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A novel hybrid MCDM approach for outsourcing vendor selection: A case study for a semiconductor company in Taiwan

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ABSTRACT

Outsourcing manufacturing is a trend in today's global business operations. Vendor selection is an essential factor affecting outsourcing operations performance and has been determined as a multiple criteria decision making (MCDM) problem. The purpose of this paper is to propose a novel hybrid MCDM technique to cope with the complex and interactive vendor evaluation and selection problem which can determine the structural relationships and the interrelationships amongst all the evaluation's dimensions and support the Analytic Network Process (ANP) method to arrange appropriate weightings to each dimension and criterion in the evaluation model by summarizing the opinions of the experts. Finally, the overall performance ranking of all alternatives can be obtained to assist the decision making. Taiwan semiconductor industry is the largest provider in worldwide market. It is vertically disintegrated and outsourcing is a main stream practice. Wafer-testing is a critical manufacturing step in the semiconductor supply chain that distinguishes whether the IC can meet the specifications. Consequently, it's crucial to establish a thorough model for selecting the wafer-testing vendors in order to achieve the success of the outsourcing operation. A case study of a Taiwan semiconductor company in selecting its wafer-testing outsourcing vendor by using the proposed MCDM technique is demonstrated to enhance the decision making quality. The results and proposed solution can be referred to by not only the semiconductor companies, but also other industries so that they can improve the vendor selection process in order to achieve a higher performance and satisfaction level.

1. Introduction

In the severe business competitiveness of today, outsourcing has become a main stream practice in global business operations (Bailey, Masson, & Raeside, 2002). Traditionally, outsourcing is an abbreviation for "outside resource using" (Arnold, 2000; Bühner & Tuschke, 1997; Quinn & Hilmer, 1994). By this means, companies release non-core business or processes to outside vendors, then the enterprise can focus on the most value-added and professional activities in the whole value chain (Lei & Hitt, 1995; Loh & Venkatraman, 1992; Quinn, 1999). The outsourcing items covered a wide range, including: R&D, design, manufacture, facility set up, marketing, and etc. The major benefits that enterprises outsource business to vendors are cost reduction, quality and service performance improvement (Bailey et al., 2002; Barthélemy, 2001; Sharpe, 1997).

In the outsourcing operation model, vendor selection is one of the critical factors affecting the final success. Therefore, the vendor selection issues has been widely studied and determined as a multiple criteria decision making (MCDM) issue. The papers also proposed some MCDM methods to cope with this topic including the Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA), Analytic Network Process (ANP) and extended fuzzy approaches (Chen, Lin, & Huang, 2006; Degraeve, Labro, & Roodhooft, 2000; Ha & Krishnan, 2008; Lee, 2009; Onut, Kara, & Isik, 2009; Shyur & Shih, 2006; Wu & Lee, 2007; Wu, Sukoco, Li, & Chen, 2009; Yang, Chiu, & Tzeng, 2008). The AHP is widely utilized in vendor selection problem, but has been recognized that is not suitable to solve the case that contains complex interacting evaluation criteria and dimensions due to each individual criterion is not always completely independent in the complicated evaluation model (Leung, Hui, & Zheng, 2003; Shee, Tzeng, & Tang, 2003; Wu &

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Lee, 2007). In order to better solve the above-mentioned problems, this paper proposes a hybrid novel MCDM technique that can provide a better decision making quality. There are two major differences of this paper. First, Warfield's Interpretive Structural Modeling (ISM) method is utilized to construct a relation map which can help to clarify the interrelations amongst the criteria and to apply this relation map to the ANP method for deriving the weighting of each criterion of the complex vendor selection problem. Second, ANP is employed to obtain the weightings which is able to overcome the problem of interdependence and feedback amongst criteria. Thus, the overall scores for each vendor in each criterion can be obtained and the selection decision can be made accordingly. This paper also conducted an empirical case study as an illustration to demonstrate how a Taiwan semiconductor company can implement this solution.

The Semiconductor industry has evolved along with the worldwide outsourcing trend and thereby transformed their manufacturing strategy, releasing many of the manufacturing steps to outsourced subcontractors (Frederix, 1996; OhUallachain, 1997). The semiconductor industry is now composed of independent IC design houses, wafer foundry fabrication, wafer-testing, and IC packaging. The wafer-testing step tests the function and performance of the ICs. If wafer-testing companies fail to distinguish between good and defective ICs, good ICs might be scrapped and cause money loss. An even worse scenario is when wafer-testing companies fail to detect defective ICs, then erroneously sending them for packaging and ultimately, delivery to customers. When this occurs, not only is packaging cost wasted, but even more importantly, the potential loss in reputation and then business is quite hazardous. Since Integrated Device Manufacturing (IDM) companies and IC design houses concentrate on their core business functions, wafer-testing outsourcing demand to professional wafer-testing houses is a mainstream and the market is increasing (Lee, 2006). Consequently, how to evaluate and select the most suitable wafer-testing subcontractor is crucial. Then reason to use Taiwan's semiconductor industry as an empirical case study is because Taiwan's semiconductor industry is considered a global paragon (Chu, Teng, Huang, & Lin, 2005). And Taiwan's professional wafer-testing houses, ASE, SPIL, KYEC, Ardentech and etc., have 60% of the worldwide market share (IDB, 2007). Through interviews with experts in the Taiwanese semiconductor industry we observed that the semiconductor companies tend to use the existing subjective experience for wafer-testing outsourcing vendor evaluation and selection. Therefore, setting up a thorough evaluation model, criteria and method for evaluating and selecting wafer-testing outsourcing vendors is a critical topic and we will demonstrate the proposed solution to better solve this problem.

The remainder of this paper is organized as follows: In Section 2, the related researches of vendor selection criteria are reviewed. Additionally, the evaluation dimensions and criteria are established from our conclusions. Section 3 is the research methods' introduction of ISM and ANP. Section 4 is the empirical case study taking a Taiwan wafer foundry fabrication company as an example for demonstrating the wafer-testing vendor evaluation and selection from the proposed model, procedure and method. The results of the empirical research are also analyzed. Section 5 is the conclusion of this research.

2. Vendor evaluation and selection issues

In this section, our research briefly introduces the study of vendor evaluation and selection through review of relevant academic papers in Section 2.1. In Section 2.2, we introduce the process of selecting the dimensions and criteria for semiconductor companies to evaluate and select their wafer testing outsourcing vendors.

