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*Full Length Research Paper*

# An analysis of TFT-LCD industry success factors by integrating FDAHP and gray sequencing

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**As Taiwan's TFT-LCD (thin film transistor liquid crystal display) industry plays a vital global role, discussion of its success factors is importance. Previous studies of the TFT-LCD industry success factors were usually based on personal experience and subjective judgment, and did not provide specifically effective success factors assessing methods. Therefore, it is important to establish a set of TFT-LCD industry success factor evaluation methods. Based on literature review and expert interviews, this study selected and summarized 5 major perspectives, and 18 evaluation indices applicable to the TFT-LCD industry. It also established a qualitative (semantics) and quantitative (real data) integrated evaluation model of TFT-LCD industry success factors and their sequencing, using the FDAHP (fuzzy Delphi analytic hierarchy process) and gray sequencing method, in order to provide reference for the TFT-LCD industry. The result showed the top three key success factors which are innovation and R&D (research and development) capabilities, the industry chain support, and manufacturing equipment upgrades. Finally, the top three success factors are employed in sequence to illustrate managerial implications.**

**Key words:** TFT-LCD (thin film transistor liquid crystal display) industry, success factors, FDAHP (fuzzy Delphi analytic hierarchy process), gray sequencing.

## INTRODUCTION

As Taiwan's TFT-LCD industry plays a vital global role, discussion of its success factors is of importance. Since the key success factors obtained from FDAHP are expressed by semantics, evaluating packages via the subjective significance of factors is not objective (Rong et al., 2003). Therefore, this study proposes to use FDAHP to analyze the TFT-LCD industry success factors as qualitative data, and employs gray sequencing to analyze the TFT-LCD industry success factors by adopting the actual quantitative factor data from all perspectives. Finally, it integrates the quantitative (real data) and qualitative (semantics) weights to fully consider sequencing significance, regarding the success factors of semantics and quantification (Lin and Hsu, 2008).

Soh (2010) considers that the selection process for the identification of a 3PL (third party logistics) provider that best fits user requirements involves multiple criteria and alternatives and may be one of the most complex decisions facing logistics users. It is expected that the results of this study will provide a practical reference for logistics managers who want to engage the best 3PL provider. Lin and Yahalom (2009) design an evaluation system integrating balanced scorecard with activity-based budgeting to control cost and examine the achievement rate of target performance. The results of this study indicate that an organization's target and resources can be integrated by employing the BSC and ABB systems. The determination of a port's needs could be obtained using AHP (analytic hierarchy process) methods.

Deng (1982) conducted relational analysis to construct a model, and analyzed the model through prediction and decision-making. Jin and Liu (2010) consider the extended

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TOPSIS (technique for order preference by similarity to ideal solution) method which is proposed to solve multi-attribute group decision-making problems where the attribute values take the form of interval grey linguistic variables and attribute weight is unknown. To begin with, the relative concepts of interval grey linguistic variables are defined; the operation rules, the properties, and the distance between the two interval grey linguistic variables are established. Liu and Liu (2010) consider that a relative approach degree method of grey relation projection is presented to deal with multiple attribute making in which the attribute weight is unknown and attribute value is hybrid index. An application case is given to illustrate the decision making steps of the method, and it shows the validity and superiority of the method by comparing with TOPSIS.

## RESEARCH METHODOLOGY

This paper intends to determine and establish an indicative evaluation model for pharmacies through experts' opinions, experiences, and the AHP. A preliminary hierarchy framework is established through literature reviews and arrangements; then an analytic hierarchy framework is determined through two expert interviews, with a purpose of establishing a relationship of various influential indicators through an analytic hierarchy process. These procedures are followed by combining expert opinion, introduced by the FDM (fuzzy Delphi method); such a process is termed FDAHP, and is used to solve and sequence the fuzzy weights of various factors. Rong et al. (2003) suggested that, since key success factors obtained from FDAHP are expressed semantically, it is not objective to evaluate packages according to the subjective significance of its factors. Therefore, the significance of quantitative factors of various dimensions are arranged by grey relational analysis, upon the selection of important factors by FDAHP; in the event of a conflict between evaluation results and FDAHP, decision-makers could rearrange the significance order, according to grey relational analysis, with the major analytic processes shown further.

