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TFT-LCD 供應鏈之新產品開發及管理

中文摘要

在全球市場激烈競爭下，企業成功的關鍵因素在於如何滿足顧客需求，故一企業如何永續經營則考驗這企業內部之核心價值。然而，對於企業而言，核心價值不再僅僅是企業管理能力，更加考驗企業如何滿足市場所期待之產品研發能力。TFT-LCD 產業為目前台灣最亮麗的產業之一。隨著全球 TFT-LCD 產業邁入成熟階段，未來將面臨劇烈之市場競爭及價格割喉戰。台灣 TFT-LCD 製造之競爭優勢源於低成本、高品質、具彈性、相關產業之專業技術與完整的群聚供應鏈等。然而在全球競爭環境下，企業生存與成功之關鍵在於如何因應市場快速變化與顧客需求的不確定性，許多企業也都紛紛了解到，新產品開發(NPD)對企業生存極為重要。因此，新產品開發將是保持競爭優勢並維持企業長期利潤之首要關鍵，故在產品設計與製造上必須滿足顧客需求之產品品質及功能。因此，本研究結合品質機能展開(QFD)與模糊網路分析法(FANP)以解決 TFT-LCD 製造商於新產品開發階段所面臨之問題。專家的主觀判斷中，往往無法處理過多因子之比較，故本研究先運用模糊德爾菲(FDM)篩選出關鍵之因子。為處理模糊語意及不確定因素，以及因子間之相互依存關係，本研究提出之架構結合了 QFD 及 FANP 二種方法以協助設計人員利用系統化之模式於新產品開發上。然而，一項產品之開發需要有良好的前置規劃外，更需考量原物料品質之重要性，故供應商合作與選擇即為相當重要之決策。本研究延續新產品開發架構，運用模糊分析網絡程序(FANP)與利益、機會、成本與風險(BOCR)建立可靠度較佳之供應商選擇，以利決策者做為參考之依據。

關鍵詞：新產品開發(NPD)，品質機能展開(QFD)，模糊網路分析法(FANP)， TFT-LCD，利益、機會、成本與風險(BOCR)，模糊德爾菲(FDM)。

New product development and management in TFT-LCD supply chain

ABSTRACT

Global competitiveness has become the biggest concern of manufacturing companies, especially in TFT-LCD industries. However, as the global TFT-LCD industry enters the mature stage, an extremely competitive and cost-cutting war is foreseeable. While providing the products with a lower cost, better quality at the right time and place is important for Taiwan's TFT-LCD manufacturers, new product development (NPD) is essential to maintain a competitive edge and to make a decent profit in a longer term. Thus, the introduction of successful new products is a source of new sales and profits and is a necessity in the intense competitive international market. After a product is developed, a firm needs the cooperation of upstream suppliers to provide satisfactory components and parts for manufacturing final products. Therefore, the selection of suitable suppliers has also become a very important decision. In this research, a model that incorporates quality function deployment (QFD) and fuzzy analytic network process (FANP) is built to solve the NPD problem in TFT-LCD manufacturing. Since people are not willing and capable to handle comparisons properly when there are too many factors, fuzzy Delphi method (FDM) is used first to limit the number of factors included in the model. In considering the impreciseness and vagueness in human judgments and information, and the interrelationship among factors, a QFD model incorporated with FANP is constructed to facilitate the NPD process. In addition, an analytical approach is proposed to select the most appropriate critical-part suppliers in order to maintain a high reliability of the supply chain. A fuzzy analytic network process (FANP) model, which incorporates the benefits, opportunities, costs and risks (BOCR) concept, is constructed to evaluate various aspects of suppliers. The proposed model is adopted in a TFT-LCD manufacturer in Taiwan in evaluating the expected performance of suppliers with respect to each important factor, and an overall ranking of the suppliers can be generated as a result.

Keywords: New product development (NPD); Quality function deployment (QFD); Fuzzy analytic network process (FANP); TFT-LCD; Fuzzy Delphi method (FDM); Supplier selection; Benefits, opportunities, costs and risks (BOCR)

目　錄

圖 目 錄

表 目 錄

1. Introduction

Under a globally competitive business environment, technological innovation and satisfaction of customer needs are the keys to survival and success for firms, especially for TFT-LCD firms. Many companies realize that the emphasis on new products as a source of new sales and profits is a necessity in the intense competitive international market. Since poor product definition commonly leads to product failure in the marketplace or extended product development time, companies need to consider issues such as performance, aesthetics, delivery, quality and cost in developing their products. They must know the wants (like-to-have), needs (must-have), and desires (wish-to-have) of their customers as completely as possible (Ho et al., 1999), and design and manufacture products efficiently at a competitive cost within a short period of time over those offered by competitors (Chen et al., 2004). In addition, the selection of a supplier for partnership is one of the most important steps in creating a successful supply chain and in attaining reasonable profits for a firm. A firm, in order to maintain its competitive edge, must protect its core businesses; however, it must be and usually is willing to enter buyer-supplier relationships in peripheral activities (Todeva and Knoke, 2005). To achieve the benefits of buyer-supplier integration, in terms of increased internal efficiency and profitability of both parties, identifying and selecting viable suppliers is a preliminary step that needs to be properly managed (Bottani and Rizzi, 2007). In addition to develop an understanding of suppliers' expectations and objectives, the firm must carry out a careful screening of potential suppliers, which is a time-consuming process (Dacin and Hitt, 1997). Nevertheless, if the process is done correctly, a higher quality, longer lasting relationship is more attainable, and a win-win solution can be achieved.

Successful introduction and acceleration of new product development (NPD) is an important source of competitive advantage, survival and renewal for many organizations (Howell et al., 2006). Companies have to develop successful new products continuously because of fast changing technologies, shortening product lifecycles and increased globalize competition. The advantages of NPD include fast and economic (Wheelwright and Clark, 1992), increased product reliability (Sanderson and Uzumeri, 1995), increased variety, simplified managerial complexity and increased flexibility of strategic targets (Meyer and Lehnerd, 1997). In NPD, product conceptualization is the first step and is critical to the final success of the product, and quality function deployment (QFD) is a well-known comprehensive quality management system to consider customer requirements carefully starting from product conceptualization. However, conventional QFD has its shortcomings. Even though many modified QFD models have been proposed, a comprehensive model is necessary.

The introduction of successful new products is important to survive in today's fierce competitive international market. Suppliers' early involvement in the NPD process and the intense patterns of communication flows are driving forces for faster releases of new products, lower costs, and prompt responses to competitors' moves (Sobrero & Roberts, 2002). Even though the research on supplier selection is abundant, the works usually only consider the critical success factors in the buyer-supplier relationship and do not emphasize the NPD capabilities of the suppliers. The negative aspects of the buyer-supplier relationship and suppliers' NPD capabilities must be considered simultaneously in today's competitive TFT-LCD industries.

In this project, a model that incorporates quality function deployment (QFD) and fuzzy analytic network process (FANP) is built to solve the NPD problem in TFT-LCD manufacturing. Through literature review and interview with domain experts, a list of factors, including customer attributes (CAs) and engineering characteristics (ECs) for TFT-LCD, is prepared first. Since people are not willing and capable to handle comparisons properly when there are too many factors, fuzzy Delphi method (FDM) is used next to limit the number of factors included in the model. In considering the impreciseness and vagueness in human judgments and information, and the interrelationship among factors, a QFD model incorporated with fuzzy analytic network process (FANP) is constructed to facilitate the NPD process. The model can provide a general framework capable of helping designers to systematically consider relevant NPD information and effectively determine the key success factors for customer-driven design and manufacturing of new products.

Another objective of this project is to propose an analytical approach to select critical-part suppliers under a fuzzy environment. A fuzzy analytic network process (FANP) model, which incorporates the benefits, opportunities, costs and risks (BOCR) concept, is constructed to evaluate critical-part suppliers. Multiple factors that are positively or negatively affecting the success of the relationship are analyzed by taking into account experts' opinions on their importance, and a performance ranking of the suppliers is obtained.

2. TFT-LCD manufacturing

TFT-LCD has a sandwich-like structure consisting of two glass substrates with a layer of liquid crystal inside. The top substrate is fitted with a color filter that contains the black matrix and resin film containing three primary-color (red, green and blue) dyes or pigments. The bottom substrate is TFT array that contains the TFTs, storage capacitors, pixel electrodes and interconnect wiring. The two glass substrates are assembled with a sealant, and spacers are used to maintain the gap between the substrates (AU Optronics, 2010). Liquid crystal material is injected between two substrates. The outer face of each glass substrate has a sheet of polarizer film. Each end of the gate has a set of bonding pads and data-signal bus-lines to attach LCD Driver IC (LDI) chips (AU Optronics, 2010).

The manufacturing of TFT-LCD, as depicted in Figure 1, can be categorized into five major processes: TFT array fabrication, color filter (BM) fabrication, color filter (RGB) fabrication, cell assembly and module assembly. A TFT-LCD manufacturer usually has different plants for TFT array fabrication, cell assembly and module assembly. On the other hand, color filters are usually purchased from color filter manufacturers, even though there is a trend for vertical integration between color filter manufacturers and TFT-LCD manufacturers or a certain degree of alliance between the two.

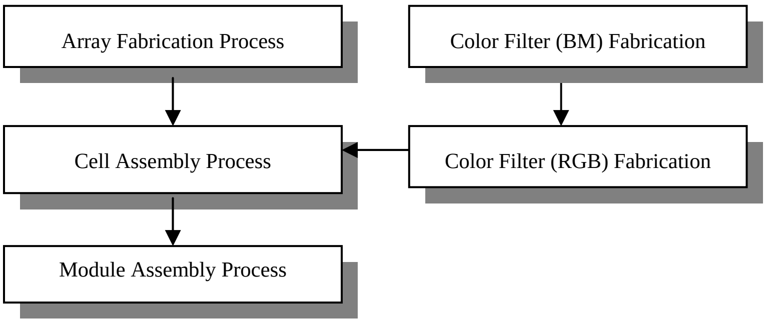

Figure 1. TFT-LCD manufacturing process

As global information industry increases, the demand of TFT-LCD panels with low weight, slender profile, low power consumption, high resolution, high brightness and low radiance, increases tremendously. As a result, product innovation of TFT-LCD has become an important focus for TFT-LCD manufacturers for gaining a good share of the profitability in this flourishing market.

3. Methods

3.1. Fuzzy Delphi method (FDM)

Since its development by Dalkey and Helmer in 1963, the Delphi method, which facilitates consensus by converging a value through the feedback of experts after several rounds, has been widely applied in many management areas, such as forecasting, project planning and public policy analysis. However, the method does have its shortfalls: repetitive questionnaires and evaluations, declining response rate of experts, inappropriate convergence, ambiguity and uncertainty in survey questions and in response, lengthy time and high cost (Chang *et al.*, 2000; Chang and Wang, 2006). Therefore, today the Delphi method has been expanded and modified into numerous techniques, and the incorporation of fuzzy set theory is one of the approaches.

From a collection of numerous factors, the fuzzy Delphi method can be applied to downsize th factors into a limited number of more important factors. The procedures are as follows (Ishikawa *et al.,* 1993; Chang *et al.*, 1995; Chang and Wang, 2006; Hsiao, 2006):

1. Conduct a questionnaire and ask experts for their most pessimistic (minimum) value and the most optimistic (maximum) value of the importance of each factor in the possible sub-criteria set S in a range from 1 to 10. A score is denoted as:

$$c_i = \left(l_{ik}, u_{ik}\right), i \in S \tag{1}$$

2. Select the minimum and maximum values and calculate geometric mean of the group's most

pessimistic (minimum) index and the values of the most optimistic (maximum) index for each factor. Determine the triangular fuzzy numbers for the most pessimistic index and the most optimistic index for each factor. The triangular fuzzy number for the most pessimistic index is $l^i = (l_l^i, l_m^i, l_u^i)$ and for the most optimistic index is $u^i = (u_l^i, u_m^i, u_u^i)$.

3. Inspect the consensus of experts' opinions and calculate the significance value for each factor. As shown in Figure 2, the gray zone, the overlap section of l^i and u^i, is used to inspect the consensus of experts in each factor and to calculate the consensus significance value of the factor, s^i.

