An Application of Fuzzy Delphi and Fuzzy AHP on Evaluating Wafer Supplier in Semiconductor Industry

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Abstract: - Because of the pressure of globalization in the last two decades, professional services has become an important strategic decision so that supplier selection is a prime concern. In the semiconductor industry, the prior researches worked on analyzing and improving the process, and evaluating the equipment manufacturers. Therefore, being the semiconductor industry applying a wide huge of advanced technologies, wafer suppliers and foundry and DRAM manufacturers acquire a large volume of critical materials and components. Consequently, this study is to identify critical factors related to the wafer supplier selection. It also has become a new subject by how to prompt current position of semiconductor industry and their wafer supplier in Taiwan. Primary criteria to evaluate supplier selection is acquired by the literatures survey, wafer manufacturers' data and applying fuzzy Delphi method (FDM), and then fuzzy analytic hierarchy process (FAHP) is employed to calculate the weights of these criteria, so as to establish the fuzzy multi-criteria model of wafer supplier selection. The results indicated a greatest weight on the dimension of wafer supplier selection, and seven critical criteria related to wafer supplier selection were: (1) wafer quality, (2) delivery time, (3) service, (4) price, (5) process capability, (6) reputation, and (7) past performance.

Key-Words: - Wafer Supplier, Supply Chain, Semiconductor, Analytic Hierarchy Process (AHP), Fuzzy Delphi Method (FDM), Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Multi-Criteria Decision Making (FMCDM).

1 Introduction

In high capital investment semiconductor industry, a key to success and profits of the foundry firms and DRAM manufacturers is the ability to introduce innovative process, high productivity, and quality products ahead of its competitors. Consequently, they have needs and demand lower price to wafer materials with stable and higher quality, with advanced process capability with greater flexibility, and exact delivery with good after-sales service for their production facilities. For semiconductor industry is like a development paradigm industry. Therefore, it has become a new subject by how to prompt current position of semiconductor industry and their wafer supplier in Taiwan.

Being the semiconductor industry applying a wide huge of advanced technologies, wafer suppliers and foundry and DRAM manufacturers acquire a large volume of critical materials and components. To ensure long-term availability of these items at a competitive cost, manufacturers have to manage the risk and complexities of global sourcing in an efficient and effective manner (Chan and Chan, 2004). One main of aspects is to select the right sources of suppliers in the global business environment, with reducing the operational risks and costs. Since then, the semiconductor industry has combined a process within upstream and downstream cooperative manufacturers to become the whole semiconductor industrial chain. It is very important to select the component suppliers because they must link together closely within the product connects and interacts with surrounding components in a limited number of ways.

Concerning semiconductor industry, the prior researches worked on analyzing and improving the process, and evaluating the equipment manufacturers, etc. Today, the foundry and DRAM manufacturers would want to be successful and survival in the high competitive environment, they must have the strategies to build the industrial system linking with the upstream and downstream manufacturers, such as the wafer suppliers, IC (Integrated Circuit) test, IC packaging, and so on. In order to achieve this successful goal ahead of its competitors, the foundry and DRAM manufacturers need to identify and implement performance that are appropriate, valid, reliable, and measurable that fit their production processes criteria within whole semiconductor industry. Therefore, the foundry and DRAM manufacturers need to select the wafer suppliers carefully and successfully through low cost and high quality wafer under competitive operating environment (Weber et al, 1991). One of the most important decisions is to select a competent group of suppliers (Weber et al, 1991). In this perspective, they need index measures to evaluate, control, and improve production processes. The core purpose of this study is to find out a more complete and concerned collection of explanatory variables and identify critical factors of wafer supplier selection from the collections. Thus, we adopted a perspective of foundry and DRAM manufacturers to explore the supplier selection criteria when the manufactory chose the wafer suppliers.

In our research, the survey of studies is to identify critical factors related to the wafer supplier selection, and the collection of variables are divided into seven groups to serve as preliminary evaluation dimensions. Primary criteria to evaluate supplier selection is obtained by the literatures survey, wafer manufacturers' data and applying FDM, and then FAHP is employed to calculate the weights of these criteria, so as to establish the fuzzy multi-criteria model of wafer supplier selection. The selection criteria include characteristics of wafer quality, delivery time, service, price, process capability, reputation, and past performance Hence, the aims of this paper are: (1) to identify wafer manufacture to select and practices based on the industry's opinion, wafer manufactures' data, and literature reviews in supply chain, and (2) to built the actual selection criteria when manufacture makes decisions.

The questionnaire investigation with four stages was conducted in this study. At the first stage, according the literatures review and wafer manufacturers' data, we came up with more dimensions. And, we sought three industrial experts to evaluate and to select the some key dimensions, in order to let the dimensions converged that we used the triangulation on qualitative method. At the second stage, we designed the instruments to explore and extract potential variables related to wafer supplier selection. And, potential explanatory variables related to wafer supplier were obtained from literature survey based on the first-stage dimensions. Then, at the third stage, the questionnaire investigation of explanatory variables was conducted by FDM. The variables with more concerns by industrial experts' consensus served as primary evaluation criteria in wafer industry. At this stage, the questionnaire was designed in a fuzzy linguistic scale, and every expert rated the importance of individual criterion in the form of a triangular fuzzy number, and then they reached a consensus in determining the importance to serve as the primary evaluation criteria of wafer industry. At the fourth stage, the statistic results were provided to these experts and pair-comparison of all criteria was made, thus the weight of individual criteria is calculated by FAHP. Hence, the fuzzy multi-criteria model of wafer industry was established through the process of the experts' rating of the criteria.

