonstrate the feasibility and practicability of the proposed model. Results show the proposed model can effectively deal with the multi period performance assessment problem and can be easily used in similar problems.
6. In the further research, the proposed model can applied to assess the residents' satisfaction degree, the quality management system audit, and the maturity of property management system etc. In the improvement of methodology, the weights of different periods can be considered in the future studies. If the performance of the latest periods are paid more attentions, the better method is to give larger weights on the recent periods.

REFERENCES

Chang, W. C. 2000. A comprehensive study of grey relational generating, *Journal of Grey System* 3: 53–62.

Chen, C. H.; Kao, H. S. 2009. The determination of optimum process mean and screening limits based on quality loss function, *Expert Systems with Applications* 36: 7332–7335. http://dx.doi.org/10.1016/j.eswa.2008.07.002

Chen, J. K.; Chen, I. S. 2010. Using a novel conjunctive MCDM approach based on DEMATEL, fuzzy ANP, and TOPSIS as an innovation support system for Taiwanese higher education, *Expert Systems with Applications* 37: 1981–1990. http://dx.doi.org/10.1016/j.eswa.2009.06.079

Chen, M. F.; Tzeng, G. H. 2004. Combining gray relation and TOPSIS concepts for selecting an expatriate host country, *Mathematical and Computer Modelling* 40: 1473–1490. http://dx.doi.org/10.1016/j.mcm.2005.01.006

Cho, Y. G.; Cho, K. T. 2008. A lossfunction approach to group preference aggregation in the AHP, *Computers & Operations Research* 35: 884–892. http://dx.doi.org/10.1016/j.cor.2006.04.008

Chung, S. H.; Lee, A. H. L.; Pearn, W. L. 2005. Analytic network process (ANP) approach for product mix planning in semiconductor fabricator, *International Journal of Production Economics* 96: 15–36. http://dx.doi.org/10.1016/j.ijpe.2004.02.006

Hsu, Y.; Lee, C.; Kreng, V. 2010. The application of fuzzy Delphi method and fuzzy AHP in lubricant regenerative technology selection, *Expert Systems with Applications* 37: 419–425. http://dx.doi.org/10.1016/j.eswa.2009.05.068

Hwang, C. L.; Yoon, K. P. 1981. *Multiple attribute decision making*. Berlin: Springer-Verlag. http://dx.doi.org/10.1007/978-3-642-48318-9

Ishikawa, A.; Amagasa, M.; Shiga, T.; Tomizawa, G.; Tatsuta, R.; Mieno, H. 1993. The max–min Delphi method and fuzzy Delphi method via fuzzy integration, *Fuzzy Sets and Systems* 55: 241–253. http://dx.doi.org/10.1016/0165-0114(93)90251-C

Janic, M. 2003. Multi criteria evaluation of high-speed rail, transrapid maglev, and air passenger transport in Europe, *Transportation Planning and Technology* 26: 491–512. http://dx.doi.org/10.1080/0308106032000167373

Kim, G.; Park, C. S.; Yoon, K. P. 1997. Identifying investment opportunities for advanced manufacturing systems with comparative-integrated performance measurement, *Internal Journal of Production Economics* 50: 23–33. http://dx.doi.org/10.1016/S0925-5273(97)00014-5

Kuo, Y. F.; Chen, P. C. 2008. Constructing performance appraisal indicators for mobility of the service industries using fuzzy Delphi method, *Expert Systems with Applications* 35: 1930–1939. http://dx.doi.org/10.1016/j.eswa.2007.08.068

Kwong, C. K.; Tam, S. M. 2002. Case-based reasoning approach to concurrent design of low power transformers, *Journal of Materials Processing Technology* 128: 136–141. http://dx.doi.org/10.1016/S0924-0136(02)00440-5

Lee, J. W.; Kim, S. H. 2000. Using analytic network process and goal programming for interdependent information system project selection, *Computers and Operations Research* 27: 367–382. http://dx.doi.org/10.1016/S0305-0548(99)00057-X