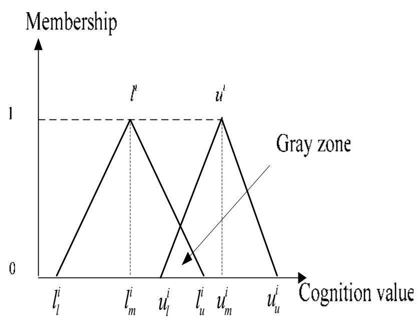

Figure 2. Gray zone of l^i and u^i.

4. Extract factors from the candidate list. Compare consensus significance value with a threshold value, *T*, which is determined by experts subjectively based on the geometric mean of all s^i. If $s^i \geq T$, select factor *i* for further analysis.

3.2. Quality function deployment (QFD)

A typical QFD system consists of four phases, product planning, part deployment, process planning and production planning, and each phase contains a matrix called house of quality (HOQ) (Zhang *et al.*, 1999; Chen *et al.*, 2004). In the product planning phase, product planning matrix contains information about what customers want, how technically customer requirements can be achieved, and the relationships between each of these aspects (Ho *et al.*, 1999). The four phases are depicted in Figure 3 (Ho *et al.*, 1999; Sohn and Choi, 2000; Kahraman *et al*., 2006). Through the above four phases, the voice of the customer is systematically cascaded into the design, process, and production of the product (Zhang *et al.*, 1999).

The systematic procedure for the first HOQ contains seven steps, and is depicted in Figure 4 (Chan *et al*., 1999; Wang, 1999; Ramasamy and Selladurai, 2004):

1. Obtaining customer attributes (CAs). In addition to questionnaire, interviewing, claim and complaint information, customer needs can also be collected by focus groups or individual interviews. From the collected information, the required CAs are established.

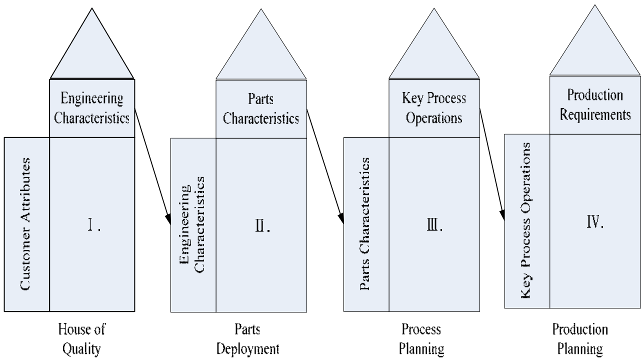

Figure 3. Four phases of QFD

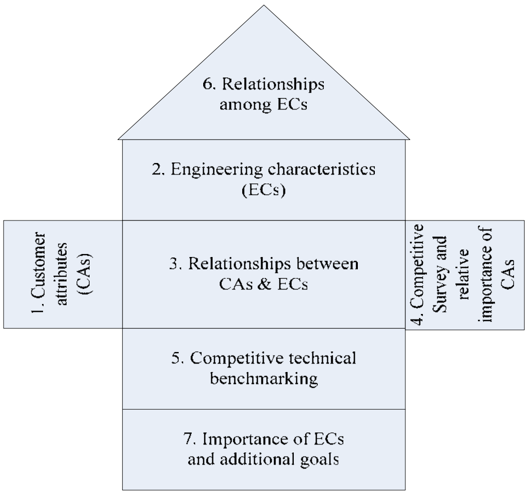

Figure 4. The components of HOQ

2. Developing engineering characteristics (ECs). ECs are also known as design requirements, product features, product technical requirements, engineering attributes, engineering characteristics or substitute quality characteristics (Karsak *et al*., 2002).

3. Building relationship between customer attributes (CAs) and engineering characteristics (ECs). By correlating CAs and ECs, a relationship matrix is prepared indicating how much each EC affects each CA, and such a relation can either be presented by a number or a symbol.

4. Completing competitive survey and calculating relative importance of CAs. The product performance of the company and its main competitors is rated so that the competitive positions of the company's product in terms of the CAs can be assessed (Chan *et al*., 1999).

5. Performing the competitive technical benchmarking. The performance of the company and its main competitors is rated with respect to each EC.

6. Determining the relationships among ECs. A correlation matrix, or "roof", is used to show the positive and negative relationship and the degree of relationship among the ECs.

7. Calculating the importance of ECs and additional goals. The importance and ranking of ECs are established from the results in step 5 and step 6.

In the QFD implementation, the determination of the correct importance weights for the CAs and ECs is essential since it affects the final outcomes of the whole process significantly. The simplest method to prioritize the CAs is based on a point scoring scale, such as 1 to 5 or 1 to 10 (Griffin and Hauser, 1993; Kwong and Bai, 2003; Buyukozkan *et al*., 2007). However, this method cannot effectively capture human perception, and a substantial degree of subjective judgment has to be involved in the scoring process (Kwong and Bai, 2003; Buyukozkan *et al*., 2007). Gustafsson and Gustafsson (1994) used a conjoint analysis method to determine the relative importance of the customer requirements by employing a pairwise comparison of customer requirements.

Because of the interrelationships among CAs and among ECs, ANP is used in some recent works (Partovi, 2001; Karsak *et al.*, 2002; Partovi and Corredoira, 2002). In all these methods, the input variables are assumed to be precise and are treated as numerical data. In addition, human decision making often contains ambiguity and uncertainty. Hence, conventional ANP are inadequate to explicitly capture the importance assessment of CAs and ECs. To confront this problem, many researchers incorporate the fuzzy set theory into QFD.

3.3. Fuzzy analytic network process (FANP)

Saaty (1996) proposes the analytic network process (ANP) approach, which is a generalization of the AHP. The ANP approach replaces hierarchies with networks, in which the relationships between levels are not easily represented as higher or lower, dominated or being dominated, directly or indirectly (Meade and Sarkis, 1999). After evaluating the importance of all factors, including goal, cluster, criteria and alternatives through pairwise comparisons, a “supermatrix” is formed, following by a weighted supermatrix that ensures column stochastic. Finally, a limit supermatrix is calculated to obtain final solutions.

Although the conventional ANP has overcome some of the shortcomings of the AHP, it still cannot effectively handle problems with imprecise information. To resolve this difficulty, fuzzy set theory can be introduced to the conventional ANP, and this new type of method is called the fuzzy ANP (FANP).

4. The proposed model for NPD and supplier selection

Even though there have been many studies on the incorporation of fuzzy AHP to QFD, the applications of fuzzy ANP to QFD are rather limited. In order to consider the interrelationship among CAs and ECs more and the inner dependence among CAs and among ECs accurately, ANP, instead of AHP, should be adopted. In order to take into account the impreciseness and vagueness in human judgments and information, fuzzy set theory should be applied. Therefore, in this study, we propose to use fuzzy ANP with QFD. However, people are not willing and capable to handle comparisons properly when there are too many CAs and ECs. Therefore, fuzzy Delphi method (FDM) will be used in advance to limit the number of CAs and ECs included in the model. In addition, a fuzzy analytic network process (FANP) model, which incorporates the benefits, opportunities, costs and risks (BOCR) concept, is constructed to evaluate critical-part suppliers. Multiple factors that are positively or negatively affecting the success of the relationship are analyzed by taking into account experts' opinions on their importance, and a performance ranking of the suppliers is obtained.

An integrated model for NPD and supplier selection is constructed. The procedures are as follows:

Step 1. Form a committee of decision makers to define the NPD problem in a TFT-LCD manufacturer. The environmental issues of the product life cycle will be considered in the NPD process. List all possible CAs and ECs in the product planning phase through methods, such as interview, questionnaire and brainstorming.

Step 2. Apply FDM to extract CAs and ECs from the candidate lists. Questionnaire is prepared to evaluate the importance of CAs (ECs), and customers, designers and related personnel are invited to fill out the questionnaire. A group average is calculated for each of l_{ik} and u_{ik} first, and the abnormal value which is outside of two standard deviations is eliminated. The geometric mean of the pessimistic (l_m^i) and the optimistic (u_m^i) importance of each CA (EC), gray zone interval value g^i and consensus significance value (s^i) are calculated. Threshold value for CA (EC) is determined subjectively, and the CA (EC) with a consensus significance value greater than or equal to the threshold value is selected.

Step 3. Use ISM to determine the inner dependence among CAs and among ECs. Note that only the adjacency matrix and reachability matrix are used to construct the relationships of CAs and of ECs. Network structures for CAs and for ECs are plotted.

Step 4. Construct a HOQ. A HOQ is constructed first, as shown in Figure 5 (Karsak et al., 2002; Lee et al., 2010). Unlike the conventional HOQ, both the inner dependence among CAs and the inner dependence among ECs are considered here. A check is entered if there is an influence of one factor to another factor.

Step 5. Prepare a questionnaire and receive feedback from experts. A questionnaire based on the structure of the HOQ is prepared using Satty's nine-point scale of pairwise comparison. Experts are asked to fill out the questionnaire.

Step 6. Perform consistency test. The consistency of each pairwise comparison matrix obtained from the questionnaire is examined first by calculating the consistency index (CI) and consistency ratio (CR).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

$$CR = \frac{CI}{\mathrm{RI}} \tag{3}$$

where n is the number of items being compared in the matrix, and RI is random index (Saaty, 1980). If an inconsistency is present, the expert is asked to revise the part of the questionnaire.

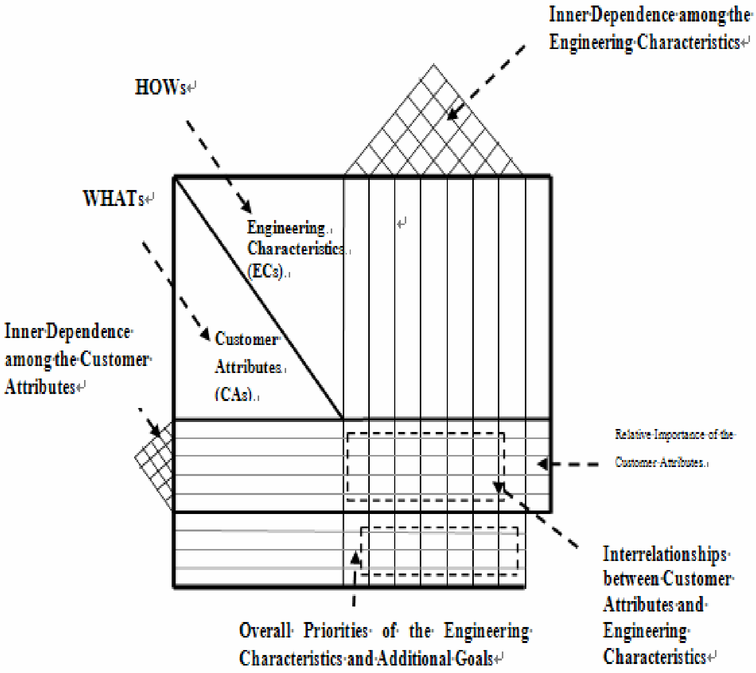

Figure 5. House of Quality (Lee et al., 2010)

Step 7. Construct fuzzy pairwise comparison matrices. The pairwise comparison matrix of each part of the questionnaire from each expert is transformed into a fuzzy pairwise comparison matrix.

Step 8. Construct fuzzy aggregated pairwise comparison matrices. Combine fuzzy pairwise comparison matrices from all experts by a geometric mean approach.

Step 9. Construct defuzzified aggregated pairwise comparison matrices. The fuzzy aggregated pairwise comparison matrices are transformed into defuzzified aggregated pairwise comparison matrices using the center of gravity (COG) method.

Step 10. Calculate priority vectors of the defuzzified aggregated pairwise comparison matrices. A local priority vector is derived for each defuzzified aggregated comparison matrix as an estimate of the relative importance of the elements (Saaty, 1980; Saaty, 1996):

$$\mathbf{A} \cdot w = \lambda_{max} \cdot w \tag{4}$$

where $\mathbf{A}$ is the defuzzified aggregated pairwise comparison matrix, w is the eigenvector, and $\lambda_{\max}$ is the largest eigenvalue of $\mathbf{A}$.