The remainder of the paper is structured as follows. In Section 2, we discussed the literatures concerning our topic. Section 3 we described our methodology including choosing the experts and characteristics, survey design, and the application of FDM and FAHP. Finally, section 4 presented our final conclusions and suggestions.

2 Literature Review

2.1 Semiconductor Industry

In the early 1970's, Taiwan's government and local and foreign scholars realized that Taiwan should establish an export-oriented strategy for economic development, which should develop high-tech industries to sustain economic growth. They searched the no existing industry in Taiwan could lead the way to sustain economic growth for more than ten years. They recognized and anticipated that the high-tech industries were the future industries to the country. Hence, in order for the domestic industry to acquire the fundamental expertise required for developing high-tech, the government had to support the initial development of high-tech industries. The main high-tech industries were the IC industry and the semiconductor industry.

Due to the high risk, high competition, high investment, and high technology intensity of the IC industry, the semiconductor industry increased the speed of R&D and competitiveness for it. The IC industry and semiconductor industry supported Taiwan's high-tech industries in increasing its competitiveness in world markets has become the main focus at present. In semiconductor industry, the type of manufacturing can separate into three related markets, the market for original equipment manufacturers (OEM), the original design manufacturing (ODM), and own branding and manufacturing (OBM). However, in Taiwan, most of the semiconductor manufacturers are belong to the OEM. The OEM manufactories must base on the customers' demand to product and to ship the production, even if, to select the component suppliers

Since the mid-1980's, with the TSMC built to OEM model for the IC manufactured in the semiconductor industry fast changing the semiconductor operation, and many high-tech firms began to establish in Taiwan. This not only brought the high economics rate for the country but also changed the high-tech industrial chain for the world. Unfortunately, the predominance of small- and medium-sized firms in the industrial structure of the country may be a burden to developing high-tech sectors. In order to ahead of its competitors to satisfy the market demands, the foundry and DRAM manufacturers stress on the productive capability, such as low cost, high speed productivity, innovative process, product flexibility, and high yield, quality, and services. For these goals, the key successful factor is to integrate the semiconductor industrial chain. Then, in order to supporting the semiconductor industrial chain, the wafer suppliers have appeared in the early 1990s, which supplies the high quality and stable wafer materials for the foundry and DRAM manufacturers. At the same time, there are few academic researches in discussing the semiconductor supplier selection criteria, especially to evaluate the wafer suppliers.

The wafer component market is similar to the primary market for the computer industry, while the related, which is characterized by a higher degree of competition. Hence, wafer supplier selection not only plays an important role in semiconductor industry chain due to increasing the quality and service but also is a critical in building and maintaining competition for the foundry and DRAM manufacturers.

2.2 Relative Criteria of Supplier Selection

To analyze the criteria and measuring in performance of suppliers has been the focus of many researchers and practitioners since Dickson (1966) and Weber et al. (1991). More firms pay attention to the evaluation and selection between suppliers (Barbarosoglu and Yazgac, 1997; Chan and Chan, 2004; Choi and Hartley, 1996; Ellram, 1990; Swift, 1995; Weber et al., 1991; Weber and Ellram, 1993). To manufacturer, the selection and evaluation is one of the most critical activities by which to attempt to achieve positional competitive advantage. Today, from a managerial point of view, a lot set of supplier selection criteria have to be identified in any industry. Regarding the supplier selection criteria literatures, many researchers have studied and addressed the supplier selection criteria in many industries (i.e. Barbarosoglu and Yazgac, 1997; Chan and Chan, 2004; Choi and Hartley, 1996; Dickson, 1966; Dulmin and Mininno, 2003; Ellram, 1990; Swift, 1995; Watts, Kim, and Hahn, 1992; Weber et al., 1991; Weber and Ellram, 1993).

The firms must usually trade off to select the supplier among the existing various criteria. In prior researches, Dulmin and Mininno (2003) considered the supplier selection based on cost and supplier's ability to meet quality requirements and delivery schedule. Dickson (1966) studied and analyzed the vendor selection systems and decisions, and posited the 23 criteria to select the suppliers. Based on the Dickson's research (1966), Weber et al. (1991) analyzed and summarized the literatures of supplier choice, and addressed 11 criteria factors (quality, delivery, net price, geographical location, production facilities and capacity, technical capability, attitude, management and organization, packaging, operational controls, and repair service) to select vendor of just-in-time systems. In linking purchasing to corporate competitive strategy, Watts et al. (1992) posited 8 criteria (process capability, product capability, operation capability, management capability, technology, quality, delivery, and cost) to select supplier. Leong, Snyder, and Ward (1990) expanded the number of generic capabilities to five criteria (cost, delivery performance, quality, flexibility and innovation). Swift (1995) analyzed 21 instruments and extracted the items to 5 criteria factors (product, availability, dependability, experience, and price) to evaluate the supplier. Choi and Hartley (1996) explored the supplier selection practices and extracted 26 instruments to 8 criteria factors (finances, consistency, reliability, relationship, technological capability, flexibility, price, and service) to choose the supplier cross the supply chain. Chan and Chan (2004) studied and pointed out 6 criteria factors (cost, delivery, flexibility, innovation, quality, and service.) to evaluate suppliers in advanced technology industry. For interested readers, all of the supplier selection criteria of the literatures were summarized in Table 1.