2.1. Introduction of vendor evaluation and selection

Since outsourcing is main stream worldwide, vendor evaluation and selection are essential for the purchaser in achieving the final result at their aspired level in their service or product. If any one of the outsourcing vendors in the supply chain cannot fulfill the purchaser's requirements, it will impact the final operations' efficiency of the purchaser, and potentially even cause business loss. In order to ensure the performance of outsourcing vendors, the purchaser needs to establish a suitable framework to evaluate and select and its vendors. The suitable framework must embrace not only the highly relative criteria with the purchaser's satisfaction (Lee & Billington, 1992), but also the appropriate mathematical methodology. Degraeve, Roodhooft, and Doveren (2005) made a review of the vendor selection issues and they indicated that in the purchasing related literature and practice, the simple, subjective and incomplete approaches for vendor selection have been commonly used. The same phenomenon happens in the semiconductor industry. Degraeve et al. (2000) commented that in order to have better results with vendor evaluation and selection, a weighted scoring method has been applied in some cases. Weber, Current, and Benton (1991) had reviewed 74 articles on supplier selection criteria and methods over the last 30 years. It appears the linear weighting model was the most commonly utilized quantitative approach for this issue. In this approach, a weight is given subjectively for each criterion; and ultimately, the total score of a vendor is calculated by summing up all of its weighted scores. However, the shortcoming of the above methods is the personal bias due to the weightings being given subjectively. Some researches noticed the phenomena, and therefore, have suggested some mathematical approaches, such as AHP, ANP, DEA, PROMETHEE and extended fuzzy methods. Some selections were made by using the AHP method (Sarkis & Talluri, 2002; Ting & Cho, 2008; Weber & Current, 1993; Wu & Chien, 2008; Yahya & Kingsman, 1999). The AHP method has some fallible premises that the criterion of each layer is assumed to be independent of the other layers. However, in real business practice, it is common that problems are mutually, or recursively, related. The more problems and elements that exist, the more complicated the relationships will be in the evaluation model. Therefore, the AHP model is not very suitable in the complex vendor selection case (Leung et al., 2003; Shee et al., 2003; Wu & Lee, 2007). For instance, delivery is correlated with quality and service priority, therefore if a supplier has a poor in-line manufacturing quality, its delivery performance may be affected. Additionally, the AHP model cannot explain the interrelationships amongst the various dimensions or the criteria inside an evaluation model. However, the experts in the industry commented that causal interrelationships are the key of an evaluation model, since the users can utilize the interrelationships' results to have a clear understanding of how the different dimensions or criteria affect each other. The ANP method has been recognized as a more suitable solution to cope with complex and interacting problems (Meade & Presley, 2002; Sarkis & Talluri, 2002; Wu et al., 2009). Besides, the understanding of the interrelationships can also help the buyer to evaluate a vendor, as well as to build up improvement strategies to enhance the outsourcing performance effectively. Yang et al. (2008) conducted a research in order to establish a vendor selection model that embraces the analysis of causal relations inside the model.

2.2. Establishing an evaluation's dimensions and criteria

This section explains the procedures to establish the wafer-testing outsourcing vendor evaluation's dimensions and criteria through the literature review and interviews with experts in Taiwan semiconductor industry. In the past, companies tended to use a single index as their target for manufacturing performance, such as: output quantity, delivery achievement, abnormal rate, etc. However, a single index cannot represent the company's overall performance, nor can it be used to evaluate the performance of outsourcing. The research of Yahya and Kingsman (1999) reviewed the developmental history of vendor evaluation and selection criteria. Their research shows that Dickson (1966) was the pioneer to validate 23 criteria for assessing a vendor's performance. Skinner (1969) was the first to use the four dimensions of cost, quality, delivery and flexibility. This was done in order to evaluate the manufacturing performance of a company. Weber et al. (1991) reviewed 74 academic papers, analyzing the criteria used for vendor selection. They found that net price was the most discussed criterion, followed by delivery and quality based on Dickson's well known study. Many researchers afterwards also utilized these four dimensions, cost (price), quality, delivery and flexibility (service) in the research on outsourcing and vendor selection (Ha & Krishnan, 2008; Krajewski & Ritzman, 1998; Leong, Snyder, & Ward, 1990; Lin & Lee, 2005; Wu et al., 2009).

From the literature review, we collected usable dimensions and criteria to be used when evaluating and selecting an outsourcing vendor. In order to better determine the suitable dimensions and criteria of each dimension, this research further interviewed experts in the semiconductor industry to screen for the suitable dimensions and criteria, based on our literature review. Finally, by integrating them, this research then summarized and constructed an evaluation model with four dimensions and fourteen criteria that are most suitable. The four dimensions include: Delivery Management Capability, quality management capability, integrated service capability, and price. Regarding financial capability, experts in this industry stated that almost all companies set vendor financial capability as a must before vendor selection. Consequently, we won't put this criterion in the evaluation model. Under the four dimensions, there are 14 criteria. The dimension of Delivery Management Capability (*D*) includes three criteria: (1) accuracy of delivered contents; (2) on-time delivery; and (3) delivery adjustment flexibility. The dimension of Quality Management Capability (*Q*) includes four criteria: (1) correctness of testing data; (2) quality abnormal rate; (3) capability to prevent repeated error; and (4) error judgment rate. The dimension of Integrated Service Capability (*S*) includes four criteria: (1) response-time for customers' request; (2) efficiency of engineering support; (3) fulfilling customers' special requests; and (4) customer service for information platform. The dimension of Price (*P*) includes three criteria: (1) testing price; (2) compensation rate for broken wafers; and (3) acceptance criteria. These dimensions and criteria are listed below in Table 1. We utilized these dimensions and criteria to set up a vigilant evaluation model for evaluating and selecting the most suitable outsourcing vendor, which can then ensure the desired results, while preventing potential risks.

3. Research method

3.1. Interpretive structural modeling (ISM)

Interpretive structural modeling was proposed by Warfield (1974a, 1974b, 1976) as a computer assisted methodology (Agarwal, Shankar, & Tiwari, 2007; Huang, Tzeng, & Ong, 2005; Sharma, Gupta, & Sushil, 1995). It is used to derive an understanding of the interrelationships amongst complex elements, and allows a set of different and directly related elements to be structured into a comprehensive systemic model (Fontela, 2003). Mandal and Deshmukh (1994) utilized ISM to identify the interrelationships amongst criteria in a vendor selection problem. Therefore, this paper applies ISM to build a relation map to identify the independence or dependence of all criteria. The theory of ISM is based on discrete mathematics, graph theory, social sciences, group decision-making, and computer assistance (Warfield, 1974a, 1974b, 1976). The first step of ISM is to identify the variables relevant to the problems or issues. It then extends with a group problem-solving technique. A structural self-interaction matrix (SSIM) is then developed based on a pair-wise comparison of variables. The SSIM is formed by asking questions such as, "Will element e_i affect element e_j?" If the answer is yes, then $\pi_{ij} = 1$. If the answer is no, then $\pi_{ij} = 0$. SSIM can be described as below:

Table 1
The criteria for wafer test vendor selection.