Step 11. Form an unweighted supermatrix. Priority vectors are entered in the appropriate columns of a matrix, known as an unweighted supermatrix, to represent the relationships in the HOQ.

$$\mathbf{M}_1^{\text{unweighted}} = \begin{array}{c} \\ \text{G}_1 \\ \text{CA} \\ \text{EC} \end{array} \begin{array}{c} \begin{array}{ccc} \text{G}_1 & \text{CA} & \text{EC} \end{array} \\ \begin{bmatrix} \mathbf{I} & & \\ w_{\text{CG}} & \mathbf{W}_{\text{CC}} & \\ & \mathbf{W}_{\text{EC}} & \mathbf{W}_{\text{EE}} \end{bmatrix} \end{array} \tag{5}$$

where w_{CG} is a vector that represents the impact of the goal on CAs, $\mathbf{W}_{\text{EC}}$ is a matrix that represents the impact of CAs on ECs, $\mathbf{W}_{\text{CC}}$ indicates the interdependency of CAs, $\mathbf{W}_{\text{EE}}$ indicates the interdependency of ECs, $\mathbf{I}$ is the identity matrix, and entries of zeros correspond to those elements that have no influence (Saaty, 1996; Lee et al., 2010).

Step 12. Calculate a weighted supermatrix.

Step 13. Calculate the limit supermatrix and obtain the final priorities of ECs.

Step 14. Determine the goals for the NPD and the priority level of the goals. Experts are invited to determine the additional goals in the development of the product. The priority level of the goals must be determined too. Under each level, there might be more than one goal.

Step 15. Determine the relative importance of the goals under the same priority level and the relative performance of ECs with respect to each additional goal. Methods such as the Delphi method, AHP or FAHP can be applied to obtain a consensus of experts' opinions.

Step 16. Set the preemptive GP model which considers the relative importance of the goals under the same priority level for NPD. The objective is to maximize the satisfaction in developing the product. Goals under a higher priority level must be met before the goals under a lower priority level can be met. The goals are $\text{G}_1, \text{G}_2, \ldots, \text{G}_N$, P_l is the priority level l and $P_1 \succ P_2 \succ \ldots \succ P_L$.

Priority level l : $P_l = \{G_{n_g} | n_g \in l\}$,

$\bigcup_g n_g = \{1, 2, \ldots N\}$, l=1,2,…L (6)

Min $Z = \sum_{l=1}^{L} P_l \left[\sum_{n_g \in l} (w_{n_g} d_{n_g}^{+} + w_{n_g} d_{n_g}^{-}) \right]$ (7)

s.t.

$f_{n_g}(x_i) - d_{n_g}^{+} + d_{n_g}^{-} = G_{n_g}$, for all n_g and i (8)

$x \in F$ (F is a feasible set) (9)

where l is the priority level ; w_{n_g} represents the weight attached to the deviation; G_{n_g} is the targeted values; $d_{n_g}^{+}$ and $d_{n_g}^{-}$ are, respectively, over- and under-achievements of the n_gth goal.

Step 17. Form a committee of decision makers to define the supplier selection problem.

Step 18. Decompose the problem into a control hierarchy. The goal of the control hierarchy, as shown in Figure 6, is to calculate the relative importance of the four merits, benefits (B), opportunities (O), costs (C) and risks (R), based on the control criteria that the firm would like to achieve in evaluating suppliers. Pairwise comparison of the importance of control criteria towards the goal and the importance of the merits towards each control criterion are calculated.

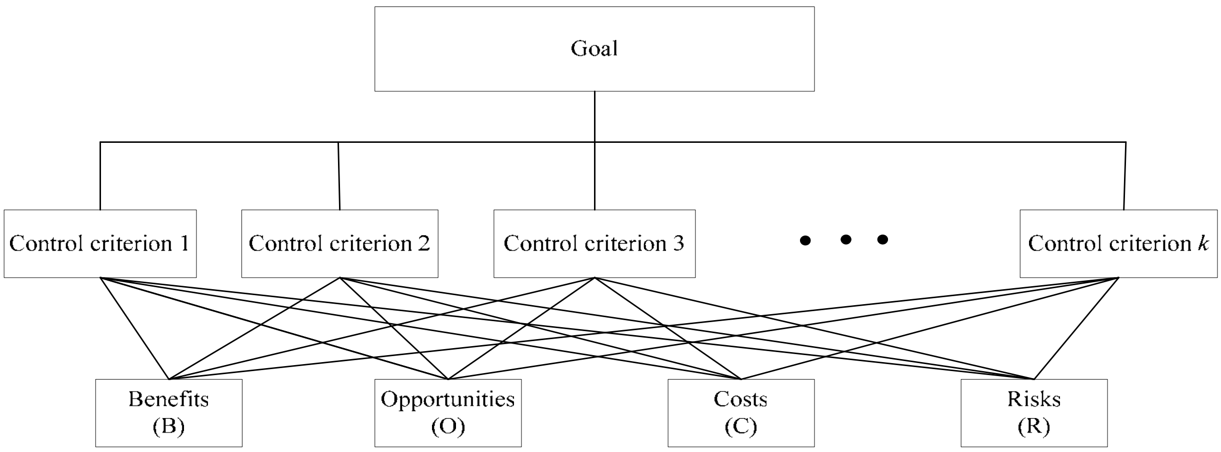

Figure 6. The control hierarchy (Lee, 2009b).

Step 19. Decompose the problem into a BOCR network. A network with four sub-networks, B, O, C and R, is constructed. Four merits, which reflect both positive and negative impacts of selecting a particular supplier, must be considered in achieving the overall goal. A sub-network is formed for each of the merits. For instance, for the sub-network for benefits (B) merit, there are criteria and/or detailed criteria that are related to the achievement of the benefits of the ultimate goal. The lowest level contains the alternatives (suppliers) that are under evaluation.

Step 20. Prepare a questionnaire based on the control hierarchy and the BOCR network. Experts in the field are invited to contribute their expertise and to fill out the questionnaire.

Step 21. Determine the priorities of the control criteria. Pairwise comparison results of the importance of control criteria toward achieving the overall objective are transformed into triangular fuzzy numbers using Table 1. A fuzzy positive reciprocal matrix is formed for each expert. The geometric mean method is applied next to form an aggregate fuzzy pairwise comparison matrix for all experts, and then the centroid method is adopted to defuzzify the fuzzy numbers in the aggregate fuzzy pairwise comparison matrix. The synthesized priorities of the control criteria can be calculated after a consistency test of the matrix is passed.

Step 22. Determine the importance of benefits, opportunities, costs and risks to each control criterion. The linguistic term and the triangular fuzzy number of each scale for evaluating the importance of benefits, opportunities, costs and risks to each control criterion is assigned to be very high (7,9,9), high (5,7,9), medium (3,5,7), low (1,3,5), and very low (1,1,3). As in Step 21, the opinions of the experts are aggregated by the geometric mean method, and the centroid method is used to defuzzify the fuzzy numbers. The crisp weights of the strategic criteria are normalized.

Step 23. Calculate the priorities of the merits, b, o, c and r. By multiplying the priority of a merit on each control criterion from Step 21 with the priority of the respective control criterion from Step 22 and summing up the calculated values for the merit, the priority of a merit can be obtained. Normalize the priorities of benefits, opportunities, costs and risks, and they are b, o, c and r, respectively.

Step 24. Calculate relative importance weights (priority vector) for criteria with respect to the same merit, relative importance weights (priority vector) for detailed criteria with respect to the same upper-level sub-criterion, relative priorities for the alternatives (suppliers) with respect to each criterion (detailed criterion) using a similar procedure in the inner dependence among criteria (detailed criteria) are calculated in a similar way.

Step 25. Form an unweighted supermatrix for each sub-network. The priority vectors obtained from Step 24 are entered in the appropriate columns in the unweighted supermatrix for each merit sub-network. An unweighted supermatrix for the benefits sub-network is:

$$\mathbf{B} = \begin{array}{c} \\ \text{Benefits} \\ \text{Criteria} \\ \text{Alternatives} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Benefits} & \text{Criteria} & \text{Alternatives} \end{array} \\ \begin{bmatrix} 0 & 0 & 0 \\ w_{CB} & \mathbf{W_{CC}} & 0 \\ 0 & \mathbf{W_{AC}} & \mathbf{I} \end{bmatrix} \end{array} \quad (10)$$

where w_{CB} is a vector that represents the impact of the benefits on the criteria, WCC indicates the interdependency of the criteria, WAC is a matrix that represents the impact of criteria on each of the alternatives, I is the identity matrix, and entries of zeros correspond to those elements that have no influence.

Step 26. Calculate the weighted supermatrix for each merit sub-network. Transform the unweighted supermatrix into a weighted supermatrix to make the supermatrix stochastic.

Step 27. Calculate the limit supermatrix and obtain the priorities of the alternatives for each merit sub-network. By raising the weighted supermatrix to powers, a limit supermatrix can be obtained when a convergence is met. The priorities of the alternatives (suppliers) under a merit are calculated by normalizing the alternative-to-merit column of the limit supermatrix of the merit.

Step 28. Calculate the overall priorities of alternatives (suppliers). By synthesizing priorities of each alternative under each merit from Step 27 with the corresponding normalized weights b, o, c and r from Step 23, the overall priorities of alternatives (suppliers) can be generated. There are five ways to aggregate the priorities of each alternative (supplier) under B, O, C and R.

1. Additive

$$P_i=bB_i+oO_i+c[(1/C_i)_{\text{Normalized}}]+r[(1/R_i)_{\text{Normalized}}] \quad (11)$$

where Bi, Oi, Ci and Ri represent respectively the synthesized results of alternative i under merit B, O, C and R, and b, o, c and r are respectively normalized weights of merit B, O, C and R.

2. Probabilistic additive

$$P_i=bB_i+oO_i+c(1-C_i)+r(1-R_i) \quad (12)$$

3. Subtractive

$$P_i=bB_i+oO_i-cC_i-rR_i \quad (13)$$

4. Multiplicative priority powers

$$P_i=B_i^b\, O_i^o\, [(1/C_i)_{\text{Normalized}}]^c\, [(1/R_i)_{\text{Normalized}}]^r \quad (14)$$

5. Multiplicative

$$P_i=B_iO_i/C_iR_i \quad (15)$$

Table 1. Transformation of linguistic variables

Linguistic variables	Positive triangular fuzzy numbers	Positive reciprocal triangular fuzzy numbers
Extremely strong	(9,9,9)	(1/9,1/9,1/9)
Intermediate	(7,8,9)	(1/9,1/8,1/7)
Very strong	(6,7,8)	(1/8,1/7,1/6)
Intermediate	(5,6,7)	(1/7,1/6,1/5)
Strong	(4,5,6)	(1/6,1/5,1/4)
Intermediate	(3,4,5)	(1/5,1/4,1/3)
Moderately strong	(2,3,4)	(1/4,1/3,1/2)
Intermediate	(1,2,3)	(1/3,1/2,1)
Equally strong	(1,1,1)	(1,1,1)

5. Case study

This research focuses on both the perspectives of consumers and manufacturers, and collects CAs and ECs for TFT-LCD new product development through literature review and interview with experts. There are many CAs and ECs in TFT-LCD NPD, and it is not worthwhile and possible to include all the factors in the NPD process. Therefore, the FDM is used to collect the opinions of the experts and to select the most important factors for further FANP-QFD analysis. The results of the FDM are as shown in Table 2. To limit the number of CAs and ECS, only 6 CAs and 7 ECs are selected as shown in Table 3. These selected factors will be used in the construction of the HOQ as in Figure 7.