### Major steps of FDAHP and grey relation sequencing

#### *Setting up a Fuzzy pairwise comparison matrix*

Hierarchy framework is based on target problems. It analyzes the possible factors of different levels by hierarchical approach. Hierarchy framework of the problems can be constructed by expert interview and literature review. This study screens the critical factors of target problems by FDM, and establishes the hierarchy framework. Based on the fuzzy theory, this study can not only solve the experts' fuzziness of common consensus and provide the experts with a more flexible evaluation scale, but also reduce the incomplete questionnaires, and enhance the efficiency and quality of questionnaire. According to the statistical result, more objective evaluation factors can be screened. The steps are:

Step 1: Collect the opinions of decision-making group - collect the experts' ratings on importance evaluation of the factors by linguistic variable of the questionnaire.
Step 2: Construct the triangular fuzzy number - calculate the experts' evaluation of triangular fuzzy number of the factors, and recognize the triangular fuzzy number of importance of the factors. This study adopts the geometric mean of normal model proposed by Klir and Yuan (1995) to calculate the group decision common consensus, as shown in equation (1).

Let i expert's evaluation value of importance of *k* factor be $W_{ik} = (a_{ik}, b_{ik}, c_{ik})$, $i = 1, 2, ..., n$, fuzzy weights $w_k$ of *k* factors is shown in equation(1):

$$w_k = (a_k, b_k, c_k), k = 1, 2, ..., n \quad (1)$$

$$a_k = \underset{i}{Min}\{a_{ik}\}, b_k = \frac{1}{m}\sum_{i=1}^{m} b_{ik}, c_k = \underset{i}{Max}\{c_{ik}\}$$

Step 3: Defuzzify - by simple gravity, defuzzify the fuzzy weights $w_k$ of the factors into definite value $S_k$. The equation is shown as follows:

$$S_k = \frac{a_k + b_k + c_k}{3}$$

Step 4: Screen evaluation indices - set the threshold value α, and select more proper factors. The screening principles are:

When $S_k \geq \alpha$, *k* factor is regarded as evaluation index.

When $S_k < \alpha$, *k* factor is eliminated.

The matrix is established by assessment criteria derived from fuzzy semantic variables (Buckley, 1985), as listed in Table 1. Through questionnaire investigations by experts, viewpoint $B_{ijk}$ of expert K on the relative significance between factors *i* and *j* within a specific hierarchy could be obtained, and then, a fuzzy Delphi pairwise comparison matrix could be established based on questionnaire investigative results.

#### *Similarity aggregation method*

SAM (similarity aggregation method) is used to integrate assessed fuzzy values for a number of experts, where the weights are obtained by the FDM. This method uses a "similarity function" to measure the "agreement degree" of two expert opinions, according to the concept of AM (agreement matrix), which represents the agreement degree of the assessed expert values. Meanwhile, with a view to the RAD (relative agreement degree) and CDC (consensus degree coefficient) of all experts regarding overall assessed value, the CDC is treated as weights. The weighted calculation results are the assessed integrated fuzzy values of expert consensus. The calculation steps are as shown in Equations (2) to (7) (Lin, 2000):

Step 1: Calculate agreement degree $S\ \ R_k, R_1$ of any two decision-makers:

$$S\ \ R_k, R_l\ \ \in [0,1] \quad (2)$$

where $S\ \ R_k, R_l$, the agreement degree of the fuzzy assessed values of No. k and No. l experts:

$R_k, R_l$: The fuzzy assessed values of No. k and No. l experts, k , l = 1,2,..., *m*