Dimensions	Criteria	Explanation of the criterion
Delivery management capability (*D*)	1. Accuracy of delivered contents	Wafer-test vendors need to deliver correct quantity and part number to the customer
	2. On time delivery	Wafer-test vendors need to deliver tested wafers on time
	3. Delivery adjustment flexibility	Wafer-test vendors can have the flexibility to adjust the production priority and schedule according to customers' adjustment
Quality management capability (*Q*)	1. Correctness of testing data	Wafer-test vendors need to provide correct testing information and results to the customers
	2. Quality abnormal rate	The abnormal rate, including broken, scratched, data error, etc. wafers, during the wafer-test at vendor sites
	3. Capability to prevent repeated error	Wafer-test vendors need to have the capability to prevent repeated quality abnormal issue and improve their quality
	4. Error judgment rate	Wafer-test vendors should reduce their error judgment rate
Integrated service capability (*S*)	1. Response time for customers' request	Response time for vendors' response to customers' requests
	2. Efficiency of engineering support	Wafer-test vendors need to fulfill customers' engineering support demand, including testing program development, tester adjustment, and related engineering processes
	3. Fulfilling customers' special requests	Except the normal request from customers, wafer-test vendors should fulfill other special demands from them, such as manufacturing process priority change, special price request, change in the original delivery plan, extra engineering service or extra engineering resource to support a critical issue.
	4. Customer information service platform	The customer information system is an interface between the vendor and customer which can provide manufacturing status, delivery, and some related information immediately. This system should be very stable and easy to use.
Price (*P*)	1. Testing price	Testing price per wafer or per hour, and other related expense
	2. Compensation rate for broken wafers	The compensation rate for abnormal case or wafer damage
	3. Acceptance criteria	Reasonable acceptance criteria based on customers' requirements

$$D = \begin{array}{c} \\ e_1 \\ e_1 \\ \vdots \\ e_m \end{array} \begin{array}{c} \begin{array}{cccc} e_1 & e_2 & \cdots & e_n \end{array} \\ \begin{bmatrix} 0 & \pi_{12} & \cdots & \pi_{1n} \\ \pi_{21} & 0 & \cdots & \pi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{m1} & \pi_{m2} & \cdots & 0 \end{bmatrix} \end{array}$$

The e_i means the ith element. The π_{ij} means the interrelationship between the ith and the jth elements. D is an SSIM. After establishing the SSIM, we can then convert it into a reachability matrix. Its transitivity is then checked with Eqs. (1) and (2) (Huang et al., 2005):

$$M = D + I \tag{1}$$

$$M^* = M^k = M^{k+1},\ k > 1 \tag{2}$$

where $\boldsymbol{I}$ is the unit matrix, k denotes the powers, and $\boldsymbol{M}^*$ is the reachability matrix. Note that the reachability matrix is under the operations of the Boolean multiplication and addition (i.e. 1 · 1 = 1, 1 + 1 = 1, 1 · 0 = 0, 1 + 0 = 0 + 1 = 1, 1 · 0 = 0 · 1 = 0). For example:

$$M = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix},\ M^2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \tag{3}$$

3.2. The Analytic Network Process (ANP)

The ANP is the general form of the AHP (Saaty, 1980, 1996; Saaty & Vargas, 1998; Yu & Tzeng, 2006). The ANP was designed to overcome the problem of dependence and feedback amongst criteria (Yu & Tzeng, 2006). Therefore, the evaluation's results through the ANP will be closer to the real practice. The ANP has been used for MCDM to release the restrictions of the hierarchical structure. It has been applied to project selection (Lee & Kim, 2000; Meade & Presley, 2002), product planning, strategic decision making (Karsak, Sozer, & Alptekin, 2002; Sarkis, 2003), and optimal scheduling (Momoh & Zhu, 2003). The ANP is robust and is hence, a more suitable method for this kind of complex MCDM issue (Leung, Lam, & Cao, 2005). The advantages of the ANP are that it is not only appropriate for both quantitative and qualitative data types, but also, it can overcome the problem of interdependence and feedback amongst criteria. The following three steps are undertaken to evaluate the decision making problem with the ANP method (Saaty, 2006; Shyur, 2006; Shyur & Shih, 2006): (1) building the network hierarchical structure; (2) calculating the weighing of factors in each hierarchy; and (3) calculating the weighting of the whole hierarchical structure.

4. Empirical case study of the vendor evaluation and selection for wafer-testing outsourcing

In this section, we illustrate this novel hybrid evaluation and selection process by using an empirical case study in Taiwan's semiconductor industry as an example. There are four steps needed for this study. The first step is to construct the evaluation model from Section 2 by a literature review and interviews with the experts in Taiwan's semiconductor industry. Through this process, we obtained four dimensions and fourteen criteria which are suitable to evaluate a wafer-testing vendor. The second step is to distinguish the interrelationships amongst dimensions in the evaluation model by applying the ISM method, so that then a structural network relationship map (NRM) can be constructed accordingly. The third step is finding the weightings of each dimension in the evaluation model. The ANP is then utilized to derive the weightings, based on these interrelationships and the NRM, from the ISM step. The final step is to discuss and analyze the results of this case study. The research methods that were applied in this empirical case study are illustrated in the sub-sections below.

4.1. Background of the empirical study

The semiconductor industry is composed of independent IC design houses, wafer foundry fabrication, wafer-testing, and IC packaging. In this industry, Fabless IC design houses focus on circuit design, and then release wafers to wafer-testing companies for wafer sorting/testing (also referred to as *circuit probing*, or CP). More and more IDMs, IC design houses, and wafer foundry fabrication companies have been releasing their wafer-testing demand to professional wafer-testing houses to reduce their cost and investment in testing (Lee, 2006). Taiwan semiconductor industry has the important position in worldwide market and the wafer-testing outsourcing is a key operation in the manufacturing chain. The semiconductor companies need to outsource most of their wafer-testing operation to subcontractors and therefore the vendor evaluation and selection is crucial. So, this paper takes a case from Taiwan semiconductor industry to demonstrate the proposed vendor selection model and method. Due to the restrictions of the Non Disclosure Agreement (NDA), the real company names in this paper are replaced by codes. The company that needed to select the most suitable wafer-testing outsourcing vendor in this case study is a global, first tier wafer foundry fabrication company located in Taiwan, hereby referred to as "company *X*." Company *X* had five available and qualified wafer-testing vendors, hereafter referred to as companies *A*, *B*, *C*, *D* and *E*. These five wafer-testing vendors are all public open companies and dedicated for professional wafer-testing service. Company *X* had a new wafer testing outsourcing project and needed to select the most suitable outsourcing vendor amongst all the current five qualified vendors. In the past, company *X* had made their vendor selection based on existing personal experience. This research establishes a thorough model and procedure that enables the industry experts to enhance their decisions' quality and obtain the best performance from their outsourcing operations.