ISM is applied to determine the inner dependence among CAs and among ECs. Using the CAs (ECs) selected from FDM, relation matrix which shows the contextual relationship among the CAs (ECs) is established for each expert. A questionnaire is prepared to ask the contextual relationship between any two CAs (ECs), and the associated direction of the relation. For example, a relation matrix for CAs formed based on an expert's opinions is as follow:

$$D_I = \begin{array}{c} \\ CA_1 \\ CA_2 \\ CA_3 \\ CA_4 \\ CA_5 \\ CA_6 \end{array} \begin{array}{c} \begin{array}{cccccc} CA_1 & CA_2 & CA_3 & CA_4 & CA_5 & CA_6 \end{array} \\ \begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 0 \end{bmatrix} \end{array}$$

Table 2. Fuzzy Delphi method results

Aspect	Indicatora	Experts 1			Experts 2			Experts 3			Experts 4			Experts 5			C^i		O^i		a^i		Geometric mean			C.V.	Consensus	Remarks
		min	uni	max	min	uni	max	min	uni	max	min	uni	max	min	uni	max	min	max	min	max	min	max	C^i	O^i	a^i	$M^i - Z^i$	G^i	
Voice of the Customers	Color saturation	7	8	8	8	9	10	7	8	10	6	7	8	3	4	6	3	8	6	10	4	9	5.8845	8.2578	6.9425	0.3733	7.032553154	Selected
	Color contrast	7	7	8	7	8	10	6	8	9	5	6	7	5	6	7	5	7	7	10	6	8	5.9328	8.1191	6.9425	2.1863	7	Selected
	Screen update frequency	8	8	10	5	6	7	5	6	7	8	9	10	8	9	9	5	8	7	10	6	9	6.6289	8.4896	7.4744	0.8607	7.52071478	Selected
	Screen update frequency	4	5	7	5	7	8	4	5	7	5	5	7	4	5	7	4	5	7	8	5	7	4.3734	7.1895	5.3481	4.816	6.535639004	
	Reaction time	8	9	9	5	7	8	6	8	9	6	8	9	7	8	10	5	8	8	10	7	9	6.3196	8.9777	7.9748	2.658	8	Selected
	Broader perspective	10	10	10	5	7	8	4	5	6	8	9	10	10	10	10	4	10	6	10	5	10	6.9314	8.6347	7.9371	-2.297	7.847865628	Selected
	Low power consumption	8	8	9	8	9	10	9	9	10	8	9	10	8	8	9	8	9	9	10	8	9	8.1907	9.5873	8.5858	1.3966	9	Selected
	Product quality and stability	9	9	10	8	9	10	7	8	9	8	8	9	10	10	10	7	10	9	10	8	10	8.3388	9.5873	8.7687	0.2485	9.261202553	Selected
	High-quality display	8	9	10	9	9	10	7	8	8	8	9	9	8	9	10	7	9	8	10	8	9	7.9748	9.3641	8.7905	0.3893	8.570932221	Selected
	Size	6	7	8	6	6	7	5	6	7	7	7	8	6	7	8	5	7	7	8	6	7	5.9663	7.5839	6.5814	1.6176	7	Selected
	Ultra-thin design	6	8	10	6	8	8	6	7	8	6	7	9	5	6	7	5	6	7	10	6	8	5.7852	8.3388	7.1599	3.5537	6.138283538	
	Small variations structure	10	10	10	6	8	10	8	8	9	7	7	8	8	9	10	6	10	8	10	7	10	7.6893	9.3641	8.3388	-0.325	8.742407711	Selected
	Additional features	8	9	9	6	8	10	7	8	9	8	9	9	6	7	8	6	8	8	10	7	9	6.9425	8.9777	8.1649	2.0352	8	Selected
	Product weight	6	8	9	5	6	7	6	7	8	6	6	7	5	6	7	5	6	7	9	6	8	5.578	7.5601	6.5543	2.9821	6.429706557	
	Rapid delivery	9	9	10	8	9	9	8	8	9	8	9	10	7	8	10	7	9	9	10	8	9	7.9748	9.5873	8.5858	1.6125	9	Selected
	Reasonable prices	10	10	10	8	9	10	9	9	10	8	8	9	6	7	8	6	10	8	10	7	10	8.0856	9.3641	8.5376	-0.722	8.83216414	Selected
	Brand request	5	6	7	7	8	9	6	7	8	4	5	6	6	7	8	4	7	6	9	5	8	5.5016	7.5289	6.5175	1.0274	6.505039365	
	After-sales service	6	7	8	5	6	7	5	6	6	8	8	9	5	6	7	5	8	6	9	6	8	5.6968	7.3305	6.5543	-0.366	6.732323448	
	Design	5	5	6	6	8	10	6	7	8	5	5	6	7	8	9	5	7	6	10	5	8	5.7527	7.6336	6.4542	0.8809	6.567029253	
Technical Specifications	Strengthen thin glass	7	8	8	5	7	9	6	8	8	7	8	10	6	7	8	5	7	8	10	7	8	6.1531	8.5645	7.5839	3.4114	7.600039512	Selected
	Glass cutting	8	9	10	6	8	10	8	9	10	7	8	10	6	8	8	6	8	8	10	8	9	6.9425	9.5635	8.3859	2.621	8	Selected
	Coating uniformity	8	9	9	6	8	10	6	7	7	6	8	8	7	8	8	6	8	7	10	7	9	6.5543	8.3388	7.9748	0.7845	7.480811727	Selected
	High-brightness B / L	4	6	7	6	8	10	6	8	9	6	7	8	5	6	8	4	6	7	10	6	8	5.3345	8.3388	6.9425	4.0043	6.332021979	
	Polarizer	6	7	8	6	7	9	6	6	7	6	7	7	6	7	8	6	6	7	9	6	7	6	7.7647	6.7875	2.7647	6	
	Anti-Hyun polarizer	3	4	6	6	6	8	5	5	6	5	6	7	6	7	8	3	6	6	8	4	7	4.8559	6.9425	5.5016	2.0866	6	
	Backlight-proliferation	7	8	10	7	9	10	6	8	9	8	8	9	6	7	9	6	8	9	10	7	9	6.7595	9.3874	7.9748	3.6279	8.762015706	Selected
	Backlight module integrated design	8	8	8	7	9	10	8	9	10	7	8	9	7	9	10	7	8	8	10	8	9	7.3841	9.3641	8.5858	1.9801	8	Selected
	Quality control of raw materials	7	8	9	7	8	9	6	10	8	6	7	8	8	8	9	6	8	8	9	7	10	6.7595	8.5858	8.1447	1.8263	8	Selected
	Quality control process	8	9	10	8	9	10	9	9	10	8	8	10	9	9	10	8	9	10	10	8	9	8.3859	10	8.7905	2.6141	10	Selected
	Environmental Law	8	8	8	5	6	9	5	6	8	6	8	9	5	6	7	5	8	7	9	6	8	5.6968	8.1649	6.7317	1.4681	7.335895302	Selected
	IC power-saving	7	8	9	6	8	10	8	8	10	6	7	9	7	7	9	6	8	9	10	7	8	6.7595	9.3874	7.5839	3.6279	8.762015706	Selected
	Backlight light design	6	7	8	6	8	9	6	8	8	6	7	8	7	8	9	6	7	8	9	7	8	6.1879	8.3859	7.5839	3.1981	7.677875674	Selected
	PCB version of the expansion and warping of the copper foil	6	8	10	6	8	10	7	7	9	6	8	8	6	7	8	6	7	8	10	7	8	6.1879	8.9554	7.5839	3.7675	7.459476825	Selected
	Back control of the glorious	6	7	8	6	6	7	6	7	8	6	6	7	5	8	9	5	6	7	9	6	8	5.7852	7.7647	6.7595	2.9795	6.219335281	
	Power consumption control	6	7	9	6	9	10	7	9	9	7	7	10	6	8	9	6	7	9	10	7	9	6.3816	9.3874	7.9498	5.0058	8.229658759	Selected
	Size control structure	5	8	9	5	7	9	5	6	8	6	8	9	5	7	8	5	6	8	9	6	8	5.1857	8.5858	7.1599	5.4001	7.163198693	Selected
	Test control of experiments	6	7	9	5	7	8	4	6	7	7	7	8	8	8	9	4	8	7	9	6	8	5.8274	8.1649	6.9712	1.3375	7.349038707	Selected
	Information Management System	7	8	9	6	7	8	8	8	9	7	8	9	8	9	9	6	8	8	9	7	9	7.1599	8.7905	7.9748	1.6306	8	Selected

The geometric mean of experts' opinions on the relationship between a pair of CAs (ECs) is calculated. A threshold value of 0.5 is used to determine whether the two CAs (ECs) are dependent or not (Yang *et al.*, 2008). That is, a relation matrix is prepared for each expert first, and a mean relation matrix is calculated using the geometric mean method to combine relation matrices from all experts. If the geometric mean value between two CAs (ECs), i. e. $\bar{\pi}_{ij}$, in the mean relation matrix is higher than the threshold value, x_j is deemed reachable from x_i, and we let $\bar{\pi}_{ij} = 1$ (Yang et al., 2008). The integrated relation matrix between CAs is calculated and is as shown in Table 4.

$$D = \begin{array}{c} \\ CA_1 \\ CA_2 \\ CA_3 \\ CA_4 \\ CA_5 \\ CA_6 \end{array} \begin{array}{c} \begin{array}{cccccc} CA_1 & CA_2 & CA_3 & CA_4 & CA_5 & CA_6 \end{array} \\ \begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Table 3. Customer attributes and engineering characteristics for TFT-LCD

	Customer attributes (CAs)		Engineering characteristics (ECs)
CA_1	Low power consumption	EC_1	Glass cutting technology
CA_2	Product quality and stability	EC_2	Backlight module integrated design
CA_3	High-quality display	EC_3	Quality control of raw materials
CA_4	Small variations structure	EC_4	Quality control process
CA_5	Rapid delivery	EC_5	IC power-saving design
CA_6	Reasonable prices	EC_6	Power consumption control
		EC_7	Information Management System

Table 4. Relation matrix among CAs

	CA_1	CA_2	CA_3	CA_4	CA_5	CA_6
CA_1	0	0.5	0.6	0	0.2	0
CA_2	0.3	0	0.2	0.6	0.3	0.8
CA_3	0.6	0.6	0	0.7	0.2	0.2
CA_4	0.2	0.3	0.2	0	0.3	0.3
CA_5	0.4	0.7	0	0.3	0	0
CA_6	0.2	0.4	0	0.2	0	0

The initial reachability matrix M for CAs is:

$$\mathbf{M}=\mathbf{D}+\mathbf{I}=\begin{bmatrix}0&1&1&0&0&0\\0&0&0&1&0&1\\1&1&0&1&0&0\\0&0&0&0&0&0\\0&1&0&0&0&0\\0&0&0&0&0&0\end{bmatrix}+\begin{bmatrix}1&0&0&0&0&0\\0&1&0&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\\0&0&0&0&1&0\\0&0&0&0&0&1\end{bmatrix}=\begin{bmatrix}1&1&1&0&0&0\\0&1&0&1&0&1\\1&1&1&1&0&0\\0&0&0&1&0&0\\0&1&0&0&1&0\\0&0&0&0&0&1\end{bmatrix}$$

The final reachability matrix M* for CAs is:

$$\mathbf{M}^*=\mathbf{M}^3=\mathbf{M}^4=\begin{bmatrix}1&1&1&1&0&1\\0&1&0&1&0&1\\1&1&1&1&0&1\\0&0&0&1&0&0\\0&1&0&1&1&1\\0&0&0&0&0&1\end{bmatrix}$$

Based on M*, the inner dependence among the six CAs can be depicted as in Figure 7. The same procedure can be carried out for determining the inner dependence among ECs.

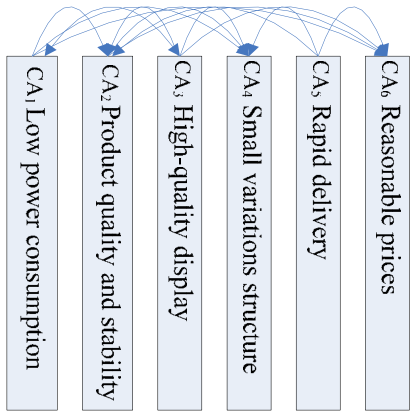

Figure 7. Inner dependence among CAs

Te examine the practicality of the proposed model, a case study is carried out in an anonymous TFT-LCD manufacturer in Taiwan. Seven experts from the firm are asked to contribute their expertise in the study. The HOQ is shown in Figure 8. Based on the relationship among factors shown in the HOQ in Figure 2, a pairwise comparison questionnaire is prepared, and the seven experts are asked to do the questionnaire. The consistency test is performed to check all the pairwise comparison matrices from the experts. If an inconsistency is found, a revision of the inputs to the questionnaire is requested. The opinions are aggregated, and aggregated pairwise comparison matrices are prepared. The center of gravity (COG) method is applied next to prepare defuzzified comparison matrices. The priority vectors of the defuzzified aggregated pairwise comparison matrices are calculated.