**Table 1.** Table of triangular fuzzy semantics.

| Fuzzy number | Semantics |
|---|---|
| $\tilde{1}$=(1,1,1) | As important as |
| $2$ =(1,2,3) | Between important and slightly important |
| $\tilde{3}$=(2,3,4) | Slightly important |
| $4$ =(3,4,5) | Between slightly important and very important |
| $\tilde{5}$=(4,5,6) | Very important |
| $\tilde{6}$=(5,6,7) | Between very important and quite important |
| $7$ =(6,7,8) | Quite important |
| $\tilde{8}$=(7,8,9) | Between quite important and extremely important |
| $\tilde{9}$=(8,9,10) | Extremely important |

Source: Buckley (1985).

$u_{R_k}\ x\ , u_{R_l}\ x$ : The membership function of the fuzzy assessed values of No. $k$ and No. $l$ experts.

Step 2: Establish AM:

$$AM = \ S_{kl}\ _{n\times n},\ k,l = 1,2,\cdots,m. \quad (3)$$

If k=$l$, then $S_{kl}$ = 1; if k≠$l$, then $S_{kl}$ = $S(R_k, R_l)$

Step 3: Calculate each expert's k average agreement degree $A$ ($E_k$) of:

$$A(E_k) = \frac{1}{m-1}\sum_{\substack{l=1\\ l\neq k}}^{m} S_{kl},\quad k,l = 1,2,\cdots m. \quad (4)$$

Step 4: Calculate each experts k RAD:

$$RAD_k = \frac{A(E_k)}{\sum_{k=1}^{m} A(E_k)},\quad k,l = 1,2,\cdots m \quad (5)$$

Step 5: Calculate each experts $k$ of CDC:

$$CDC_k = \beta \times w_k + (1-\beta)\times RAD_k, k = 1,2,.. \quad (6)$$

Step 6: Weighted calculations are integrated as the fuzzy assessed values of the experts:

$$R_{ij} = \sum_{k=1}^{m} CDC_K \otimes R_{ij}^{k},\quad k,l = 1,2...m \quad (7)$$

where, $R_{ij}$ : fuzzy assessed value of significant comparison of integrated expert opinions regarding any two elements i, $j$; $R_{ij}^{k}$ : the fuzzy assessed value, given by No. k expert, regarding any two elements of i, $j$.

***Calculate the fuzzy weights of criteria factors, as shown in equations (8) and (9)***

$$Z_i = [a_{ij} \otimes ... \otimes a_{in}]^{\frac{1}{n}} \quad (8)$$

$$W_i = Z_i \otimes [Z_i \oplus ... \oplus Z_n]^{-1} \quad (9)$$

where, $a_1 \otimes a_2 \cong (\alpha_1 \times \alpha_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2)$ ; $\otimes$ is the multiplication operations of the fuzzy numbers, and $\oplus$ is the addition operations of fuzzy numbers; $W_i$ is a fuzzy weight vector of the criteria.

***Fuzzy consistency test***

Buckley (1985) pointed out that the consistency test method of fuzzy matrix $A$ could be obtained from a traditional AHP proposed by Saaty (1980) to calculate the intermediate matrix of the fuzzy number. When $A = [a_{ij}]$ conforms to the requirements of consistency testing *C.I.* (consistency index) < 0.1; *C.R.* (consistency ratio) < 0.1, it is concluded that $\tilde{A} = [a_{ij}]$ of FAHP (fuzzy analytic hierarchy process) is also consistent.