In sum, Choi and Hartley (1996) considered supplier selection criteria differ among industries different layers levels of supply chain, direct suppliers, and indirect suppliers. Although supplier selection was an important strategic issue that has been explored by researchers (i.e. Barbarosoglu and Yazgac, 1997; Chan and Chan, 2004; Choi and Hartley, 1996; Dickson, 1966; Dulmin and Mininno, 2003; Ellram, 1990; Swift, 1995; Watts, Kim, and Hahn, 1992; Weber et al., 1991; Weber and Ellram, 1993) in many different topics and industries, the wafer supplier selection criteria used by the semiconductor industry in direct and indirect supplier firms were less well understood. We doubt the wafer supplier selection criteria may be less different with the prior researches. Hence, we investigated the semiconductor industrial information to evaluate the wafer supplier in practice. We gathered some wafer supplier evaluation criteria form three firms of foundry and DRAM manufacturers. These criteria were summarized: (1) quality, (2) delivery time, (3) service, (4) price, and (4) process capability. Therefore, we adopt the literatures, manufacturers' data, and industry experiences regarding semiconductor manufacturers' perspective to our study.

Table 1 Summary the supplier selection criteria literatures

Literatures	Supplier selection criteria factors
Dickson (1966)	Quality, Delivery, Performance history, Warranties and claim policies, Production facilities and capacity, Price, Technical capability, Financial position, Procedural compliance, Communication system, Reputation and position in industry, Desire for business, Management and organization, Operating controls, Repair service, Attitude, Impression, Packaging ability, Labor relations record, Geographical location, Amount of past business, Training aids, and Reciprocal arrangements.
Leong et al.(1990)	Cost, Delivery performance, Quality, Flexibility, and Innovation.
Weber et al. (1991)	Quality, Delivery, Net price, Geographical location, Production facilities and capacity, Technical capability, Attitude, Management and organization, Packaging, Operational controls, and Repair service.
Watts et al. (1992)	Process capability, Product capability, Operation capability, Management capability, Technology, Quality, Delivery, and Cost.
Swift (1995)	Product, Availability, Dependability, Experience, and Price
Choi and Hartley (1996)	Finances, Consistency, Reliability, Relationship, Technological capability, Flexibility, Price, and Service.
Chan and Chan (2004)	Cost, Delivery, Flexibility, Innovation, Quality, and Service.

2.3 FDM and FAHP

Reviewed the literatures (Chan and Chan, 2004; Chen, Tzeng, Tang, 2005; Cheng, Chen, Chuang; 2008; Dickson, 1966; Dulmin and Mininno, 2003; Narasimhan, 1983; Nydick and Hill, 1992; Swift, 1995; Weber et al., 1991) and summarized the existing approaches to supplier selection shows that these aim to fulfill a combination of objectives between qualitative and quantitative. Therefore, there is no straightforward methodology which can be applied to solve supplier selection especially when the different organizations have different qualitative requirements. The tools, FDM and FAHP, can take both perspectives into consideration. The methodology of combining the FDM and FAHP is a good candidate for these kinds of supplier selection problem that both qualitative and quantitative objectives have to be considered.

The role of decision-making has become more complicated today. And, the importance of decision-making model and experts' suggestion can be more emphasized and applied in various fields. Delphi method is a technique for structuring an effective group communication process by providing feedback of contributions of information and assessment of group judgments to enable individuals to re-evaluate their judgments. Since its development in the 1960s at Rand Corporation, Delphi method has been widely used in various fields. On the other hand, Delphi Method use crisp number and mean to become the evaluation criteria, these shortcomings might distort the experts' opinion.

In order to deal with the fuzziness of human participants' judgments in traditional Delphi method, Ishikawa et al. (1993) posited fuzzy set theory proposed by Zadeh (1965) into the Delphi method to improve time-consuming problems such as the convergence of experts' options presented by Hwang and Lin (1987). Fuzzy set theory is increasingly applied in many researches such as by Caballero et al.

(2004) and by Lin et al. (2006). Furthermore, because people are often uncertain in assigning the evaluation in crisp number, to overcome the problem, this study adopts the fuzzy linguistic scale.

The analytic hierarchy process (AHP) methodology was a systematic method developed by Satty (1980). It is a powerful and flexible method in solving complex, and multi-criteria decision problems. AHP method helps decision-makers' organize the critical components and aspects of a problem into a hierarchical structure similar to a family tree. By reducing complex decisions to a series of simple pair wise comparisons and rankings, then synthesizing the results, the AHP not only helps the analysts to arrive at the best decision, but also provides a clear rationale for the choices made. Cheng et al. (2008) employed the fourth party logistics using the concept of FAHP method to assist supply chain integration capabilities and information technology capabilities. Antón et al. (2004) and Oddershede et al. (2006) also employ the AHP method to solve their decision-making problems. Besides, due to the defect of traditional AHP application by Buckley (1985) such as the characteristics of subjectiveness, fuzziness, and imprecision, many researches incorporated the Fuzzy theory into the AHP method to improve its application (Cheng, Chen, Lee, 2006). Hence, AHP approach has been widely applied in various relative fields to solve the decision-making problems with multiple hierarchies under the situation of uncertainty.