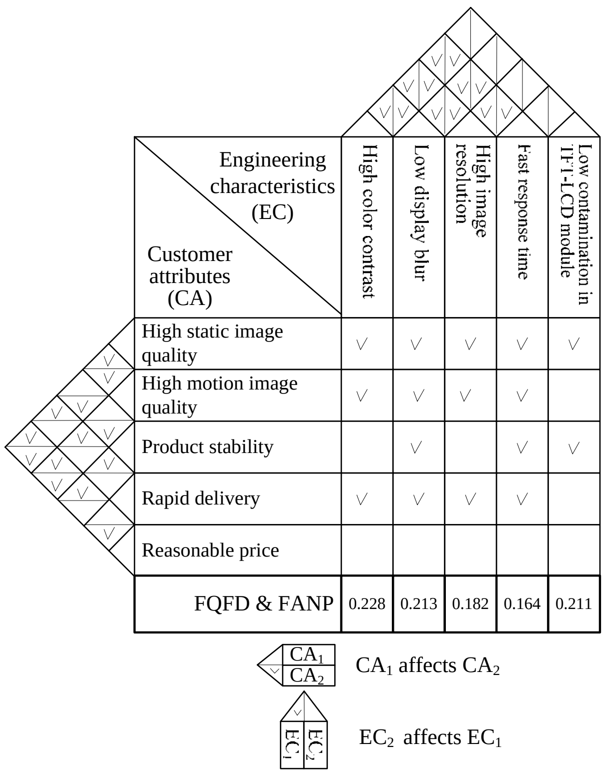

Figure 8. House of Quality

Based on the relationship among factors shown in the HOQ in Fig. 9, a pairwise comparison questionnaire is prepared, and the seven experts are asked to do the questionnaire. The consistency test is performed to check all the pairwise comparison matrices from the experts, and a revision of the inputs to the questionnaire is requested if necessary. The opinions are aggregated, and aggregated pairwise comparison matrices are prepared.Use the comparison of the importance of high static image quality (CA_1) and high motion image quality (CA_2) as an example. The experts' opinions are transformed into triangular fuzzy numbers, i.e., (1/6,1/5,1/4), (3,4,5), (1,1,1), (1,1,1), (1/4,1/3,1/2), (1/6,1/5,1/4) and (1/6,1/5,1/4). Geometric mean approach is employed to aggregate experts' responses, and the synthetic triangular fuzzy number for the comparison between CA_1 and CA_2 is (0.4553,0.5227,0.6292). The same procedure is carried out for all pairwise comparisons of other CAs. The fuzzy aggregated pairwise comparison matrix for the CAs is:

$$\tilde{\mathbf{W}}_{21} = \begin{array}{c} \\ CA_1 \\ CA_2 \\ CA_3 \\ CA_4 \\ CA_5 \end{array} \begin{array}{c} \begin{array}{ccccc} CA1 & CA2 & CA3 & CA4 & CA5 \end{array} \\ \begin{bmatrix} 1 & (0.4453, 0.5227, 0.6292) & (0.2225, 0.2624, 0.3320) & (0.4202, 0.5742, 0.7430) & (0.3048, 0.3712, 0.4640) \\ & 1 & (0.2225, 0.2669, 0.3441) & (0.4283, 0.5870, 0.7626) & (0.2876, 0.3451, 0.4202) \\ & & 1 & (0.6454, 0.8824, 1.1266) & (0.3598, 0.4602, 0.5656) \\ & & & 1 & (0.2714, 0.3173, 0.3743) \\ & & & & 1 \end{bmatrix} \end{array}$$

To prepare a defuzzified comparison matrix, the center of gravity (COG) method is applied next. For example, with the synthetic triangular fuzzy number for the comparison between CA_1 and CA_2, the defuzzified comparison between CA_1 and CA_2 is 0.5324. The defuzzified aggregated pairwise comparison matrix is:

$$\mathbf{W}_{21} = \begin{array}{c} \\ CA_1 \\ CA_2 \\ CA_3 \\ CA_4 \\ CA_5 \end{array} \begin{array}{c} \begin{array}{ccccc} CA_1 & CA_2 & CA_3 & CA_4 & CA_5 \end{array} \\ \begin{bmatrix} 1 & 0.5324 & 0.2723 & 0.5791 & 0.3800 \\ & 1 & 0.2778 & 0.5926 & 0.3510 \\ & & 1 & 0.8848 & 0.4619 \\ & & & 1 & 0.3210 \\ & & & & 1 \end{bmatrix} \end{array}$$

The priority vector of the defuzzified aggregated pairwise comparison matrix for CAs is calculated.

$$w_{21} = \begin{matrix} \mathrm{CA}_1 \\ \mathrm{CA}_2 \\ \mathrm{CA}_3 \\ \mathrm{CA}_4 \\ \mathrm{CA}_5 \end{matrix} \begin{bmatrix} 0.0883 \\ 0.1124 \\ 0.2473 \\ 0.1738 \\ 0.3783 \end{bmatrix}$$

The consistency test is performed by calculating the consistency index (*CI*) and consistency ratio (*CR*):

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{5.3355 - 5}{5-1} = 0.08388, \text{ and}$$

$$CR = \frac{CI}{\mathrm{RI}} = \frac{0.08388}{1.12} = 0.07489.$$

Since *CR* is less than 0.1, the experts' judgment is consistent. If the consistency test fails, the experts are required to fill out the specific part of the questionnaire again until a consensus is met.

The obtained priorities are entered into the designated places in the supermatrix, which is the unweighted supermatrix. The unweighted supermatrix is transformed into a weighted supermatrix first, and the weighted supermatrix is raised to powers to capture all the interactions and to obtain a steady-state outcome. The resulting supermatrix is the limit supermatrix, which shows the priority weights of the ECs:

$$w^{ANP} = \begin{bmatrix} w_{f1} \\ w_{f2} \\ w_{f3} \\ w_{f4} \\ w_{f5} \end{bmatrix} = \begin{matrix} \\ \mathrm{EC}_1 \\ \mathrm{EC}_2 \\ \mathrm{EC}_3 \\ \mathrm{EC}_4 \\ \mathrm{EC}_5 \end{matrix} \begin{matrix} \mathrm{G}_1 \\ \begin{bmatrix} 0.228 \\ 0.213 \\ 0.182 \\ 0.164 \\ 0.211 \end{bmatrix} \end{matrix}$$

High color contrast (EC_1) is the most important EC with priority of 0.228, followed by low display blur (EC_2) and low contamination in TFT-LCD module (EC_5) with priorities of 0.213 and 0.211, respectively.

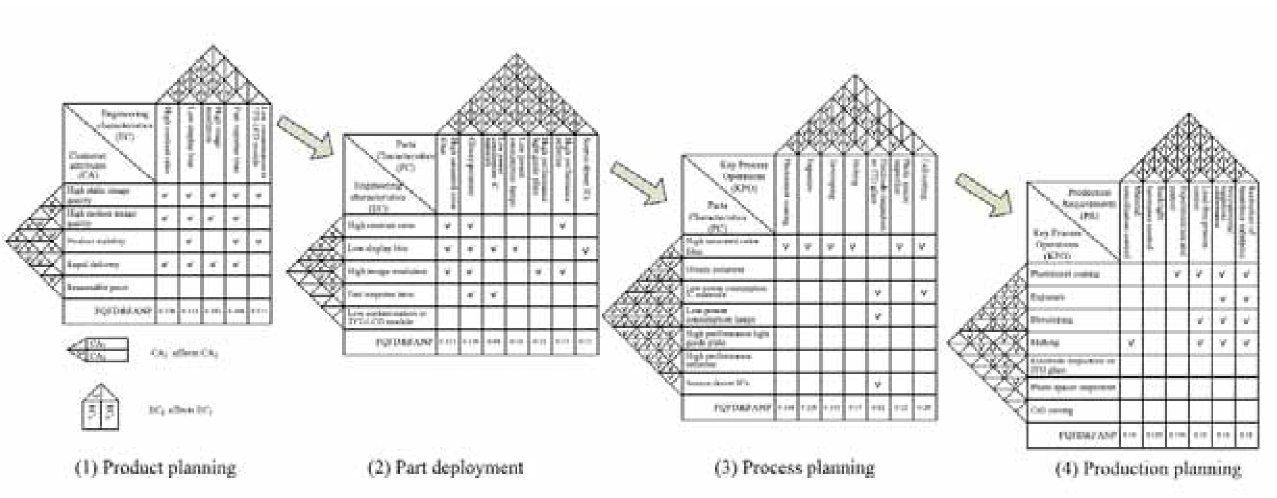

Figure 9. The four HOQs for the case study

Next, multiple goals with different priority levels are considered in the NPD. While increasing customer satisfaction may be the main purpose in the QFD process, other issues such as cost expenditure and technical difficulty may also need to be taken into account in the design stage. Let G1, G2 and G3 be goals of maximizing customer satisfaction, minimizing technical difficulty, and minimizing cost expenditure, respectively. Suppose that G1 is considered to be more important than G2 and G3; therefore, two priority levels are recommended in the QFD process. For simplifying the computational efforts, a recently proposed model is adopted in this case study (Lee et al., 2010). With G1 belonging to priority level 1 and G2 and G3 belonging to priority level 2, the preemptive fuzzy goal programming model is as follows:

G1:
$$\sum w_{f_i} \times (d^+_{f_{i1}} + d^-_{f_{i1}}) = w_{f_1} \times (d^+_{f_{11}} + d^-_{f_{11}}) + w_{f_2} \times (d^+_{f_{12}} + d^-_{f_{12}}) + w_{f_3} \times (d^+_{f_{13}} + d^-_{f_{13}}) + w_{f_4} \times u_{f_4}(d^+_{f_{14}} + d^-_{f_{14}}) + w_{f_5} \times (d^+_{f_{15}} + d^-_{f_{15}})$$

$$= 0.2288 \times (d^+_{f_{11}} + d^-_{f_{11}}) + 0.2137 \times (d^+_{f_{12}} + d^-_{f_{12}}) + 0.1823 \times (d^+_{f_{13}} + d^-_{f_{13}}) + 0.1642 \times u_{f_4}(d^+_{f_{14}} + d^-_{f_{14}}) + 0.2110 \times (d^+_{f_{15}} + d^-_{f_{15}})$$

G2:
$$\sum w_{t_i} \times (d^+_{t_{i1}} + d^-_{t_{i1}}) = w_{t_1} \times (d^+_{t_{11}} + d^-_{t_{11}}) + w_{t_2} \times (d^+_{t_{12}} + d^-_{t_{12}}) + w_{t_3} \times (d^+_{t_{13}} + d^-_{t_{13}}) + w_{t_4} \times u_{t_4}(d^+_{t_{14}} + d^-_{t_{14}}) + w_{t_5} \times (d^+_{t_{15}} + d^-_{t_{15}})$$

$$= 0.1925 \times (d^+_{t_{11}} + d^-_{t_{11}}) + 0.2564 \times (d^+_{t_{12}} + d^-_{t_{12}}) + 0.3215 \times (d^+_{t_{13}} + d^-_{t_{13}}) + 0.1582 \times u_{t_4}(d^+_{t_{14}} + d^-_{t_{14}}) + 0.0714 \times (d^+_{t_{15}} + d^-_{t_{15}})$$