***Comprehensive evaluation of fuzzy weights (defuzzification)***

The weights of assessment items must be converted into fuzzy values through defuzzification. In this paper, defuzzification is conducted by the gravity method. When a fuzzy number is a triangular fuzzy number, the defuzzification process is shown by the following expression: assuming it is a triangular fuzzy number, the defuzzified weight $DF_{ij}$ is, as shown in equation (10):

$$DF_{ij} = \frac{[(\gamma_{ij} - \alpha_{ij}) + (\delta_{ij} - \alpha_{ij})]}{3} + \alpha_{ij} \quad (10)$$

where, $\alpha_{ij}$ is the minimum value of the triangular fuzzy number, $\delta_{ij}$ is the maximum value of the triangular fuzzy number, and $\gamma_{ij}$ is the median of the triangular fuzzy number.

***Arrangements of significant assessment factors, through grey relational analysis***

The degree of relationship among sub-systems or elements could be evaluated through grey relational analysis (Deng, 1982), and important influential factors for the development trend are determined, in order to learn the major features of the system the following steps are followed.

Step 1: normalize original data. Normalization occurs by dividing the original data $x_i(k)$ by the mean value of its sequence, as shown in equation (11):

$$r_i(k) = \frac{x_i(k)}{\sum_{k=1}^{N} \frac{x_i(k)}{N}}, i = a,...,d \qquad k = A,...,N \quad (11)$$

Step 2: designate a standard sequence, and calculate the difference sequence. Take the mean value as a standard sequence, that is sequence 0; the difference sequence $\Delta_{0i}(k)$ indicates the absolute difference of element k, between other sequence i and standard sequence 0, as shown in equation (12):

$$\Delta_{0i}(k) = \left| r_0(k) - r_i(k) \right|, i = 1,2,3,... \quad k = A,...,N \quad (12)$$

Step 3: calculate maximal difference $\Delta_{\max}$ and minimal difference $\Delta_{\min}$, as shown in equations (13) and (14):

$$\Delta_{\max} = \underset{i,k}{Max}\, \Delta_{0i}(k) \quad (13)$$

$$\Delta_{\min} = \underset{i,k}{Min}\, \Delta_{0i}(k) \quad (14)$$

Step 4: calculate grey relational coefficient $\gamma_{0i}(k)$. The relational coefficient $\gamma_{0i}(k)$ is defined as below, where $\varsigma$ is the adjustment factor, as shown in equation (15):

$$\gamma_{0i}(k) = \frac{\Delta_{\min} + \varsigma \cdot \Delta_{\max}}{\Delta_{0i}(k) + \varsigma \cdot \Delta_{\max}} \quad (15)$$

Step 5: calculate the grey relationship $\Gamma_{0i}$ between every sequence and standard sequence, where the grey relationship $\Gamma_{0i}$ is defined as below, and shown in equation (16):

$$\Gamma_{0i} = \sum_{k=A}^{N} \frac{\gamma_{0i}(k)}{N} \quad (16)$$

***Obtain the percentage weight of parameter $DF_{ij}$ by FDAHP, and obtain the percentage weight of parameter $\Gamma_{0i}$ by gray sequencing***.

Add parameters $\alpha_1$ and $\alpha_2$, with an additional 50% weight each in order to obtain the qualitative and quantitative integrated weights of key success factor $W_i$, as shown in equation (17):

$$W_i = (\alpha_1 \times DF_{ij}) + (\alpha_2 \times \Gamma_{0i}) \quad (17)$$

Sequence the $W_i$ of all key success factors, and discuss the management implications of the top three key success factors.

## EXAMPLE ILLUSTRATION

With Taiwan's TFT-LCD industry as the research subject, this paper first establishes a preliminary indicative hierarchical structure by literature review and summary. Then, the indicative hierarchical structure is established and twice confirmed by expert interviews. At the first stage, 12 management experts from R&D, sales, and production departments of the top three TFT-LCD manufacturers are interested in sales volume in Taiwan, and 11 expert questionnaires are collected to establish key success factors for analysis of the 18 indicators and 5 perspectives. The extracted 18 indicators, in 5 perspectives, are as shown in Table 2. The construction approaches, as described in earlier, are key success factors in a chain management system.