The interviews were conducted with 12 experts in company *X*, who were all to have more than 10 years experience in the wafer-testing field. They not only replied to the questionnaires for constructing this evaluation and selection model, but they also provided their professional knowledge and experience in wafer-testing and subcontractor management, along with an industrial perspective.

4.2. Distinguishing the interrelationships of the evaluation models by using the ISM technique

The four evaluation dimensions of wafer-testing outsourcing in this research include: (1) Delivery Management Capability (*D*); (2) Quality Management Capability (*Q*); (3) Integrated Service Capability (*S*); and (4) Price (*P*). The original interrelationships data amongst all the dimensions are listed in Table 2.

Setting the threshold value = 0.50 which represents that more than 50% of the experts determine the interrelationship is existent. If the value of the element inside the matrix is ⩾ 0.50, the value is

Table 2
Original interrelation matrix.

Dimensions	*D*	*Q*	*P*	*S*
Delivery management capability *(D)*	0.00	0.35	0.14	0.50
Quality management capability *(Q)*	0.82	0.00	0.44	0.74
Price *(P)*	0.79	0.38	0.00	0.76
Service *(S)*	0.41	0.85	0.38	0.00

Table 3
Interrelation matrix (*D*).

Dimensions	*D*	*Q*	*P*	*S*
Delivery management capability *(D)*	0.00	0.00	0.00	1.00
Quality management capability *(Q)*	1.00	0.00	0.00	1.00
Price *(P)*	1.00	0.00	0.00	1.00
Service *(S)*	0.00	1.00	0.00	0.00

Table 4
Matrix (*M*) of all dimensions.

Dimensions	*D*	*Q*	*P*	*S*
Delivery management capability *(D)*	1.00	0.00	0.00	1.00
Quality management capability *(Q)*	1.00	1.00	0.00	1.00
Price *(P)*	1.00	0.00	1.00	1.00
Service *(S)*	0.00	1.00	0.00	1.00

counted as 1. If the value of the element is < 0.50, the value is counted as 0. Then the interrelationships matrix (***D***) could be gained, and the matrix (***M***) could be gained, by using Eq. (1), as shown in Tables 3 and 4.

Finally, the reachability matrix can be obtained by using Eq. (2). The star (*) indicates the derivative relationship, which did not emerge in the original relation matrix. The correlations of every aspect are shown as Table 5 and Fig. 1.

From the empirical survey, Table 5 and Fig. 1, we discovered the interrelationships amongst all the dimensions in the evaluation model. From the Delivery Management Capability (*D*)'s viewpoint, it has a two-way inter-affection with the dimension of the Quality Management Capability (*Q*), and the Integrated Service Capability (*S*). Additionally, *D* is affected by the Price dimension (*P*). From the Quality Management Capability (*Q*)'s viewpoint, it has a two-way inter-affection with the dimensions of the Delivery Management Capability (*D*), and the Integrated Service Capability (*S*). In addition, *Q* is affected by the Price dimension (*P*). From the Integrated Service Capability (*S*)'s viewpoint, it has a two-way inter-affection with the dimensions of the Delivery Management Capability (*D*) and the Quality Management Capability (*Q*). Moreover, *S* is affected by the Price dimension (*P*). From Price *P's* viewpoint, this finding is interesting in that Price affects three other dimensions in the evaluation model. In fact, it has a causal relationship with the other three dimensions.

Table 5
Reachability matrix (M^*) of all dimensions.

Dimensions	*D*	*Q*	*P*	*S*
Delivery management capability *(D)*	1	1^*	0	1
Quality management capability *(Q)*	1	1	0	1
Price *(P)*	1	1^*	1	1
Service *(S)*	1^*	1	0	1

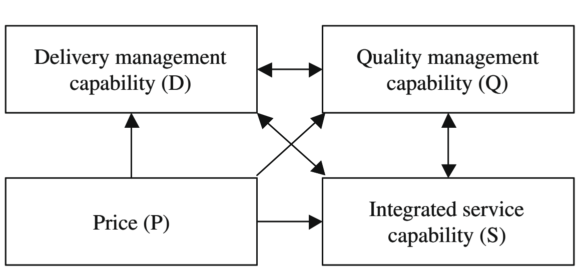

Fig. 1. Dimension interrelation structure.

4.3. Identifying the weighting by the ANP method

The ANP method was applied in this empirical research to generate a suitable weighting for each dimension within the evaluation. The ANP steps in this research are: (1) apply to the established framework the results from Section 2 and the ISM step; (2) design the questionnaires and survey; (3) establish the weightings by pair-wise comparison, establish the weightings of calculating factors, and establish the logical judgment consistency; (4) calculate the supermatrix; and, (5) determine the appropriate weighting decision (Shyur, 2006; Shyur & Shih, 2006).

Step 1: Establish the framework from Section 2Based on the literature review and the interviews with the experts in Taiwan's semiconductor industry, this research constructs an evaluation model for evaluating wafer-testing outsourcing vendors. The subordinate relationships, or the feedback from the dimensions themselves, are manifested as a one-way or two-way arrow, as shown in Fig. 1.

Step 2: Design the questionnaire and survey According to the evaluation framework, the experts judge the degree of the relative importance between dimensions and criteria. The evaluation results were obtained by collecting and analyzing questionnaires.

Step 3: Pair-wise comparison to determine relative importance of criteria The pair-wise comparison matrix shown in Table 6 can be derived from the questionnaires. The consistency index (*C.I.*) and consistency ratio (*C.R.*) were used to check the consistency of the experts' judgment. The *C.I.*'s value is defined as $C.I. = (\lambda_{\max} - n)/(n - 1)$, and the $\lambda_{\max}$ is the largest eigenvalue of the pair-wise comparison matrix. The *C.R.'s* value is defined as *C.R.* = *C.I./R.I.*(*R.I.*: random index). The *R.I.'s* value is decided by the value of *n*. As shown in Table 7, the *C.I.'s* and*C.R.'s* values are all less than 0.1, which means it matches the consistency test. Then, we calculated the eigenvalues and eigenvectors of each comparison matrix, and used the normalized eigenvector of the largest eigenvalue ($\lambda_{\max}$) as the weights of evaluation dimensions, as shown in Table 8.

Step 4: Calculate the super matrix In order to cope with the dependence relationship amongst dimensions and the feedback relationship within the dimension itself, the ANP method calculates factor weights by the super matrix, based on the NRM from the ISM step. The super matrix is composed by many sub-matrices, which are obtained from the pair-wise comparison matrix in Step 3. If no relative influence exists in the factors, the pair-wise comparison value of the sub-matrices is equal to zero. Taking Table 11 and Fig. 1 as an example, Price (*P*) and the Delivery Management Capability (*D*) have

Table 6
Pair-wise element comparison table.