G3: $$\begin{aligned}&\sum w_{c_i} \times (d^+_{c_{i1}} + d^-_{c_{i1}}) = w_{c_1} \times (d^+_{c_{11}} + d^-_{c_{11}}) \\ &+ w_{c_2} \times (d^+_{c_{12}} + d^-_{c_{12}}) + w_{c_3} \times (d^+_{c_{13}} + d^-_{c_{13}}) + \\ &w_{c_4} \times u_{c_4}(d^+_{c_{14}} + d^-_{c_{14}}) + w_{c_5} \times (d^+_{c_{15}} + d^-_{c_{15}}) \\ &= 0.2512 \times (d^+_{c_{11}} + d^-_{c_{11}}) + 0.2025 \times (d^+_{c_{12}} + d^-_{c_{12}}) \\ &+ 0.1584 \times (d^+_{c_{13}} + d^-_{c_{13}}) + 0.1796 \times u_{c_4}(d^+_{c_{14}} + d^-_{c_{14}}) \\ &+ 0.2083 \times (d^+_{c_{15}} + d^-_{c_{15}})\end{aligned}$$

s.t: $f_1(x_1) - d^+_{f_{11}} + d^-_{f_{11}} = g_{f_1}(x_1)$

$f_2(x_2) - d^+_{f_{21}} + d^-_{f_{21}} = g_{f_2}(x_2)$

$f_3(x_3) - d^+_{f_{31}} + d^-_{f_{31}} = g_{f_3}(x_3)$

$f_4(x_4) - d^+_{f_{41}} + d^-_{f_{41}} = g_{f_4}(x_4)$

$f_5(x_5) - d^+_{f_{51}} + d^-_{f_{51}} = g_{f_5}(x_5)$

$t_1(x_1) - d^+_{t_{11}} + d^-_{t_{11}} = g_{t_{11}}(x_1)$

$t_2(x_2) - d^+_{t_{21}} + d^-_{t_{21}} = g_{t_2}(x_2)$

$t_3(x_3) - d^+_{t_{31}} + d^-_{t_{31}} = g_{t_3}(x_3)$

$t_4(x_4) - d^+_{t_{41}} + d^-_{t_{41}} = g_{t_4}(x_4)$

$t_5(x_5) - d^+_{t_{51}} + d^-_{t_{51}} = g_{t_5}(x_5)$

$c_1(x_1) - d^+_{c_{11}} + d^-_{c_{11}} = g_{c_1}(x_1)$

$c_2(x_2) - d^+_{c_{21}} + d^-_{c_{21}} = g_{c_2}(x_2)$

$c_3(x_3) - d^+_{c_{31}} + d^-_{c_{31}} = g_{c_3}(x_3)$

$c_4(x_4) - d^+_{c_{41}} + d^-_{c_{41}} = g_{c_4}(x_4)$

$c_5(x_5) - d^+_{c_{51}} + d^-_{c_{51}} = g_{c_5}(x_5)$

$X \in F$ (F is a feasible set)

where $f_i(x_i)$, $t_i(x_i)$ and $c_i(x_i)$ are respectively the membership function for customer satisfaction, technical difficulty and cost expenditure for all ECs, $g_{f_i}(x_i)$, $g_{t_i}(x_i)$ and $g_{c_i}(x_i)$ are respectively the targeted values for customer satisfaction, technical difficulty and cost expenditure for all ECs.

Based on different goals, different types of membership function can be used. For example, $f_2(x_2)$ is the membership function for customer satisfaction of EC2, low display blurriness. If a maximum satisfaction is achieved, $f_2(x_2)=1$; if a minimum satisfaction is achieved, $f_2(x_2)=0$.

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6. Conclusions

With limited resources, including time, cost and human power, a firm can only focus on a certain parts of its research and design. Therefore, how to develop and manufacture a product that can acquire the highest expected benefits for the firm is an important task. In this research, a systematic process that incorporates FDM, ISM and FANP into QFD was proposed for new product development. Through comprehensive literature review and interview with experts, a list of CAs that customers perceive as important for a TFT-LCD panel and a list of ECs that may be necessary for TFT-LCD panel were prepared. The most important factors from the CA and EC lists were selected by the FDM. The ISM was applied to determine the inner dependence among CAs and among ECs. The results were used to construct the HOQ, and the priorities of CAs and ECs were generated through FANP so that the inner dependence among CAs and among ECs and the linguistic uncertainty of experts could be incorporated in the calculation. In addition, a fuzzy analytic network process (FANP) model with the consideration of benefits, opportunities, costs and risks (BOCR) was constructed for supplier selection. While there are numerous supplier selection models available, most models usually only stress on the criteria that are required by a buyer, but not consider the opportunities, costs and risks aspects of the buyer when selecting a supplier. Therefore, this research provided a comprehensive model that considers the four merits simultaneously and takes into account the interrelationships among the factors. In addition, fuzzy set theory was incorporated to overcome the uncertainty and ambiguity in human decision-making process. A case study of a TFT-LCD manufacturer in selecting the most appropriate critical-part manufacturers was introduced to examine the practicality of the proposed model.

The proposed model can help designers systematically consider relevant NPD information and effectively determine key CAs and ECs for designing and manufacturing of new products, and it can facilitate the process of selecting the most appropriate critical-part manufacturers. The model not only can be applied by a TFT-LCD manufacturer, it can also be adjusted by firms in other high-tech industries to suit the particular needs. The generated results can provide valuable references in making NPD decisions and selecting suppliers for cooperation.

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計畫成果自評

在政府大力推動兩兆雙星產業下，TFT-LCD 成為目前台灣最輝煌的產業之一。隨著全球 TFT-LCD 產業邁入成熟階段，現階段將面臨劇烈之市場競爭及價格割喉戰。台灣 TFT-LCD 製造之競爭優勢源於低成本、高品質、具彈性、相關產業之專業技術與完整的群聚供應鏈等。然而在全球競爭環境下，企業生存與成功之關鍵在於如何因應市場快速變化與顧客需求的不確定性外，同時達到環保之社會責任，新產品開發(NPD)及供應鏈管理，對企業生存極為重要。因此，新產品開發將是保持競爭優勢並維持企業長期利潤之首要關鍵。儘管過去對於新產品開發有許多專家學者進行研究，但透過文獻探討發現鮮少從顧客需求、原料採購、研發與製程等產品生命週期，完整的進行深入探討與研究，故本計劃發展一系統化之整合模型，探討 TFT-LCD 新產品開發及供應商選擇。故就上述而言，本計畫是一項創新且具學術貢獻之研究。本研究結果有利於協助 TFT-LCD 製造商或其他高科技廠商，如欲投入新產品開發(NPD)發展及後續之供應商選擇時，能透過本研究發展之模型提供決策者做為參考之依據，以縮短產品研發時間與產品失效等問題提升廠商於全球產業之優勢。對於國家而言，更能打響我國知名度並將我國產品推向全世界，以提升國際競爭力。

吾人於此三年期計畫成果共發表 4 篇 SCI 國際期刊論文與 7 篇國際研討會論文，成果尚屬豐碩。未來可朝向綠色低碳之新產品開發為目標，發展出更具綠色及低碳之新產品，同時協助供應商提升綠色價值，以創造出更大的綠色商機。

4篇SCI國際期刊如下：

Amy H. I. Lee, He-Yau Kang, Cheng-Yan Yang and Chun-Yu Lin (student), 2010, "An evaluation framework for product planning using FANP, QFD and multi-choice goal programming," *International Journal of Production Research*, Vol. 48, No. 13, 3977-3997. (SCI) （**2010 I.F.= 1.033**）

Amy H. I. Lee, He-Yau Kang and Chao-Cheng Chang, 2011, "An integrated ISM-FANP-BOCR model for selecting technologies," *International Journal of Information Technology & Decision Making,* 2011, Vol. 10, No. 5, 843-871 (SCI).（**2010 I.F.= 3.139**）

Amy H. I. Lee and Chun-Yu Lin (student), 2011, "An integrated fuzzy QFD framework for new product development," *Flexible Services and Manufacturing,* Vol. 23, 26-47 (SCI).（**2010 I.F.= 0.200**）

He-Yau Kang and Amy H. I. Lee (Corresponding Author), 2011, "A fuzzy ANP model for supplier selection as applied to IC packaging," *Journal of Intelligent Manufacturing*, on-line. (SCI) （**2010 I.F.= 1.081**）

7篇國際研討會論文如下：

Chun-Yu Lin (student), Amy H. I. Lee (Corresponding Author), Oct. 12-15, 2008, "Preliminary study of a fuzzy integrated model for new product development of TFT-LCD," *2008 IEEE/INFORMS International Conference on Service Operations and Logistics, and Informatics (IEEE/SOLI'2008)*, Beijing, China, 2689-2695. (EI Conference)

Amy H. I. Lee, Chun-Yu Lin (student), July 7-11, 2009, "An integrated model for product design: A case of TFT-LCD," *GBATA Eleventh International Conference*, Prague, Czech Republic, 730-737. (ISBN 1-932917-05-5)

Chun-Yu Lin (student), Amy H. I. Lee(Corresponding Author), March 25-27, 2010, "Fuzzy integrated model for evaluating customer requirements of TFT-LCD product," *The Conference on Engineering and Business Management (EBM 2010)*, Chengdu, China, 1304-1307. (in Chinese) (ISPT Conference)

Amy H. I. Lee, He-Yau Kang, Chun-Yu Lin (student), July 12-15, 2010, "An integrated evaluation model for new product development", *The 2010 International Conference on Modeling, Simulation and Visualization Methods (MSV'10)*, Las Vegas, U.S.A., 237-242. (EI conference)

Amy H. I. Lee, He-Yau Kang, Chun Yu Lin (student), March 22-24, 2011, "A fuzzy ANP supplier selection model", *The Conference on Engineering and Business Management (EBM 2011)*, Wuhan, China, 1694-1698. (in Chinese) (ISTP Conference)

Hsin Wei Wu (student), Amy H. I. Lee(Corresponding Author), Chun Yu Lin (student), March 22-24, 2011, "The construction of green supplier selection model", *The Conference on Engineering and Business Management (EBM 2011),* Wuhan, China, 1732-1735. (in Chinese) (ISTP Conference)

Amy H. I. Lee, He-Yau Kang, Chun-Yu Lin (student), July 25-29, 2011, "An integrated model for supplier selection for a high-tech manufacturer", *Applied Mathematics, Modeling and Computational Science Conference*, Waterloo, Canada, 251.

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

100 年 08 月 10 日

報告人姓名	李欣怡	系所 職稱	科技管理學系 教授
會議 時間 地點	自 100 年 7 月 25 日至 100 年 7 月 29 日 Waterloo, Canada	本校核定 補助字號	(99)中華研國字第 063 號
會議 名稱	(中文) 應用數學、模型及計算科學國際研討會 (英文) The International Conference on Applied Mathematics, Modeling and Computational Science		
發表 論文 題目	(中文) 高科技產業廠商選擇之 FANP 整合模型 (英文) An Integrated FANP Model for Supplier Selection in a High-Tech Industry		

報告內容應包括下列各項：

一、參加會議經過

The conference provided a great opportunity for in-depth technical discussions and exchange of ideas in mathematical and computational sciences, and gave attendants a chance to learn the applications in natural and social sciences, engineering and technology, industry and finance. The conference offered to researchers, industrialists, engineers and students to present their latest research, to interact with the experts in the field, and to foster interdisciplinary collaborations required to meet the challenges of modern science, technology, and society. The conference was also a satellite meeting of the ICIAM-2011.

二、與會心得

In the conference, I presented a paper entitled: An Integrated FANP Model for Supplier Selection in a High-Tech Industry. I also served as a session chair of the session: Mathematical Modeling for Supply Chain and Product Development in High-Tech Industries. The attendance to this conference gave me, Chung Hua University and Taiwan, a great opportunity to be known by other scholars.

三、考察參觀活動(無是項活動者省略)

After the conference, I visited three universities: Wilfrid Laurier University, University of Waterloo and University of British Columbia.

四、建議

五、攜回資料名稱及內容

1. Conference Program: The International Conference on Applied Mathematics, Modeling and Computational Science.
2. CD of the proceedings.

六、其他

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Ref: An Integrated Model for Supplier Selection for a High-Tech Manufacturer.

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We thank you for your contribution to AMMCS-2011 and look forward to meeting you in Waterloo, Canada on July 25 – 29, 2011.

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AMMCS-2011, Laurier Centennial:
International Conference on
Applied Mathematics, Modeling &
Computational Science,
Waterloo, Canada, July 25-29

An Integrated Model for Supplier Selection for a High-Tech Manufacturer

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Global competitiveness has become the biggest concern of manufacturing companies, especially in high-tech industries. Improving competitive edges in an environment with rapidly changing technological innovations and dynamic customer needs is essential for a firm to survive and to acquire a decent profit. Thus, the introduction of successful new products is a source of new sales and profits and is a necessity in the intense competitive international market. A firm, in order to maintain its competitive edge, must protect its core businesses; however, it must be and usually is willing to enter buyer-supplier relationships due to limited resources. Therefore, after products are developed, the firm needs to cooperate with upstream suppliers to provide satisfactory components and parts for manufacturing final products. To achieve the benefits of buyer-supplier integration, in terms of increased internal efficiency and profitability of both parties, identifying and selecting viable suppliers is a preliminary step that needs to be properly managed.