FAHP method is adopted increasingly by researchers. Hsieh et al. (2004) employed fuzzy analytic hierarchy process (FAHP) method to solve the problem of planning and design tenders selection in public office building. And FAHP method was also applied in the research of Chen et al. (2005) to evaluate expatriate assignments. Thus, in this study, due to the fuzziness existed in the part of evaluation criteria, we decide to adopt the FDM to form the primary evaluation criteria of wafer supplier selection, and employ the FAHP to calculate the weight of individual criteria so as to establish the Fuzzy Multi-criteria Model of wafer supplier selection criteria.

3 Methodology and the Analysis of Results

3.1 Extracting Constructs and Designing the Survey

The survey methodology was used to gather the data and to build the wafer supplier selection criteria. Before designing the survey, we gathered the industrial evaluation criteria on wafer supplier from the foundry and DRAM manufacturers. The three firms indicated the quality, delivery time, service, price, and process capability were the index measurements. We summarized the industrial evaluation criteria and measurement index:

(1) Quality: IQA gate reject rate, supplier process capability, process quality performance, and supplier quality system.
(2) Price: net price, delivery term, and payment term.
(3) Delivery: lead time, on-time delivery, accuracy of delivered quantities, support of EDC, and Request for waiving or incidents of premium freight.
(4) Service: efficiency of reply and technical support.

Beside, according the literatures, we combined the industrial criteria of wafer supplier selection and prior researches in related or other arenas, and generalized 13 important constructs. After the stage, we selected three industrial experts (Mr. Tang, senior engineer in production Div., IMI; Mr. Lin, section manager in quality department, FST; and Mr. Chen, section manager in purchasing department, PSC.) who were rich experience related the wafer suppliers in the semiconductor industry to evaluate the constructs. We adopted the triangulation method to select the core constructs on qualitative research. Based the triangulation method, we extracted seven evaluation criteria which were wafer quality, delivery time, service, price, process capability, reputation, and past performance. The results were presented in Table 2, which also described the reputation and past performance appropriated for the wafer supplier selection.

Based the extracting constructs, we referred the related literatures to develop the instruments. A pre-test was performed with two expert academics and two Ph.D. students on a questionnaire consisting of 39 items of the survey instrument to consider improvement in its content and appearance. The responses suggested only minor cosmetic changes, and no statements were removed. After minor changes were made, and further review by three other industrial experts, the instrument was deemed ready to be sent to the main firms in order to gather data for building the wafer supplier selection criteria. A survey package, including a cover letter explaining the research objectives, the questionnaire, and a stamped, return-addressed envelope, was distributed to purchasing managers and practiced staffs of each participating firm. The respondents were asked to complete the all questionnaires and as well as on the overall appearance and content of the instruments. At the same time, we offered the gift coupons of five hundred NT dollars to appreciate the support.

Table 2 Core criteria of wafer supplier selection

Experts / Criteria	Mr. Tang	Mr. Lin	Mr. Chen	Result
Price	ˇ	ˇ	ˇ	○
Delivery	ˇ	ˇ	ˇ	○
Quality	ˇ	ˇ	ˇ	○
Business Relationship	ˇ			
Process Capability	ˇ	ˇ	ˇ	○
Past Performance	ˇ		ˇ	○
Guarantee and compensation			ˇ	
Reputation		ˇ	ˇ	○
Financial Situation	ˇ			
Ability to Process Improve			ˇ	
Service	ˇ	ˇ	ˇ	○
Production Control			ˇ	
Location	ˇ			

3.2 Survey Instruments

Our overall survey instrument was based on both past literature published surveys (Chan and Chan, 2004; Choi and Hartley, 1996; Dickson, 1966; Leong et al., 1990; Swift, 1995; Watts et al., 1992; Weber et al., 1991) and the industrial experiences. To consider the wafer supplier selection practices in semiconductor industry, we built on the supplier selection criteria of Chan and Chan (2004), Choi and Hartley (1996), Dickson (1966), Leong et al. (1990), Swift (1995), Watts et al. (1992), and Weber et al. (1991). We gathered and developed the instruments of supplier selection criteria from these different sources. All of instruments were distributed in 7 critical constructs, including quality, delivery time, service, price, process capability, reputation, and past performance. All of the instruments were represented in Table 3.

3.3 Choosing the Experts

This study focused on the analysis of evaluation criteria of wafer supplier selection. Thus, the experts chosen were the professionals in the arena related to our study with the experience of industrial experts. Besides, they should be rich working experience with the semiconductor industry and their positions were at least the rank of department managers in the department on purchasing or production. In general, the numbers of expert were from three to fifteen (Manoliadis, Tsolas, and Nakou, 2006). This study was sent out to nine industrial experts of foundry and DRAM manufacturers as the questionnaire subjects from the semiconductor industry in Taiwan, the name list as the TSMC, UMC, VIS, IMI, PSC, NTC, ProMOS, Winbon, and Rexchip.