### Application of SAM

In order to integrate the opinions of the 11 experts regarding the questionnaire assessment items of identical criteria and elements (E1-E11), this study uses the SAM method, as introduced earlier for integrating the weighted points of any two factors under the same expert

**Table 2.** Summary of TFT-LCD industry success factors.

| Target layer | Rule layer | Secondary rule | Factor |
|---|---|---|---|
| TFT-LCD industry success factors | 1. Integrated R&D capabilities | i. Quality capacity (A) | i. High yield manufacturing capacity A1<br>ii. Percent defect improvement capacity A2<br>iii. Long term reliability (stability) A3 |
| | | ii. Technical capacity (B) | i. Correct product development direction B3<br>ii. Manufacturing equipment upgrading B2<br>iii. Innovation and R&D capabilities B1 |
| | 2. Logistic support capabilities | i. Manufacturing and logistic support (C) | i. Volume production capacity C1<br>ii. Product width C2<br>iii. Product depth C3<br>iv. Production management capacity C4<br>v. Staff quality C5 |
| | | ii. Market competition (D) | i. Marketing channel control capacity D1<br>ii. Price competitiveness D2<br>iii. Delivery stability D3 |
| | | iii. Service and support capabilities (E) | i. Fund raising capacity E1<br>ii. Perfect logistics E2<br>iii. Industrial chain support E3<br>iv. Brand or corporate image E4 |

perspective, in order to obtain an objective assessed value in compliance with expert consensus. Taking expert opinion of various criteria under (technical capacity B) correct product development direction (B1), and innovation and R and D capabilities (B3) as examples, this study explains the FAHP expert opinion integration processes, and weight calculation methods. Examples of the expert's original opinions are as shown in Table 3.

First, assess and compare original expert opinion to obtain concurring expert opinions, under various rules of (technical capacity B), correct product development direction (B1), and innovation and R and D capabilities (B3) as between 0 and 1; and then establish the asymmetric "AM" between the experts; where, SUM is the sum of the intersection between experts, excluding the 1 on the diagonal line, A(E) is the number from division of the SUM by the number of the expert, minus 1, and the percentage of each expert in the overall assessment value is the RAD, namely, the relative weigh of the sum of A(E). As each expert represents the same "CDC", each expert is equal to its RAD; and then, integrates expert opinion, as shown in the Tables 4 and 5, to obtain the fuzzy assessed values commonly agreed upon by all experts (Table 4, Equations 2 to 7).

The integrated result is the integrated fuzzy number of the opinions of 11 experts. Similarly, the integrated fuzzy assessed values in all the perspectives of various layers can be obtained. The examples of the integrated fuzzy assessed values and the fuzzy pairwise comparison matrix in all the perspectives of various layers are as

**Table 3.** Expert opinion under the rules of the third layer (technical capacity B)-Innovation and R&D capabilities (B1) and correct product development direction (B3).

| (1) / (2) | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 | E11 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | $\tilde{6}$ | $\tilde{2}$ | $\tilde{5}^{-1}$ | $\tilde{4}^{-1}$ | $\tilde{2}^{-1}$ | $\tilde{3}$ | $\tilde{8}^{-1}$ | $\tilde{5}$ | $\tilde{8}^{-1}$ | $\tilde{2}$ | $\tilde{3}^{-1}$ | B2 |
| B1 | $\tilde{2}$ | $\tilde{8}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{4}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{2}$ | $\tilde{5}^{-1}$ | $\tilde{2}$ | $\tilde{4}^{-1}$ | $\tilde{6}^{-1}$ | $\tilde{5}^{-1}$ | B3 |
| B2 | $\tilde{2}$ | $\tilde{8}^{-1}$ | $\tilde{5}$ | $\tilde{3}^{-1}$ | $\tilde{2}^{-1}$ | $\tilde{4}^{-1}$ | $\tilde{5}$ | $\tilde{5}^{-1}$ | $\tilde{4}$ | $\tilde{5}^{-1}$ | $\tilde{3}^{-1}$ | B3 |

(1): expert; (2): rule.