Supplier selection works based on mathematical or quantitative decision-making approaches are increasing in the past decade. Mathematical programming (MP) models on supplier selection problem can be subdivided into linear programming, mixed integer programming, and goal programming/multi-objective goal programming (MOP). In recent years, many works of supplier selection have adopted analytic hierarchy process (AHP) or analytic network process (ANP), two famous multi-criteria decision making methodologies. Even though the research on supplier selection is abundant, the works usually only consider the critical success factors in the buyer-supplier relationship and do not emphasize the new product development (NPD) capabilities of the suppliers. The negative aspects of the buyer-supplier relationship and suppliers' NPD capabilities must be considered simultaneously in today's competitive high-tech industries. Thus, the objective of this paper is to propose an analytical approach to select critical-part suppliers under a fuzzy environment.

In this study, a comprehensive approach is proposed to select the most appropriate critical-part suppliers in order to maintain a high reliability of the supply chain. A fuzzy analytic network process (FANP) model, which incorporates the benefits, opportunities, costs and risks (BOCR) concept and considers the interrelationship among the factors, is constructed to evaluate various aspects of suppliers. A committee of experts in the industry is formed to define the supplier selection problem, and the problem is decomposed into a control hierarchy and a BOCR network. The control hierarchy is used to calculate the relative importance of benefits, opportunities, costs and risks merits. The BOCR network contains multiple factors that are positively or negatively affecting the success of the relationship. By taking into account experts' opinions and applying fuzzy set theory to consider information impreciseness, FANP is used to calculate the importance of the factors in evaluating suppliers. A performance ranking of the suppliers can then be obtained. The proposed model is adopted in a TFT-LCD manufacturer in Taiwan in evaluating the expected performance of suppliers with respect to each important factor, and an overall ranking of the suppliers can be generated as a result.

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

100 年 4 月 7 日

附件三

報告人姓名	李欣怡	服務機構及職稱	工業工程與系統管理學系副教授
會議 時間 地點	2011/03/22 至 2010/03/24 Wuhan, China	本會核定補助文號	NSC 97-2410-H-216-010-MY3-3
會議名稱	(中文) 2011 工程和商業管理國際學術會議 (英文) 2011 The 2nd International Conference on Engineering and Business Management		
發表論文題目	(中文)應用模糊網路程序分析建構供應商選擇模型 (英文) A Fuzzy ANP Supplier Selection Model		

告內容應包括下列各項：

一、參加會議經過

The 2nd International Conference on Engineering and Business Management (EBM 2011) was held in Wuhan, China. The conference served as important forum for the exchange of ideas and information to promote understanding and cooperation among the Engineering, Business, Industrial Engineering and Technology Management. In the conference, I served as a keynote speaker with the topic, "How to publish in international journals." The speech was well-received. In addition, I presented a paper entitled "A fuzzy ANP supplier selection model" in the session Engineering Management (II). The topic attracted the attention of many scholars because of the well-designed model. Some presentations by other academics were interesting, and I have been inspired with some new research directions.

二、與會心得

This ISTP international conference provided good opportunities for all scholars in exchanging information and ideas in similar research fields. In addition, I was honored to have an opportunity to address a keynote speech. I believe that the speech must have made a good image of Chung Hua University.

三、考察參觀活動(無是項活動者省略)

None.

四、建議

Attending an international conference is a good activity for scholars since a well-organized international conference can gather many scholars in similar research fields to share their ideas and experiences. I suggest Chung-Hua University to hold a business-related international conference in the near future.

五、攜回資料名稱及內容

1. Conference Program: 2011 The 2nd International Conference on Engineering and Business Management
2. CD of the proceedings.

六、其他

工程和商业管理

国际学术会议

http://www.scirp.org/conf/ebm2011/

邀 请 函

尊敬的作者：

您好！

谢谢您投稿至 2011 年工程和商业管理国际学术会议（EBM 2011）.我们很高兴地通知您，您的论文：

ID：81291
题目：A Fuzzy ANP Supplier Selection Model
作者：Amy H. I. LEE, He-Yau KANG, Chun Yu LIN

已经通过组委会的评审，被本会议录用。恭喜您！

所有被会议录用并成功完成注册的文章将会被 ISTP 检索。

我们诚挚地邀请您来参加即将于 2011 年 3 月 22 日至 3 月 24 日在武汉召开的 2011 工程和商业管理国际学术会议（EBM 2011）。

会议由美国 James Madison 大学，武汉大学，浙江大学，中华大学，工程信息研究院，重庆维普资讯有限公司和美国科研出版社合作主办，会议论文集将由美国科研出版社出版。届时将会有来自世界各地的学者与会，并能与工程和商业管理界的领先学者在会上交流。

我们期待着您的参与！

祝好！

EBM2011 组委会

2011 年 3 月 3 日

A Fuzzy ANP Supplier Selection Model

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Abstract: Human development has improved greatly since the Industrial Revolution. Today, the division of work in manufacturing industries has become popular because of globalization. Firms are concerned about how to reduce costs, increase profits and competitive ability at the same time. In addition, they want to select the most appropriate suppliers since cooperation is increasingly important for the success of firms. However, in the selection of suppliers, many factors must be considered, for instance, cost, delivery date, quality, and so on. In recent years, many experts have focused on the studies of the factors that should be considered in the supply chain and have proposed many management models. Most studies assumed that all factors are independent, but in fact many criteria are interrelated. Analytic hierarchy process (AHP) has been a popular methodology for selecting suppliers, but all factors are assumed to be independent under AHP. In addition, experts may be undecided in filling out the questionnaire. There are aspects such as costs and risks that need to be considered in selecting suppliers. To tackle these issues, this study proposes a model to integrate fuzzy analytic network process (FANP) and benefits, opportunities, costs and risks (BOCR). In Taiwan, TFT-LCD industry has been emphasized and supported by the government. Since the TFT-LCD industry is increasingly competitive and globalize nowadays, it is very important to select the most suitable suppliers in order to survive and to make a reasonable profit. Thus, a case study of a TFT-LCD firm in selecting its suppliers is presented, and the proposed model is applied to facilitate the decision process. The priorities of the factors and the ranking of the suppliers can be a recommendation for decision makers when making supplier evaluation.

Keywords: TFT-LCD; analytic network process (ANP); fuzzy set; supplier; decision analysis.

应用模糊网络程序分析建构供货商选择模型

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摘　要：工业革命之崛起掀起人类快速成长与进步，而制造业在现今全球组织分工细腻的情况之下，对于企业组织如何降低成本，同时提高利润以及提升企业竞争力，凛然成为制造业所需面临之问题，故如何选择一合适供货商更是企业成功之关键因素。供货商之选择需考虑之因子相当广泛，举凡成本、交期与质量等，近年来虽有许多专家学者针对多准则之供应链投入相当多之研究，并提出不同管理模式，但大多数研究仅假设准则间相互独立，且仅有少数将模糊性纳入研究之范畴。层级分析法对于供货商选择亦是常见之方法，但由于层级分析法之问卷设计与计算方法，虽来自于专家两两比较的重要性评选，但对于因子间之相关性皆假设其独立，且专家是否真能切确判别出两两比较之间的重要程度，意味专家在进行评估时可能受混淆的语意或不确定的感受影响填答的结果。并且在现实的全球供应链管理下，一个模型不能只包涵所有正向的评估构面，亦该根据实际上有可能发生的风险或可能提高的成本二个构面来考虑。因此本研究考虑四个基本控制层，即「优势」、「机会」、「成本」、「风险」。为使评估时更加科学与客观，对于供货商评估选择以模糊理论结合分析网络程序提出一整合模型。在台湾，政府将 TFT-LCD 列为重点政策，而在全球化之驱使下，如何选择对于企业有利之供货商即显得相当重要。因此，本研究将以台湾 TFT-LCD 厂为例，了解优良供货商所应具备之能力，并将提供给与决策者作为评估供货商绩效以及选择最适合供货商之决策依据。

关键词: TFT-LCD; 分析网络程序; 模糊集合; 供货商; 决策分析。

1 引言

在全球科技产业快速成长下，台湾企业为求永续之经营，亦投入许多时间与成本，进行组织内部之改革与产品技术的提升。半导体产业经过 20 年之努力，制造技术已成为全球市场中领航之角色，台湾 TFT-LCD 产业更成为全球重要之供货商[4]。随着 TFT-LCD 需求不断之扩张，选择优良之供货商即显得相当重要。在传统进行供货商评选时，财务方面往往会成为最重要的考虑依据，但随着质量与消费者需求之提升，仅用财务指标作为供货商评选之企业也日趋渐减，企业重视之因子亦变得相当广泛与复杂[2]。在分工细腻的今日，对于供货商选择之评比皆采取低成本、高质量短交期、富弹性与长期合作为采购标准。在台湾，半导体产业会如此成功，亦是仰赖企业组织所提供的高效率、高质量与弹性。然而，对于现今而言，制造商对供货商评选所考虑之范畴已不再是传统简单之需求，由于全球化趋使下使得产业结构大幅改变，对于制造商如何快速选择优质供货商，是制造商成败之关键。虽然部分供货商对于此领域已有不少研究与因应方案，但供货商在执行的成效上却不如预期，导致企业内部资源与成本的浪费，归根究底主要的原因是供货商不了解其所需改善之项目为何，故如何快速的协助制造商进行原物料采购以及供货商之选择，亦是相当值得研究之议题。在本研究中，以科学方式了解 TFT-LCD 供货商选择时，所需考虑之准则为何，同时以台湾前五大之 TFT-LCD 厂作为评估方案。然而，人类的感官与思维往往会因环境、时间、空间之不同，对问题的决策过程皆不尽相同，造成模棱两可之状况，尤其网络程序分析法在进行两两比较时，会使专家或学者在进行问卷填写中，对问题产生含糊不确定性，故有许多研究就将 Zadeh 于 1965 年所提出的模糊理论应用其中，将语意变量加入模糊表达式中[14]，并将模糊数导入超矩阵中，以求出评估方案之权重。本研究亦运用糊模分析网络程序法(Fuzzy Analytic Network Process, FANP)进行问题之建构，对于 TFT-LCD 供货商评选机制提出一个更完整且客观之评估模型，并透过数学模式运算找出评估方案之权重。

2 供货商选择

面临全球化趋势下，组织内部除了不断成长与技术的提升外，供应链管理对于企业整体营运更扮演着重要的角色，而对于供应链上要如何选择优良之供货商，对于企业来说更为重要，故供货商评鉴制度亦油然而生，专家学者也纷纷投入这方面之研究，并建立出许多评选机制。1966 年 Dickson 就表示质量、交期以及过去绩效为评选供货商最重要的三个准则；Lehman and O’Shaughnessy (1982)也认为影响供货商评选的准则依次为成本、品质、交期以及服务[8]; Hong et al. (2005)则是将评估准则分为交期、质量、价格与订购数量[3]。到了 2007 年，Xia 将评估供货商的关键因素认定为价格、质量以及服务，许多的学者也都证实了这样的结论，这就表示长久以来企业对整个供应链上最在乎的因子不外乎就是质量、成本、服务以及交期[13]。本研究以 TFT-LCD 供货商选择为例，如图 1 所示[1]，将供应链分为上、中及下游，上游为设备及原物料供应厂商，中游为 TFT-LCD 组装制造商，下游为各式 TFT-LCD 产品制造商，本研究将以上游供货商选择为研究目标。

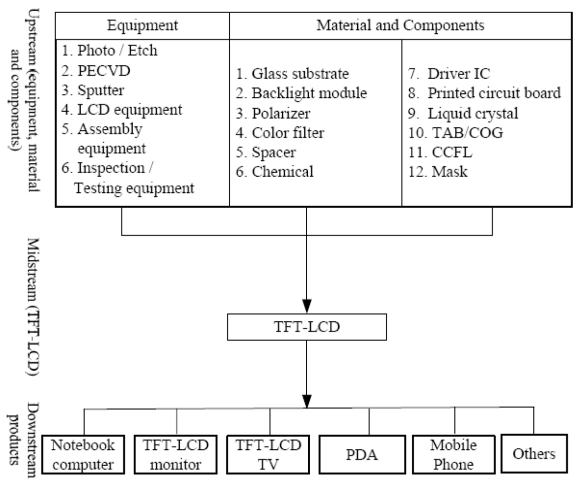

Figure 1. Supply chain of TFT-LCD
图 1. TFT-LCD 供应链
资料来源：Revised from Chang (2005)