Table 3 Wafer supplier selection instruments

No.	Content of constructs/instruments
Quality	
1	Formal quality department and affiliate
2	Internal quality audit system
3	Norm of quality standards
4	Returned rate for feed test
5	Process quality performance
6	Request rate for correction measures
7	Request rate after wafer used
8	Suppliers' quality system
Delivery Time	
9	Delivery lead time
10	Delivery time accuracy
11	Delivery quantity accuracy
12	Emergency delivery after order changed
13	Incident for over freight
Past Performance	
14	Production line operation in the past
15	Long-term revenue growth
16	Quality of records in the past
17	Long-term record prices
Reputation	
18	Supporting for manufacturer in the past
19	Long-term corporate identity and position
20	After-sales service in the past
21	Compensation for against the contract
22	Follow-up of abnormal counterpart of man-made
Service	
23	Supporting when abnormal process occurred
24	Returned rate for customer response
25	Complain process and responsibility
26	Ability to identify problems quickly
27	Ability to solve problems quickly
Price	
28	Satisfaction of purchasing cost
29	Company's payment
Process Capability	
30	Understanding semiconductor process technology
31	R&D speed in core technology
32	Systems integration capability
33	Manufactured automation capability
34	Considerations of machine and equipment safety
35	Process control capability
36	Production scale
37	R&D personnel quality
38	Process stability and incidence abnormal rate
39	Process R&D capability

3.4 Determining the Evaluation Criteria

3.4.1 Collecting the Experts' Opinions

At this stage, we designed the questionnaire in a 9-point fuzzy semantic differential scale of "absolutely important", "very important", "pretty important", "quite important", "no comment", "fairly unimportant", "quite unimportant", "very unimportant", and "absolutely unimportant". And, we asked the selected experts to answer instrument survey. The selected experts assigned a relative importance to every collected variable with respect to seven dimensions of quality, delivery time, service, price, process capability, reputation, and past performance in order to confirm critical constructs as the evaluation criteria of wafer supplier selection.

3.4.2 Applying the FDM to Select Critical Evaluation Criteria

At this stage, we used the FDM to select the critical evaluation criteria through the three step processes.

Step 1. Establishing the Triangular Fuzzy Function

All experts' estimations gathered by prior step were used to establish the triangular fuzzy function of each individual criterion through the process of FDM proposed by Ishikawa et al. (1993). The process of application was as follows:

(1) The elements of evaluation set were determined by expert questionnaires of bicycle supplier selection. Given a score of 100 and 0 to the traditional binary logics of "absolutely important" and "absolutely unimportant" respectively, the other elements of evaluation set were quantified objectively through the treatment of FDM.

(2) The questionnaires were designed for the elements of evaluation set other than "absolutely important" and "absolutely unimportant", and selected experts are invited to fill the quantitative score interval of every element in the evaluation set. The maximum of interval value was the experts' most optimistic cognition of the quantitative score for the element, and the minimum of interval value was the experts' most conservative cognition of the quantitative score for the element.

(3) Solving the minimum L, geometric mean M, and the maximum U of all experts' most optimistic cognition score for each individual element, along with the minimum l, geometric mean m, and the maximum u of all experts' most conservative cognition score for each individual element, respectively.

Triangular fuzzy number $A = (L, M, U)_{L\text{-}R}$ of all experts' most optimistic cognition for each individual element and triangular fuzzy number $a = (l, m, u)_{L\text{-}R}$ of all experts' most conservative cognition for each individual element were established respectively and illustrated in Figure 1.

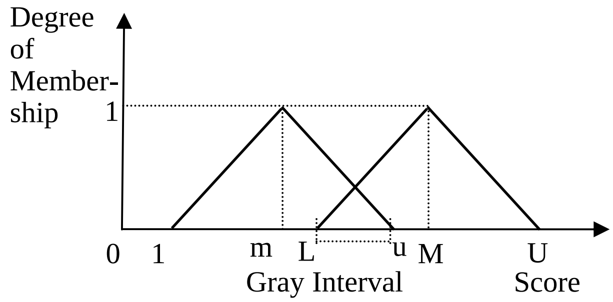


Fig. 1. Triangular fuzzy number of the most optimistic cognition and the most conservative cognition

Step 2. Analyzing the Value of Triangular Fuzzy Function

To organize and analyze the expert questionnaires collected, triangular fuzzy function with respect to every potential variable was established as represented in Table 4.

Step 3. Selecting Critical Evaluation Criteria

When selecting the evaluation criteria, it was generally considered important if relative importance is greater than 80%. It is for gaining the criteria, hence, we calculated the median of gray interval for every potential variable and took 85% as the threshold to filter out those variables with the score of less than 85% on the median of gray interval. Thus, important criteria consistently agreed by selected experts are accordingly obtained.

According to the above filtering treatment, we obtained from the collected experts' questionnaires, there are 39 important criteria commonly agreed by 7 experts. And, totally 14 instrument items were eliminated. They were listed as follows.

(1) Quality: No. 2: Internal quality audit system, No. 3: Norm of quality standards, and No. 5: Process quality performance.

(2) Delivery time: No. 9: Delivery lead time, No.10: Delivery time accuracy, and No.12: Emergency delivery after order changed.

(3) Past performance: No. 16: Quality of records in

the past.

(4) Reputation: No. 21. Compensation for against the contract.