**Table 4.** Expert opinion agreement matrix - correct product development direction (B1) and innovation and R&D capabilities (B3).

| | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 | E11 | SUM | A(E) | RAD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E1 | 1 | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.8 | 0.18 | 0.06 |
| E2 | 0.8 | 1 | 0 | 0 | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0.25 | 0.08 |
| E3 | 0 | 0 | 1 | 0.126 | 0.125 | 0.2 | 0 | 0 | 0 | 0.123 | 0 | 1.574 | 0.1574 | 0.05 |
| E4 | 0 | 0 | 0.126 | 1 | 1 | 0 | 0 | 0 | 0.123 | 1 | 1 | 4.249 | 0.4249 | 0.14 |
| E5 | 0 | 0.7 | 0.125 | 1 | 1 | 0 | 0 | 0 | 0.123 | 1 | 1 | 4.948 | 0.4948 | 0.16 |
| E6 | 0 | 0 | 0.2 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2.2 | 0.22 | 0.07 |
| E7 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0.16 | 0 | 0 | 1.16 | 0.116 | 0.04 |
| E8 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 0.2 | 0.07 |
| E9 | 0 | 0 | 0 | 0.123 | 0.123 | 0 | 0.16 | 0 | 1 | 0.123 | 0.123 | 1.652 | 0.1652 | 0.05 |
| E10 | 0 | 0 | 0.123 | 1 | 1 | 0 | 0 | 0 | 0.123 | 1 | 1 | 4.246 | 0.4246 | 0.14 |
| E11 | 0 | 0 | 0.123 | 1 | 1 | 0 | 0 | 0 | 0.123 | 1 | 1 | 4.246 | 0.4246 | 0.14 |

illustrated in Tables 5 and 6.

## Calculation of FAHP fuzzy weight and fuzzy eigenvalue of maximum

Take perspectives of technical capacity B as examples, by decision-makers' opinions, break down the fuzzy pairwise comparison matrix into the left margin, the median and the right margin matrices as shown in the following; according to the methods provided earlier, apply equations (8) and (9) to calculate relevant parameters:

$$A_L^0 = \begin{bmatrix} 1 & 0.896 & 0.351 \\ 1/1.586 & 1 & 0.987 \\ 1/0.854 & 1/1.687 & 1 \end{bmatrix}, A_M^0 = \begin{bmatrix} 1 & 0.785 & 0.588 \\ 1/0.785 & 1 & 1.268 \\ 1/0.588 & 1/1.268 & 1 \end{bmatrix}, A_U^0 = \begin{bmatrix} 1 & 1.586 & 0.854 \\ 1/0.896 & 1 & 1.687 \\ 1/0.351 & 1/0.987 & 1 \end{bmatrix}$$

Take the median matrix $A_M^0$ as an example; illustrate the solving of FAHP fuzzy weight and fuzzy eigenvalue of maximum.

### *Calculate fuzzy weight*

Input the median matrix AM into weight calculation

**Table 5.** Integrated expert opinion fuzzy number - correct product development direction (B1) and innovation and R&D capabilities (B3).