Criteria	Q_1	Q_2	Q_3	Q_4
Correctness of testing data (Q_1)	1.00 [1]	0.80 [2]	1.16	0.99
Quality abnormal rate (Q_2)	1.26 [3]	1.00	1.46	1.24
Capability to prevent repeated error (Q_3))	0.86	0.69	1.00	0.85
Error judgment rate (Q_4)	1.01	0.81	1.18	1.00

Note 1: the parenthetic value 1.000 means Q_1 and Q_1 are equally important.
Note 2: the parenthetic value 0.800 means Q_1 has 0.8 times the degree of importance than Q_2.
Note 3: the parenthetic value 1.260 means Q_2 has 1.26 times the degree of importance than Q_1.

Table 7
The testing of consistency (C.I. and C.R. testing).

$C.I. = (\lambda_{max} - n)/(n-1)$	0.0017	$C.R. = C.I./R.I.$	0.0019
Threshold value	0.1	Threshold value	0.1

Table 8
The weights (pre and post normalization) in dimension *Q*.

Criteria	Pre-normalization	Post- normalization (%)
Correctness of testing data (Q_1)	0.480	0.242
Quality abnormal rate (Q_2)	0.602	0.304
Capability to prevent repeated error (Q_3)	0.413	0.208
Error judgment rate (Q_4)	0.486	0.245
SUM	1.981	1.000

Note: Pre- normalization means that the largest eigen values are used as the factor weights; Post- normalization means that the factor weights are used as the factor weights and the sum of factor weights is equal to 1.

no interrelationship, therefore the pair-wise comparison matrix results in zero matrices. The dimension of the Delivery Management Capability (*D*) has a recursive relationship itself, which is illustrated as a unit matrix. Taking the relationship from the Quality Management Capability dimension (*Q*) to the Delivery Management Capability dimension (*D*), as shown in Table 11, we put them into each individual pair-wise comparison matrices. After considering the weighting of each dimension, as shown in Table 9, the relative weightings of dimensions can then be calculated, as shown in Table 10. Then, by multiplying the relative weighting to the pre-weighted super matrix (Table 11), we could then derive the weighted super matrix, as shown in Table 12. By the transformation process, the dependence relationship can be converged through the procedures of limitation. The relative weights of factors can be obtained by $(M \times M)^{2k+1}$, where *k* is determined by assumption (as shown in Table 13).

Step 5: Determine the optimal solution The optimal solution can be judged by using the expectation index. The possible plan indexes are defined as DI_i, where $i = 1, 2, \ldots, m$, as defined by the Eq. (4).

$$DI_i = \sum_{j=1}^{n} w_j r_{ij} \quad (4)$$

Table 9
Relationship between aspect and weights.

Aspect	Weight
Delivery management capability (*D*)	0.261
Quality management capability (*Q*)	0.283
Price (*P*)	0.244
Integrated service capability (*S*)	0.211
SUM	1.000

Table 10
Relative weighted relationship.

Aspect	Proportion rate	Relative weighted coefficient (%)
D	*D/(D+Q+S)*	0.346
Q	*Q/(D+Q+S)*	0.375
S	*S/(D+Q+S)*	0.279
SUM		1.0000

where w_j is the relative weight of criteria *j*; r_{ij} is the fitness degree of the satisfaction of the *i*th possible plan under the *j*th evaluation dimension. The most desired level is A^*, $A^* = \{r_j^* | r_j^* = \max_{i=1,2,\ldots,m} r_{ij}; j = 1, 2, \ldots, n\}$; the optimal plan is A^{Best}, $A^{Best} = \{\max_{i=1,2,\ldots,n} DI_i | i = 1, 2, \ldots, n\}$. The gap between A^{Best} and A^* is what needs to be improved.

Saaty (1996) assumed the weightings of the main level is equal in the ANP, but this paper uses the pair-wise comparison method to obtain the weightings, which can accurately reflect the real situation more authentically. From the interrelationship structure as shown in Fig. 1, we discovered that the Price dimension (*P*) was independent, there was not any interrelation between the Price dimension (*P*) and others. The whole evaluation model could thus be divided into two main portions consequently; one was the "value related dimensions (*D*, *Q* and *S*)" (we set it as "*V*") and the other was the "price dimension (*P*)". From the surveyed interrelationships, the Price dimension (*P*) was a driver to the value related dimensions. Through the super matrix calculation, we obtained the weighting of each dimension of the value related dimensions, and the weighting of the Price dimension (*P*) was zero, as shown in Table 13. The weightings of the criteria in the Price dimension (*P*) were also obtained by the pair-wise comparison. All weightings in this evaluation model were combined by these two results, as shown in Table 14. In the value related dimensions, the Quality Management Capability (*Q*) has the highest weighting, 0.375. In the Price dimension (*P*), the criterion of testing price has the highest weighting, 0.422. From the weights, we also make a ranking for each criterion in each dimension which indicates the degree of importance from the questionnaire collection. After calculated all the weightings in the evaluation model through the ANP method, the completed wafer-testing outsourcing vendor evaluation and selection model can be fully established.

The final ranking of all alternatives (the 5 qualified vendors) are calculated by synthesizing the scores of each alternative under the 4 (*D*, *Q*, *S*, *P*) dimensions and 14 criteria. Because the "value related dimensions (*D*, *Q* and *S*)(*V*)" and the Price dimension (*P*) are determined as independent, we set an index, Overall Performance (*O.P.*), to measure the overall scores of all alternatives by combining the "value related dimensions (*D*, *Q* and *S*)(*V*)" and the Price dimension (*P*). The final ranking summary of all alternatives is listed in the Table 15.

4.4. Discussion and analysis

From the interrelation map from ISM (Fig. 1) and ANP calculation (Tables 14 and 15) of the "value related dimensions (*D*, *Q* and *S*) (*V*)", it implies that the Quality Management Capability (*Q*) is the major concern for company *X* in wafer-test outsourcing vendor selection which the weight is 0.346, followed by the Delivery Management Capability (*D*) (0.346) and the Integrated Service Capability (*S*) (0.279). In the Quality Management Capability (*Q*) dimension, the most concerned criterion is Quality Abnormal Rate (Q_2) (0.115). This indicates that the outsourcing quality is the major concern of the semiconductor company. It's also an important message to the wafer-test companies that if they want to win the business, the quality related operations need to be enhanced. The first priority of quality enhancement is to reduce the Quality Abnormal Rate (Q_2) since this is determined as the most critical criterion in this vendor selection case. The second important evaluation and selection dimension is the Delivery Management Capability (*D*) (0.346). The interesting finding is that the most concerned criterion in this dimension is the Accuracy of Delivered Contents (D_1) in stead of On Time Delivery (D_2). We interviewed

Table 11
Original super matrix.