(5) Service: No. 26. Ability to identify problems quickly and No. 27: Ability to solve problems quickly.

(6) Price: No. 28: Satisfaction of purchasing cost.

(7) Process capability: No. 35: Process control capability, No. 38: Process stability and incidence abnormal rate, and No. 39: Process R&D capability.

Table 4 The triangular fuzzy function with respect to every potential variable

Factor Dimensions	Potential Variables No.	The Most Conservative Cognition [min, med, max]	Gray Interval	The Most Optimistic Cognition [min, med, max]	The Median of Gray Interval	Results
Quality	1	[49, 70, 100]	[100, 58]	[58, 76.16, 100]	79	
	2	[71, 80.82, 92]	[92, 88]	[88, 93.81, 100]	90	V
	3	[69, 79.67, 92]	[92, 89]	[89, 94.34, 100]	90.5	V
	4	[67, 73.67, 81]	[81, 90]	[90, 94.87, 100]	84.5	
	5	[68, 79.09, 92]	[92, 87]	[87, 93.27, 100]	89.5	V
	6	[49, 63.77, 83]	[83, 55]	[55, 74.16, 100]	69	
	7	[61, 71.15, 83]	[83, 77]	[77, 87.75, 100]	80	
	8	[69, 79.67, 92]	[92, 76]	[76, 87.18, 100]	84	
Delivery Time	9	[55, 74.16, 100]	[100, 77	[77, 87.75, 100]	88.5	V
	10	[78, 86.08, 95]	[95, 88]	[88, 93.81, 100]	91.5	V
	11	[49, 66.78, 91]	[91, 58]	[58, 76.16, 100]	74.5	
	12	[55, 70.75, 91]	[91, 87]	[87, 93.27, 100]	89	V
	13	[59, 69.13, 81]	[81, 67]	[67, 81.85, 100]	74	
Past Performance	14	[61, 71.15, 83]	[83, 77]	[77, 87.75, 100]	80	
	15	[39, 56.2, 81]	[81, 46]	[46, 67.82, 100]	63.5	
	16	[68, 78.23, 90]	[90, 81]	[81, 90, 100]	85.5	V
	17	[58, 73.05, 92]	[92, 77]	[77, 87.75, 100]	84.5	
Reputation	18	[67, 73.67, 81]	[81, 77]	[77, 87.75, 100]	79	
	19	[58, 73.05, 92]	[92, 68]	[68, 82.46, 100]	80	
	20	[61, 71.15, 83]	[83, 67]	[67, 81.85, 100]	75	
	21	[55, 71.13, 92]	[92, 78]	[78, 88.32, 100]	85	V
	22	[69, 79.24, 91]	[91, 78]	[78, 88.32, 100]	84.5	
Service	23	[67, 78.08, 91]	[91, 78]	[78, 88.32, 100]	84.5	
	24	[67, 78.08, 91]	[91, 77]	[77, 87.75, 100]	84	
	25	[68, 79.09, 92]	[92, 77]	[77, 87.75, 100]	84.5	
	26	[68, 79.09, 92]	[92, 78]	[78, 88.32, 100]	85	V
	27	[68, 79.09, 92]	[92, 78]	[78, 88.32, 100]	85	V
Price	28	[67, 78.51, 92]	[92, 78]	[78, 88.32, 100]	85	V
	29	[55, 70.75, 91]	[91, 67]	[67, 81.85, 100]	79	
Process Capability	30	[55, 70.75, 91]	[91, 78]	[78, 88.32, 100]	84.5	
	31	[49, 66.78, 91]	[91, 58]	[58, 76.16, 100]	74.5	
	32	[49, 63.77, 83]	[83, 58]	[58, 76.16, 100]	70.5	
	33	[49, 66.78, 91]	[91, 58]	[58, 76.16, 100]	74.5	
	34	[49, 66.78, 91]	[91, 58]	[58, 76.16, 100]	74.5	
	35	[67, 78.51, 92]	[92, 90]	[88, 93.81, 100]	91	V
	36	[49, 63, 81]	[81, 58]	[58, 72.25, 90]	69.5	
	37	[49, 66.78, 91]	[91, 55]	[55, 74.16, 100]	73	
	38	[67, 78.51, 92]	[92, 88]	[88, 93.81, 100]	90	V
	39	[67, 78.51, 92]	[92, 88]	[88, 93.81, 100]	90	V

Note: Gray zones are the sum of weight that exceeds 85 percent. “V” is the more important criteria.

3.5 Applying the FAHP Method

We applied the FAHP to calculate the weights of individual dimension and individual criteria of bicycle supplier selection. The process was listed as follows.

Step 1. Building the Hierarchical Structure

First was to build the hierarchical structure. The hierarchical structure was described as follows. The goal was placed at the top of hierarchy, and the general criteria were placed at second level. The secondary sub-criteria with respect to each dimension were placed at third level.