3 建构模糊分析网络程序模型与操作步骤

Saaty 于 1996 年提出了分析网络程序法(Analytic Network Process，ANP)，处理多准则决策的问题，ANP 源自于分析层级程序法(Analytic Hierarchy Process, AHP)，为其的一般通式。AHP 的特点在于利用有系统的方法组织数量和非数量属性，并且对于决策问题提供一个结构化，且相对简单的解决方法[12]。ANP 不

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仅符合 AHP 的特点及假设，还能够处理 AHP 所不能够解决的问题。在现实生活中并不是所有问题都如同 AHP 能恰巧满足相互独立的关系和基本假设，而是经常存在着相依(Dependence)或者回馈(Feedback)的关系[10]。尽管 AHP 的方法愈来愈广泛的应用于各种不同的领域，ANP 已经利用在供货商选择相关领域。

然而，在两两成对比较问卷中，专家学者皆以一个明确数值来代表本身的想法，但明确的数值是无法反应出现实生活上所存在之不确定性以及模糊的观念。因此，为处理过于繁杂或无法解决之问题，Zadeh 于 1975 年利用语意变量(Linguistic)评比以及模糊运算(Fuzzy Arithmetic)之运用，将模糊数导入模式中，以解决专家学者在评估或判断问题之过程，所产生之模糊性问题。本研究之操作步骤如下[7]：

步骤一：定义问题

本研究针对 TFT-LCD 厂对于供货商选择时所需考虑之范畴为何，并透过 TFT-LCD 厂相关部门之资深管理人员成立项目团队。利用专家访谈与文献搜集，明确定义其需考虑之问题、目标与预期成果。同时引用 Saaty 所提出之利益、机会、成本、风险(BOCR)作为研究架构的四大构面，其中在制造商选择上需考虑之准则包含成本、质量、交期、风险，于次准则中则可考虑总成本、生产技术与控制技术等多项评估因子。

步骤二：网络问题架构之建立

透过相关研究及与群体专家进行访谈，将问题以有系统方式拆解，依据 ANP 法找出准则间的关联性，并建构出准则与准则之间相互回馈的网络架构。找出最希望合作之数间 TFT-LCD 厂进行供货商评估，网络架构如图 2 所示。

步骤三：成对比较矩阵之建立

建立专家问卷，以两两比较方式并以九点尺度量表进行专家问卷填答[6]。由于问卷设计繁琐且复杂，故本研究协同一位问卷设计者陪同专家进行填答，使评比专家对于问卷之问题能有充分之了解，进行分析与归纳，并建立成对比较矩阵，如公式 1 所示。

$$A=[a_{ij}]_{n\times n}=\begin{bmatrix}1 & a_{12} & \cdots & a_{1n}\\ a_{21} & 1 & \cdots & a_{2n}\\ \cdots & \cdots & \ddots & \vdots\\ a_{n1} & a_{n2} & \cdots & 1\end{bmatrix}_{n\times n} \quad (1)$$

$a_{ji}=\dfrac{1}{a_{ij}}$, $i,j=1,2,......n$

$a_{ij}=1$ when $i=j$, $i=1,2,......n$

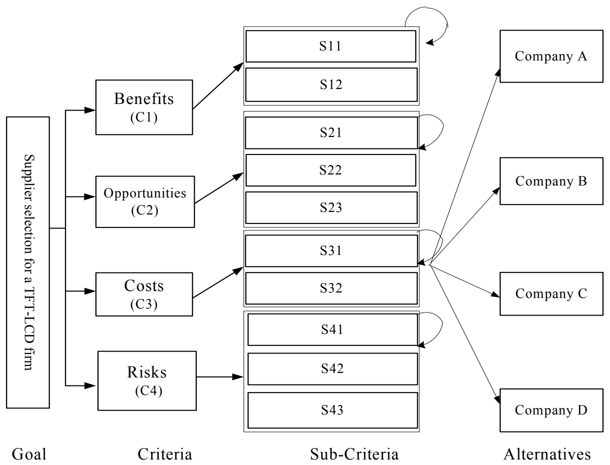

Figure 2. Supplier selection for a TFT-LCD firm
图 2. TFT-LCD 厂之供货商选择网络架构

步骤四：一致性检定

将成对比较矩阵每个因素除以该直行之加总数，可获得因子间之相对权重值，并利用公式求取出特征向量值与 λ_{max}，最后以 λ_{max} 求得最终之一致性比率(CR)，当 CR≤0.1 时，代表成对比较矩阵符合一致性[10][11]。

$$CI=\frac{\lambda_{\max}-n}{n-1} \quad (2)$$

$$CR=\frac{CI}{RI} \quad (3)$$

其中 λ_{max}：最大特征值，n：评估要数的个数，RI：为评估矩阵的随机指标值，其值是依照成对比较矩阵之阶数来订定。

步骤五：建立模糊成对比较矩阵

将每位专家所得之成对比较矩阵，透过表 1 变量转换成三角模糊数，同时建立模糊比较矩阵[6]。

步骤六：整合模糊成对比较矩阵

Saaty 认为在某些合理的假设条件下，专家问卷中为了不受极端值之影响，于数据整合上，并非运用一般算术平均数，而是运用几何平均数做为函数整合。

步骤七：解模糊化(Defuzzification)

相关研究中，对于解模糊化亦有专家学者提出许多不同之方法。Klir and Yuan (1995)所提出的重心法计算较为简易，故被应用在许多研究中，本研究亦运用重心法进行解模糊化[5] [6]。

步骤八：计算权重值与形成超矩阵

超矩阵是由多个小矩阵组合而成，在将计算后的成对比较矩阵之权重值逐一放入超矩阵中，即成为未加权之超矩阵(Unweighted Supermatrix)，并透过行随机标准化的方式得到已加权之超矩阵(Weighted Supermatrix)，最后让已加权之超矩阵间相乘数次，直到超矩阵值达到收敛为止，即形成最终之极限化矩阵(Limit Supermatrix) [9]。

Table 1. Membership functions of triangular fuzzy numbers
表 1. 三角模糊数转换表

语意变数	正数三角模糊数	正数倒数三角模糊数
非常强	(9,9,9)	(1/9,1/9,1/9)
	(7,8,9)	(1/9,1/8,1/7)
很强	(6,7,8)	(1/8,1/7,1/6)
	(5,6,7)	(1/7,1/6,1/5)
强	(4,5,6)	(1/6,1/5,1/4)
	(3,4,5)	(1/5,1/4,1/3)
普通强	(2,3,4)	(1/4,1/3,1/2)
	(1,2,3)	(1/3,1/2,1)
等同	(1,1,1)	(1,1,1)

资料来源: Lee et al., 2008.

步骤九：BOCR 整合

ANP 所获得的结果大多在探讨此目标下所得之最佳方案和权重最高或次高的准则，描述目标下较益处的正面趋向，然而，在现实的情况中一个模型并非只包涵所有正向的评估构面，应该根据实际上有可能发生的劣势或可能提高的成本二个构面来考虑。因此 Saaty 在 1996 年，提出另一个 ANP 的一般理论，在目标下设立四个次网络(构面)：利益(Benefits)、机会(Opportunities)、成本(Costs)、风险(Risks)，此方法称为「BOCR」[10]。四个构面之中，利益和机会为正向，而成本和风险为负向。结合每个方案的权重，例利用专家做两两比较问卷的搜集，并且更进一步整合每个方案在 BOCR 下的权重，可获得方案的个别综合分数结果。

一、加法(Additive)

$$= bB+oO+c(1/C)+r(1/R) \quad (4)$$

二、机率加法(Probabilistic additive)

$$=bB+oO+c(1-C)+r(1-R) \quad (5)$$

三、减法(Subtractive)

$$= bB+oO-cC-rR \quad (6)$$

四、乘法次方(Multiplicative priority powers)

$$= B^{b} O^{o} [(1/C)_{\text{Normalized}}]^{c} [(1/R)_{\text{Normalized}}]^{r} \quad (7)$$

五、乘法(Multiplicative)

$$= BO/CR \quad (8)$$

4 结论与未来研究

本研究针对台湾 TFT-LCD 厂供货商选择，以 FANP 与 BOCR 提出一整合模型，虽然近年来有几位专家学者针对供货商选择亦提出以 FANP 中的超矩阵(Supermatrix)运算模型，但其模型中假设条件过多且过于简化，其需考虑之准则因子亦不够周详。然而，本研究对于供货商选择更加深入探讨，同时将供货商选择中所许考虑之复杂因子，透过专家访谈与文献搜集，利用德菲法(Delphi method)经过反复访谈与评估，并以更客观与科学方式确认所需评估之准则。本研究提出之模型可以有效解决准则间复杂的相互依存关系，同时考虑评估者对于评比上产生语意之模糊不确定性，故加入模糊理论之概念，使回收问卷内容更符合客观标准，透过 FANP 之超矩阵运算过程，再经由极限化(Limiting)过程之计算，当矩阵内数值达到收敛时，即可得知各准则间之权重值，当权重越大者，则表示优先考虑其方案。同时在本研究于最后研究进行敏感度分析，以利了解当在不同环境与需求情况下，对于供货商选择是否产生不同变化，以做为决策者在进行供货商选择时作为评估之依据。

致　谢

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國科會補助計畫衍生研發成果推廣資料表

日期:2011/10/24

國科會補助計畫	計畫名稱: TFT-LCD 供應鏈之新產品開發及管理
	計畫主持人: 李欣怡
	計畫編號: 97-2410-H-216-010-MY3　　　　學門領域: 生產及作業管理
無研發成果推廣資料	

97 年度專題研究計畫研究成果彙整表

計畫主持人：李欣怡			計畫編號：97-2410-H-216-010-MY3				
計畫名稱：TFT-LCD 供應鏈之新產品開發及管理							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	7	7	100%	人次	
		博士生	2	2	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	4	4	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	7	7	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

   ■達成目標

   □未達成目標（請說明，以 100 字為限）

   　　□實驗失敗

   　　□因故實驗中斷

   　　□其他原因

   說明：

2. 研究成果在學術期刊發表或申請專利等情形：

   論文：■已發表 □未發表之文稿 □撰寫中 □無

   專利：□已獲得 □申請中 ■無

   技轉：□已技轉 □洽談中 ■無

   其他：（以 100 字為限）

   共發表 4 篇 SCI 國際期刊論文與 7 篇國際研討會論文

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

   在政府大力推動兩兆雙星產業下，TFT-LCD 成為目前台灣最輝煌的產業之一。隨著全球 TFT-LCD 產業邁入成熟階段，現階段將面臨劇烈之市場競爭及價格割喉戰。台灣 TFT-LCD 製造之競爭優勢源於低成本、高品質、具彈性、相關產業之專業技術與完整的群聚供應鏈等。然而在全球競爭環境下，企業生存與成功之關鍵在於如何因應市場快速變化與顧客需求的不確定性外，同時達到環保之社會責任，新產品開發(NPD)及供應鏈管理，對企業生存極為重要。因此，新產品開發將是保持競爭優勢並維持企業長期利潤之首要關鍵。儘管過去對於新產品開發有許多專家學者進行研究，但透過文獻探討發現鮮少從顧客需求、原料採購、研發與製程等產品生命週期，完整的進行深入探討與研究，故本計劃發展系統化之整合模型，以三年期分別探討 TFT-LCD 新產品開發及供應商選擇。故就上述而言，本計畫是一項創新且具學術貢獻之研究。本研究結果有利於協助 TFT-LCD 製造商或其他高科技廠商，如欲投入新產品開發(NPD)發展及後續之供應商選擇時，能透過本研究發展之模型提供決策者做為參考之依據，以縮短產品研發時間與產品失效等問題提升廠商於全球產業之優勢。對於國家而言，更能打響我國知名度並將我國產品推向全世界，以提升國際競爭力。

   吾人於此三年期計畫成果共發表 4 篇 SCI 國際期刊論文與 7 篇國際研討會論文，成果尚屬豐碩。未來可朝向綠色低碳之新產品開發為目標，發展出更具綠色及低碳之新產品，同時協助供應商提升綠色價值，以創造出更大的綠色商機。