		D			Q				P			S			
		D_1	D_2	D_3	Q_1	Q_2	Q_3	Q_4	P_1	P_2	P_3	S_1	S_2	S_3	S_4
D	D_1	1.000	0.000	0.000	0.383	0.451	0.381	0.477	0.256	0.313	0.329	0.280	0.267	0.243	0.411
	D_2	0.000	1.000	0.000	0.287	0.292	0.324	0.297	0.390	0.469	0.430	0.328	0.336	0.348	0.322
	D_3	0.000	0.000	1.000	0.330	0.257	0.295	0.225	0.354	0.219	0.241	0.392	0.397	0.409	0.267
Q	Q_1	0.242	0.214	0.198	1.000	0.000	0.000	0.000	0.223	0.166	0.253	0.275	0.235	0.232	0.294
	Q_2	0.304	0.309	0.315	0.000	1.000	0.000	0.000	0.318	0.444	0.316	0.293	0.305	0.310	0.284
	Q_3	0.208	0.214	0.227	0.000	0.000	1.000	0.000	0.176	0.235	0.152	0.191	0.209	0.201	0.194
	Q_4	0.245	0.263	0.259	0.000	0.000	0.000	1.000	0.283	0.155	0.279	0.241	0.250	0.257	0.229
P	P_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
	P_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
	P_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
S	S_1	0.235	0.247	0.208	0.159	0.174	0.200	0.193	0.229	0.175	0.210	1.000	0.000	0.000	0.000
	S_2	0.299	0.302	0.323	0.324	0.338	0.362	0.373	0.298	0.336	0.304	0.000	1.000	0.000	0.000
	S_3	0.292	0.333	0.361	0.341	0.354	0.324	0.325	0.322	0.372	0.376	0.000	0.000	1.000	0.000
	S_4	0.174	0.117	0.108	0.176	0.133	0.114	0.108	0.151	0.117	0.110	0.000	0.000	0.000	1.000

Table 12
Weighted super matrix.

		D			Q				P			S			
		D_1	D_2	D_3	Q_1	Q_2	Q_3	Q_4	P_1	P_2	P_3	S_1	S_2	S_3	S_4
D	D_1	0.346	0.000	0.000	0.132	0.156	0.132	0.165	0.067	0.082	0.086	0.097	0.092	0.084	0.142
	D_2	0.000	0.346	0.000	0.099	0.101	0.112	0.103	0.102	0.122	0.112	0.113	0.116	0.120	0.111
	D_3	0.000	0.000	0.346	0.114	0.089	0.102	0.078	0.092	0.057	0.063	0.136	0.137	0.141	0.092
Q	Q_1	0.091	0.080	0.074	0.375	0.000	0.000	0.000	0.063	0.047	0.072	0.103	0.088	0.087	0.110
	Q_2	0.114	0.116	0.118	0.000	0.375	0.000	0.000	0.090	0.126	0.090	0.110	0.114	0.116	0.106
	Q_3	0.078	0.080	0.085	0.000	0.000	0.375	0.000	0.050	0.067	0.043	0.072	0.078	0.075	0.073
	Q_4	0.092	0.099	0.097	0.000	0.000	0.000	0.375	0.080	0.044	0.079	0.090	0.094	0.096	0.086
P	P_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.244	0.000	0.000	0.000	0.000	0.000	0.000
	P_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.244	0.000	0.000	0.000	0.000	0.000
	P_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.244	0.000	0.000	0.000	0.000
S	S_1	0.066	0.069	0.058	0.045	0.049	0.056	0.054	0.048	0.037	0.044	0.279	0.000	0.000	0.000
	S_2	0.084	0.084	0.090	0.091	0.095	0.101	0.104	0.063	0.071	0.064	0.000	0.279	0.000	0.000
	S_3	0.081	0.093	0.101	0.095	0.099	0.090	0.091	0.068	0.079	0.079	0.000	0.000	0.279	0.000
	S_4	0.049	0.033	0.030	0.049	0.037	0.032	0.030	0.032	0.025	0.023	0.000	0.000	0.000	0.279

Table 13
Limited super matrix.

		D			Q				P			S			
		D_1	D_2	D_3	Q_1	Q_2	Q_3	Q_4	P_1	P_2	P_3	S_1	S_2	S_3	S_4
D	D_1	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126
	D_2	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109
	D_3	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111
Q	Q_1	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087
	Q_2	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
	Q_3	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079
	Q_4	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
P	P_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S	S_1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
	S_2	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092
	S_3	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093
	S_4	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037

the experts of company X for exploring the inner meaning of this phenomenon. After the discussion, we discovered that if the wafer-testing vendor shipped the wrong contents to the buyer, there would be some critical side effects and they also need to spend numerous efforts to solve the problem. The possible critical side effects include wrong shipment to the end customer which may lead to the critical intelligent property (IP) and product confidential information leakage issue, and also the further delivery delay since the logistic operation needs to be re-arranged. The mixed packing with wrong items also require specific and extra human and system efforts to verify the contents and all related documents. Therefore, the Accuracy of Delivered Contents (D_1) is critical to affect the efficiency of logistic related operations. In the Integrated Service Capability dimension (S), the most concerned criterion is Fulfilling Customers' Special Requests (S_3) (0.093). In order to better understand the inner meaning, we consulted the experts of company X for their comments. The reason we analyzed was that due to the wafer foundry companies are all pure manufacturing for customers' products, therefore they need to be very flexible to fulfill various requests from different customers. Consequently, as an

Table 14
Weights by using ANP and scores of all alternatives.

Value related dimension (V)	Weights by using ANP	Ranking of weights by using ANP	A	B	C	D	E
Delivery management capability (D)	**0.346**	**2**	**3.139**	**2.633**	**2.421**	**2.014**	**2.097**
Accuracy of delivered contents (D_1)	0.126	1	9.083	7.833	7.167	6.333	6.417
On time delivery (D_2)	0.109	3	9.167	8.000	7.250	6.333	6.583
Delivery adjustment flexibility (D_3)	0.111	2	9.000	7.000	6.583	4.750	5.167
Quality management capability (Q)	**0.375**	**1**	**3.100**	**2.757**	**2.592**	**2.458**	**2.419**
Correctness of testing data (Q_1)	0.087	3	8.917	8.417	7.750	7.667	7.500
Quality abnormal rate (Q_2)	0.115	1	8.000	7.250	6.500	6.333	6.000
Capability to prevent repeated error (Q_3))	0.079	4	8.167	6.750	6.583	5.917	6.083
Error judgment rate (Q_4)	0.094	2	8.083	7.000	6.917	6.333	6.333
Integrated service capability (S)	**0.279**	**3**	**2.510**	**2.045**	**2.015**	**1.639**	**1.736**
Response time for customers' request (S_1)	0.057	3	8.917	7.583	7.333	6.167	6.250
Efficiency of engineering support (S_2)	0.092	2	8.833	7.167	7.000	5.417	6.167
Fulfilling customers' special requests (S_3)	0.093	1	9.167	7.000	7.167	5.667	5.917
Customer information service platform (S_4)	0.037	4	9.000	8.083	7.667	7.000	7.000
Subtotal	1.000		**8.749**	**7.435**	**7.029**	**6.110**	**6.252**
Price (P)			**8.279**	**7.821**	**7.803**	**5.441**	**5.696**
Testing price (P_1)	0.422	1	7.833	7.583	7.667	4.417	4.583
Compensation rate for broken wafers (P_2)	0.336	2	8.500	7.750	7.833	6.083	6.333
Acceptance criteria (P_3)	0.242	3	8.750	8.333	8.000	6.333	6.750
Subtotal	1.000		**8.279**	**7.821**	**7.803**	**5.441**	**5.696**

Table 15
The final ranking of all alternatives.