Leu, S. S.; Yang, C. H. 1999. A GA-based multicriteria optimal model for construction process under resource constraints, *Journal of Construction Engineering and Management* 125: 420–427. http://dx.doi.org/10.1061/(ASCE)0733-9364(1999)125:6(420)

Liao, C. N.; Kao, H. P. 2010. Supplier selection model using Taguchi loss function, analytical hierarchy process and multi-choice goal programming, *Computers & Industrial Engineering* 58: 517–577. http://dx.doi.org/10.1016/j.cie.2009.12.004

Lin, Y. H.; Lee, P. C.; Chang, T. P. 2009. Practical expert diagnosis model based on the grey relational analysis technique, *Expert Systems with Applications* 36: 1523–1528. http://dx.doi.org/10.1016/j.eswa.2007.11.046

Liu, H. T.; Wang, W. K. 2009. An integrated fuzzy approach for provider evaluation and selection in third-party logistics, *Expert Systems with Applications* 36: 4387–4398. http://dx.doi.org/10.1016/j.eswa.2008.05.030

Milani, A. S.; Shanian, A.; Madoliat, R. 2005. The effect of normalization norms in multiple attribute decision making models: a case study in gear material selection, *Structural Multidisciplinary Optimization* 29: 312–318. http://dx.doi.org/10.1007/s00158-004-0473-1

Noorderhaben, N. 1995. *Strategic decision making*. UK: Addison-Wesley.

Pan, N. S.; Liu, C. H. 2010. Property management performance evaluation system, *Journal of Property Management* 1: 1–14.

Saaty, L. T. 1980. *The analytic hierarchy process*. New York: McGraw-Hill.

Saaty, L. T. 1996. *Decision making with dependence and feedback: the analytic network process*. Pittsburgh: RWS Publications.

Srdjevic, B.; Medeiros, Y. D. P.; Faria, A. S. 2004. An objective multi-criteria evaluation of water management scenarios, *Water Resources Management* 18: 35–54. http://dx.doi.org/10.1023/B:WARM.0000015348.88832.52

Torfi, F.; Farahani, R. Z.; Rezapour, S. 2010. Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives, *Applied Soft Computing* 10: 520–528. http://dx.doi.org/10.1016/j.asoc.2009.08.021

Tseng, M. L.; Chiang, J. H.; Lan, L. W. 2009. Selection of optimal supplier in supply chain management strategy with analytic network process and choquet integral, *Computers & Industrial Engineering* 57: 330–340. http://dx.doi.org/10.1016/j.cie.2008.12.001

Wang, J. W.; Cheng, C. H.; Huang, K. C. 2009. Fuzzy hierarchical TOPSIS for supplier selection, *Applied Soft Computing* 9: 377–386. http://dx.doi.org/10.1016/j.asoc.2008.04.014

Wu, C. S.; Lin, C. T.; Lee, C. 2010. Optimal marketing strategy: a decision-making with ANP and TOPSIS, *International Journal of Production Economics* 127: 190–196. http://dx.doi.org/10.1016/j.ijpe.2010.05.013

Yang, T.; Chou, P. 2005. Solving a multiresponse simulation-optimization problem with discrete variables using a multi-attribute decision-making method, *Mathematics and Computers in Simulation* 68: 9–21. http://dx.doi.org/10.1016/j.matcom.2004.09.004

Yoon, K.; Hwang, C. L. 1985. Manufacturing plant location analysis by multiple attribute decision making: part I – single-plant strategy, *International Journal of Production Research* 23: 345–359. http://dx.doi.org/10.1080/00207548508904712

Zammori, F. A.; Braglia, M.; Frosolini, M. 2009. A fuzzy multi-criteria approach for critical path definition, *International Journal of Project Management* 27: 278–291. http://dx.doi.org/10.1016/j.ijproman.2008.03.006

Zhang, S. F.; Liu, S. Y. 2011. A GRA-based intuitionistic fuzzy multi-criteria group decision making method for personnel selection, *Expert Systems with Applications* 38: 11401–11405. http://dx.doi.org/10.1016/j.eswa.2011.03.012