In our case, the ultimate goal at the top level was “evaluation of wafer supplier selection”, and there were seven general criteria, “quality”, “delivery time”, “past performance”, “reputation”, “service”, “price”, and “process capability” at second level. As to each individual criterion, there were subordinate sub-criteria listed at third level. For example, fourteen sub-criteria including (1) quality: No. 2: Internal quality audit system, No. 3: Norm of quality standards, and No. 5: Process quality performance, (2) delivery time: No. 9: Delivery lead time, No.10: Delivery time accuracy, and No.12: Emergency delivery after order changed, (3) Past performance: No. 16: Quality of records in the past, (4) Reputation: No. 21. Compensation for against the contract, (5) Service: No. 26. Ability to identify problems quickly and No. 27: Ability to solve problems quickly, (6) Price: No. 28: Satisfaction of purchasing cost, and (7) Process capability: No. 35: Process control capability, No. 38: Process stability and incidence abnormal rate, and No. 39: Process R&D capability.

Step 2. Building the Pair-wise Comparison Matrix

By the second questionnaires gathered from selected experts, we obtained the relative importance of paired criteria factors at level n+1 under the evaluation of criteria at level n by individual experts’ opinions, and the pair-wise comparison matrix was accordingly conducted.

Step 3. Calculating Triangular Fuzzy Numbers

Concerning the relative importance of each individual evaluation construct in pair-wise comparison matrix, triangular fuzzy number was calculated to integrate all experts’ opinions. It can be used to present the fuzziness of all experts’ opinions with respect to the relative importance of paired factors.

$$\tilde{\alpha}_{ij} = \left(\alpha_{ij}, \beta_{ij}, \delta_{ij}\right)_{L-R} \quad \text{…………(1)}$$

Where

$\tilde{\alpha}_{ij}$: Triangular fuzzy number

α_{ij} : The minimum of the j-th subcriterion subordinated to the i-th general criterion

β_{ij} : The geometric mean of the j-th subcriterion subordinated to the i-th general criterion

δ_{ij} : The maximum of the j-th subcriterion subordinated to the i-th general criterion

L-R: Fuzzy interval of triangular fuzzy numbers

Step 4. Building the Fuzzy Positive Reciprocal Matrix

After triangular fuzzy numbers were solved to represent the fuzziness of experts’ opinions, the fuzzy positive reciprocal matrix A can be further built.

$$A = \left[\tilde{\alpha}_{ij}\right]$$
$$\tilde{\alpha}_{ij} = \left[\alpha_{ij}, \beta_{ij}, \delta_{ij}\right] \quad \text{……………….....(2)}$$

Step 5. Calculating the Fuzzy Weights of Fuzzy Positive Reciprocal Matrix

In our study, the method developed by Buckley (1985) and improved by Hsu (1998) was employed to calculate the fuzzy weights. This method was based on the experts’ precise value and synthesized the experts’ opinions with the geometric mean instead of the fuzzy numbers input directly by experts.

Thus, not only the consistency but also the concept of normalization was easily achieved. Through the following formulas, the positive reciprocal geometric mean Z_i of triangular fuzzy numbers and the fuzzy weight $\overline{W_i}$ can be obtained.

$$Z_i = \left[\tilde{\alpha}_{i1} \otimes \ldots \otimes \tilde{\alpha}_{in}\right]^{1/n}, \forall_i$$
$$\overline{W_i} = Z_i \otimes (Z_1 \oplus \ldots \oplus Z_n)^{-1} \quad \text{………………. (2)}$$
$$\tilde{\alpha}_1 \otimes \tilde{\alpha}_2 \cong \left(\alpha_1 \times \alpha_2, \beta_1 \times \beta_2, \delta_1 \times \delta_2\right) \text{………(3)}$$
$$\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 \cong \left(\alpha_1 + \alpha_2, \beta_1 + \beta_2, \delta_1 + \delta_2\right) \text{…….. (4)}$$
$$Z_1^{-1} = \left(\delta_1^{-1}, \beta_1^{-1}, \alpha_1^{-1}\right)_{L-R} \text{……………………(5)}$$
$$\tilde{\alpha}_1^{\frac{1}{n}} = \left(\alpha_1^{\frac{1}{n}}, \beta_1^{\frac{1}{n}}, \delta_1^{\frac{1}{n}}\right) \text{……………………….. (6)}$$

Step 6. Defuzzification

Since the weights of all evaluation criteria were fuzzy values, it was necessary to compute a non-fuzzy value by the process of defuzzification. In our study, the Centroid method was employed to defuzzy because of two reasons: (1) the Centroid method was widely used in relative literatures such as Klir and Yuan (1995), and (2) the solution can be figured out quite quickly. Through the following formulas, the defuzzified weight W_i can be obtained.

$$W_i = \frac{W_{\alpha i} + W_{\beta i} + W_{\delta i}}{3} \quad \ldots\ldots\ldots\ldots(7)$$

$W_{\alpha i}$: The right-end value of the fuzzy weight

$W_{\beta i}$: The value of the fuzzy weight with the degree of membership as 1

$W_{\delta i}$: The left-end value of the fuzzy weight

Step 7. Normalization

In order to effectively compare the relative importance among evaluation criteria, we normalized the obtained weights using the following formula.