	A	B	C	D	E
Value related dimension (V)					
ANP score	8.749	7.435	7.029	6.110	6.252
ANP rank	(1)	(2)	(3)	(5)	(4)
Price dimension (P)					
ANP score	8.279	7.821	7.803	5.441	5.696
ANP rank	(1)	(2)	(3)	(5)	(4)
Overall performance ($O.P.$)					
ANP score	8.511	7.626	7.406	5.766	5.967
ANP rank	(1)	(2)	(3)	(5)	(4)

Remark: The Overall Performance (O.P.) is set as $(V \times P)^{1/2}$.

outsourcing vendor of the wafer foundry company, she needs to be flexible as well to fulfill the various and numerous requirements from the wafer foundry company. In the Price dimension (P), the most concerned criterion is Testing Price (P_1) (0.422) which implies that the cost is still a critical concern in the wafer-test outsourcing vendor selection topic.

The final rank of the 5 qualified vendors shows that vendor A is the most preferred one for the wafer-test outsourcing demand of company X. It's interesting that vendor A has the highest score in both the "value related dimensions (D, Q and S) (V)" and the Price dimension (P) which is different from the traditional understanding of price and other dimensions. The Price dimension (P) contains the Testing Price (P_1), Compensation Rate for Broken Wafers (P_2) and Acceptance Criteria (P_3). We asked for the comments for the experts of company X, they explained that because vendor A had better engineering, technology and manufacturing capabilities, its overall production, operation efficiency and quality were better than its competitors. And as a result, vendor A could follow the tighter criteria in the Price dimension, including acceptance criteria and the compensation rate of broken wafers specifically requested by company X. Vendor A could accept and follow these two tighter price related criteria, which made the customer more satisfied with and more confident in the outsourcing vendor. In addition, company X was concerned more about the total cost of ownership (TCO), rather than the pure testing price. This process revealed that due to the higher production and operation performance of vendor A, company X could save extra and potential costs for dealing with abnormal quality issues, inputting engineering resources for failure analysis and conducting prevention activities, building inventory to avoid delivery delay, or even compensate for defected parts rejected and claimed by its end customers. Therefore, vendor A has the highest score in the rank in terms of "value related dimensions (D, Q and S) (V)", the Price dimension (P) and the Overall Performance ($O.P.$).

5. Conclusion

This paper proposes a novel hybrid method to cope with the problem of the different dimensions' interdependence and feedback in vendor selection problem. Although there are numerous supplier selection solutions available, but this proposed hybrid method can provide a better understanding of the interrelationship amongst evaluation and selection dimensions and solve a complex interacting vendor selection issue which can enhance the quality of decision making.

A case study of a Taiwan semiconductor company in selecting the most suitable wafer-test outsourcing vendor is implemented to demonstrate the procedure of the proposed hybrid method. It can provide informative and practical suggestions to semiconductor companies for evaluating and selecting their outsourcing partners. The decision maker can obtain a better understanding of not only the interrelationship in the selection model but also the importance ranking of each evaluation dimension and criterion. Therefore, the decision maker can obtain the ranking of all alternatives which can provide a better decision quality in vendor selection. This hybrid MCDM technique is valuable for not only the vendor selection in the wafer-testing field, but also other vendor selection issues of the semiconductor industry and, further, other industries and territories. Through this comprehensive, thorough and conscientious model and procedure, the buyers can thus achieve their aspired and desired level with their outsourcing operations.

References

Agarwal, A., Shankar, R., & Tiwari, M. K. (2007). Modeling agility of supply chain. *Industrial Marketing Management, 36*(4), 443–457.

Arnold, U. (2000). New dimensions of outsourcing: A combination of transaction cost economics and the core competencies concept. *European Journal of Purchasing and Supply Management, 6*(1), 23–29.

Bailey, W., Masson, R., & Raeside, R. (2002). Outsourcing in Edinburgh and the Lothians. *European Journal of Purchasing and Supply Management, 8*(2), 83–95.

Barthélemy, J. (2001). The hidden costs of IT outsourcing. *MIT Sloan Management Review, 42*(3), 60–69.

Bühner, R., & Tuschke, A. (1997). *Outsourcing. Die Betriebswirtschaft, 57*(1), 20–30.

Chen, C. T., Lin, C. T., & Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics, 102*(2), 289–301.

Chu, P. Y., Teng, M. J., Huang, C. H., & Lin, H. S. (2005). Virtual integration and profitability: Some evidence from Taiwan's IC industry. *International Journal of Technology Management, 29*(1-2), 152–172.

Degraeve, Z., Labro, E., & Roodhooft, F. (2000). An evaluation of vendor selection models from a total cost of ownership perspective. *European Journal of Operational Research, 125*(3), 4–58.

Degraeve, Z., Roodhooft, F., & Doveren, B. (2005). The use of total cost of ownership for strategic procurement: A company-wide management information system. *Journal of the Operational Research Society, 56*(1), 51–59.

Dickson, G. W. (1966). An analysis of vendor selection systems and decisions. *Journal of Purchasing, 2*, 5–17.

Fontela, E. (2003). The future societal bill: Methodological alternatives. *Futures, 35*(1), 25–36.

Frederix, F. (1996). Planning and scheduling multi-site semiconductor production chains: a survey of needs, current practices and integration issues. In *Proceedings of the conference on integration in manufacturing, Galway, Ireland* (pp. 107–116).

Ha, S. H., & Krishnan, R. (2008). A hybrid approach to supplier selection for the maintenance of a competitive supply chain. *Expert Systems with Applications, 34*(2), 1303–1311.

Huang, J. J., Tzeng, G. H., & Ong, C. S. (2005). Multidimensional data in multidimensional scaling using the analytic network process. *Pattern Recognition Letters, 26*(6), 755–767.

Industrial Development Bureau, Ministry of Economic Affairs (2007). Press release. http://www.moeaidb.gov.tw/external/ctlr?PRO=news.NewsView&id=169. Accessed 10.07.07.

Karsak, E. E., Sozer, S., & Alptekin, S. E. (2002). Product planning in quality function deployment using a combined analytic network process and goal programming approach. *Computers and Industrial Engineering, 44*(1), 171–190.

Krajewski, L. J., & Ritzman, L. P. (1998). *Operations management: Strategy and analysis* (5th ed.). Wokingham: Addison-Wesley Publishing Co..

Lee, A. H. I. (2009). A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Systems with Applications, 36*(2), 2879–2893.

Lee, H. L., & Billington, C. (1992). Managing supply chain inventory: Pitfalls and opportunities. *Sloan Management Review, 33*(3), 65–73.

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*(4), 367–382.

Lee, Y. C. (2006). Semiconductor industry prospect 2007. *Topology Research Institute Report, 23*, 2–14.

Lei, D., & Hitt, M. (1995). Strategic restructuring and outsourcing: The effect of mergers and acquisitions and LBOs on building firm skills and capabilities. *Journal of Management, 21*(5), 835–859.

Leong, G. K., Snyder, D. L., & Ward, P. T. (1990). Research in the process and content of manufacturing strategy. *International Journal of Management Science, 18*(2), 109–122.

Leung, L. C., Hui, Y. V., & Zheng, M. (2003). Analysis of compatibility between interdependent matrices in ANP. *The Journal of the Operational Research Society, 54*(7), 758–768.

Leung, L. C., Lam, K. C., & Cao, D. (2005). Implementing the balanced scorecard using the analytic hierarchy process and the analytic network process. *Journal of the Operational Research Society, 57*(6), 682–691.

Lin, L. Y., & Lee, W. F. (2005). The influences of outsourcing strategies and outsourcing management policies on manufacturing performances of petrochemical industry in Taiwan. *Fu Jen Management Review, 12*(3), 95–116.

Loh, L., & Venkatraman, N. (1992). Determinants of information technology outsourcing: A cross-sectional analysis. *Journal of Management Information Systems, 9*(1), 7–24.

Mandal, A., & Deshmukh, S. G. (1994). Vendor selection using interpretive structural modeling. *International Journal of Operations and Production Management, 14*(6), 52–59.

Meade, L. M., & Presley, A. (2002). R&D project selection using the analytic network process. *IEEE Transactions on Engineering Management, 49*(1), 59–66.

Momoh, J. A., & Zhu, J. (2003). Optimal generation scheduling based on AHP/ANP. *IEEE Transactions on Systems, Man, and Cybernetics – Part B: Cybernetics, 33*(3), 531–535.

OhUallachain, B. (1997). Restructuring the American semiconductor industry: Vertical integration of design houses and wafer fabricators. *Annals of the Association of American Geographers, 87*(2), 217–237.

Onut, S., Kara, S. S., & Isik, E. (2009). Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert Systems with Applications, 36*(2), 3887–3895.

Quinn, J. B. (1999). Strategic outsourcing: Knowledge capabilities. *Sloan Management Review, 40*(4), 9–21.

Quinn, J. B., & Hilmer, F. G. (1994). Strategic outsourcing. *Sloan Management Review, 35*(3), 43–55.

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

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

Saaty, T. L. (2006). Rank from comparisons and from ratings in the analytic hierarchy/network processes. *European Journal of Operational Research, 168*(2), 557–570.

Saaty, T. L., & Vargas, L. G. (1998). Diagnosis with dependent symptoms: Bayes theorem and the analytic hierarchy process. *Operations Research, 46*(4), 491–502.

Sarkis, J. (2003). A strategic decision framework for green supply chain management. *Journal of Cleaner Production, 11*(4), 397–409.

Sarkis, J., & Talluri, S. (2002). A model for strategic supplier selection. *Journal of Supply Chain Management, 38*(1), 18–28.

Sharma, H. D., Gupta, A. D., & Sushil (1995). The objectives of waste management in India: A futures inquiry. *Technological Forecasting and Social Change, 48*(3), 285–309.

Sharpe, M. (1997). Outsourcing, organizational competitiveness and work. *Journal of Labor Research, 18*(4), 535–549.

Shee, D. Y., Tzeng, G. H., & Tang, T. I. (2003). AHP, fuzzy measure and fuzzy integral approaches for the appraisal of information service providers in Taiwan. *Journal of Global Information Technology Management, 6*(1), 8–30.

Shyur, H. J. (2006). COTS evaluation using modified TOPSIS and ANP. *Applied Mathematics and Computation, 177*(1), 251–259.

Shyur, H. J., & Shih, H. S. (2006). A hybrid MCDM model for strategic vendor selection. *Mathematical and Computer Modeling, 44*(7-8), 749–761.

Skinner, W. (1969). Manufacturing-missing link in corporate strategy. *Harvard Business Review, 47*(3), 136–145.

Ting, S. G., & Cho, D. I. (2008). An integrated approach for supplier selection and purchasing decisions. *Supply Chain Management: An International Journal, 13*(2), 116–127.

Warfield, J. N. (1974a). Toward interpretation of complex structural modeling. *IEEE Transactions on Systems, Man, and Cybernetics, 4*(5), 405–417.

Warfield, J. N. (1974b). Developing interconnection matrices in structural modeling. *IEEE Transactions on Systems, Man, and Cybernetics, 4*(1), 81–87.

Warfield, J. N. (1976). *Societal systems: Planning, policy, and complexity*. New York: Wiley.

Weber, C. A., & Current, J. R. (1993). A multi-objective approach to vendor selection. *European Journal of Operational Research, 68*, 173–184.

Weber, C. A., Current, J. R., & Benton, W. C. (1991). Vendor selection criteria and methods. *European Journal of Operational Research, 50*, 2–18.

Wu, J. Z., & Chien, C. F. (2008). Modeling strategic semiconductor assembly outsourcing decisions based on empirical settings. *OR SPECTRUM, 30*(3), 401–430.

Wu, W. W., & Lee, Y. T. (2007). Selecting knowledge management strategies by using the analytic network process. *Expert Systems with Applications, 32*(3), 841–847.

Wu, W. Y., Sukoco, B. M., Li, C. Y., & Chen, S. H. (2009). An integrated multi-objective decision-making process for supplier selection with bundling problem. *Expert Systems with Applications, 36*(2), 2327–2337.

Yahya, S., & Kingsman, B. (1999). Vendor rating for an entrepreneur development programma: A case study using the analytic hierarchy process method. *Journal of the Operational Research Society, 50*, 916–930.

Yang, J. L., Chiu, H. N., & Tzeng, G. H. (2008). Vendor selection by integrated fuzzy MCDM techniques with independence and interdependence. *Information Sciences, 178*(21), 4166–4183.

Yu, R. C., & Tzeng, G. H. (2006). A soft computing method for multiple criteria decision making with dependence and feedback. *Applied Mathematics and Computation, 180*(1), 63–75.