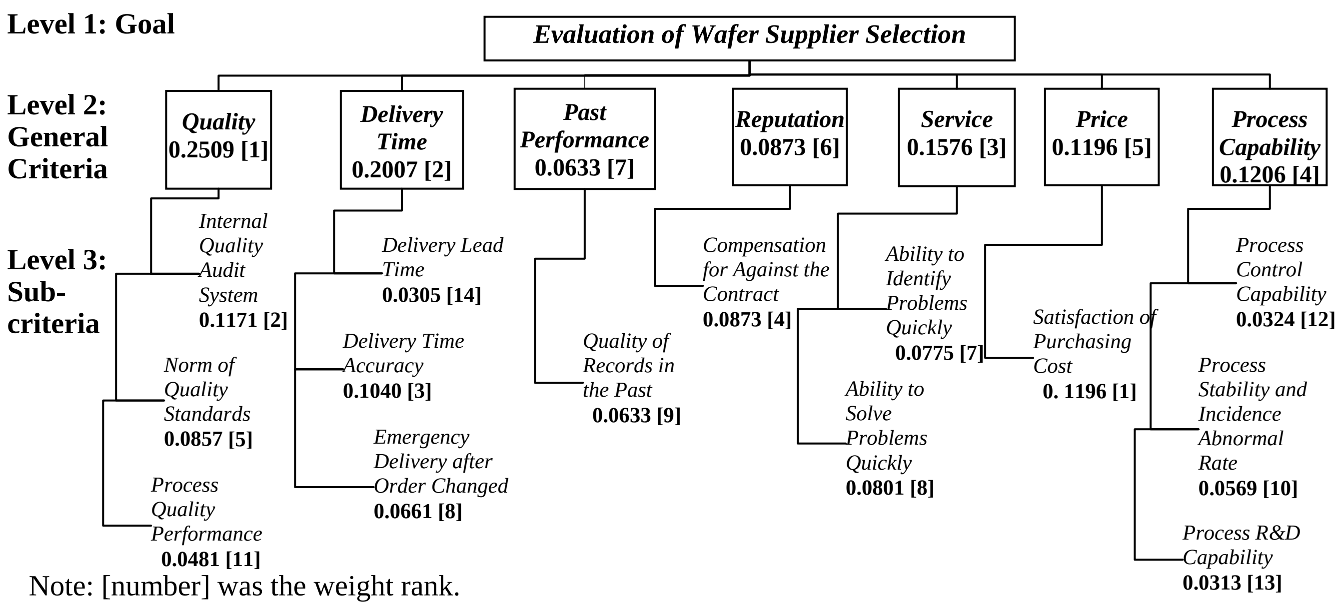
$$NW_i = \frac{W_i}{\sum_{i=1}^{i=n} W_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Step 8. Synthesis of Hierarchy

The weight of each individual evaluation criterion at bottom level can be obtained by the implementation of step 1 through step 7. And the weights of criteria or sub-criteria at upper level were the synthesis of the weights of their subordinations applying the following formula. Hence, the weights of all criteria at every level of hierarchy can be obtained.

$$NW_k = NW_i \times NW_{ip} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

The detail of hierarchical structure and results were illustrated as Figure 2.



Note: [number] was the weight rank.

Fig. 2. Hierarchy structure for evaluation criteria of wafer supplier selection

4 Conclusions and Suggestions

Suppliers are viewed as critical resources for the foundry and DRAM manufacturers in semiconductor industry. The manufacturers must manage to drive the maximum potential benefits in the supply chain, and how to select the supplier is one of the most critical tasks in supply management. Actually, to evaluate decision alternatives in a new and complex problem setting often involves subjective evaluation by a group of decision makers with respect to a set of qualitative criteria. The aim of the study is to offer an evaluation framework of wafer supplier, which built by the key criteria in the complex business environment. To address this decision problem, we have presented a FDM and FAHP to develop the criteria model in a fuzzy group MCDM approach with an effective to extend the concept of the degree of optimality. Adopting the FDM and FAHP model, the criteria for supplier selection are clearly identified and the problem is structured systematically. This helps decision makers to examine the strengths and weaknesses of the supplier by comparing them with respect to appropriate criteria and sub-criteria. In the result, we presented that there were fourteen sub-criteria in the seven dimensions of wafer supplier selection criteria, as shown in Fig. 2.

In our empirical study, we approved the wafer quality, delivery time, service, price, process capability, reputation, and past performance are the critical criteria to choose the wafer suppliers. However, the results indicate that there are different weight criteria between the industrial experiences and our results. Actually, the results show that the highest priority criteria are quality (weight, 0.25), delivery time (weight, 0.20), and service (weight, 0.16). The results also explained the industrial properties in semiconductor industry, which is high capital investment industry and continuity in line production for foundry and DRAM manufacturers. All of the machines and equipments are very expensive. And, many machines and equipments can process and produce mutil-processing layers. Based on the conductions, the managers of foundry and DRAM manufacturers are afraid of the pollution of particle, liquid photoresists, and metal in the line production, which they must avoid. Hence, the results of the wafer supplier selection criteria are most importance in the quality, delivery time, and service.

This study contributes to extract critical factors related to more complete dimensions rather than only cost ones on the selection of wafer supplier and to estimate the relative importance of these constructs in the industrial experts' views. It can be used to facilitate the decision-making process of evaluation of wafer supplier selection for foundry and DRAM manufacturers. Our results can be referred and extended in the future to develop more in-depth researches. Many fuzzy multi-attribute decision-making methods, like fuzzy DEA, fuzzy TOPSIS, and fuzzy ANP, can be used to build different evaluation models and then their results can be analyzed and compared.

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