| Expert | Weight (Wi) | Expert opinion (Li) | Integrated (Wi×Li) | Expert opinion (Mi) | Integrated (Wi×Mi) | Expert opinion (Ui) | Integrated (Wi×Ui) |
|---|---|---|---|---|---|---|---|
| E11 | 0.06 | 1 | 0.060 | 2 | 0.120 | 3 | 0.180 |
| E2 | 0.08 | 0.13 | 0.010 | 0.14 | 0.011 | 0.17 | 0.014 |
| E3 | 0.05 | 0.25 | 0.013 | 0.33 | 0.017 | 0.5 | 0.025 |
| E4 | 0.14 | 0.2 | 0.028 | 0.25 | 0.035 | 0.33 | 0.046 |
| E5 | 0.16 | 0.25 | 0.040 | 0.33 | 0.053 | 0.5 | 0.080 |
| E6 | 0.07 | 1 | 0.070 | 2 | 0.140 | 3 | 0.210 |
| E7 | 0.04 | 0.17 | 0.007 | 0.2 | 0.008 | 0.25 | 0.010 |
| E8 | 0.07 | 1 | 0.070 | 2 | 0.140 | 3 | 0.210 |
| E9 | 0.05 | 0.2 | 0.010 | 0.25 | 0.013 | 0.33 | 0.017 |
| E10 | 0.14 | 0.14 | 0.020 | 0.17 | 0.024 | 0.2 | 0.028 |
| E11 | 0.14 | 0.17 | 0.024 | 0.2 | 0.028 | 0.25 | 0.035 |
| Expert opinion integrated results | | Σ(Wi×Li) | 0.351 | Σ(Wi×Ui) | 0.588 | Σ(Wi×Ui) | 0.854 |

**Table 6.** SAM-integrated fuzzy pairwise comparison matrix of the third layer (technical capacity B).

| Variable | B1 | B2 | B3 |
|---|---|---|---|
| B1 | (1,1,1) | (0.896,0.785,1.586) | (0.351,0.588,0.854) |
| B2 | (1/1.586,1/0.785,1/0.896) | (1,1,1) | (0.987,1.268,1.687) |
| B3 | (1/0.854,1/0.588,1/0.351) | (1/1.687,1/1.268,1/0.987) | (1,1,1) |

equations (8) and (9) to determine the factor weights of the perspective. Where, the calculation of the weights of $B_1$, $B_2$ and $B_3$, under technical capacity B is as follows:

$$B_1 = (1 \times 0.785 \times 0.588)^{1/3} = 0.773$$

$$B_2 = (1/0.785 \times 1 \times 1.268)^{1/3} = 1.173$$

$$B_3 = (1/0.588 \times 1/1.268 \times 1)^{1/3} = 1.103$$

$W_1$=0.773/(0.773+1.173+1.103)=0.254

$W_2$=1.173/(0.773+1.173+1.103)=0.384

$W_3$=1.103/(0.773+1.173+1.103)=0.362

Therefore, $W_1$, $W_2$, $W_3$ are the weights of $B_1$, $B_2$, $B_3$, respectively.

***Calculation of the fuzzy eigenvalue of maximum $\lambda_{\max}$***

By equation, the calculation of $\lambda_{\max}$ is:

$$A \cdot W = \lambda_{\max} \cdot W$$

Therefore, $\lambda_{\max} = 3.023$

***The fuzzy weights and consistency testing of various assessment criteria***

Repeat steps (1) and (2) to obtain the fuzzy weights of all the perspectives and assessment factors for the calculation of the *C.I.* and the *C.R.* In the fuzzy weight, and consistency tests of various assessment criteria, *C. I.* $\leq 0.1$ and *C.R.* $\leq 0.1$ are all in line with the norms. Where, in case of perspectives under the third layer (technical capacity B), $\lambda_{\max} = 3.023$, *C. I.* $\leq 0.1$ and *C.R.* $\leq 0.1$. The fuzzy weights of the perspectives of the third layer (technical capacity B) are as shown in Table 7.

**Table 7.** The fuzzy weight of the third layer in the perspectives of (technical capacity B).

| Technical capacity B factor | Fuzzy weight |
|---|---|
| Correct product development direct B1 | (0.3648, 0.2540, 0.3932) |
| Manufacturing equipment upgrading B2 | (0.3235, 0.3840, 0.3464) |
| Innovation and R&D capabilities B3 | (0.3798, 0.3620, 0.2624) |

**Table 8.** FAHP triangular fuzzy weight vector and integrated results in the perspectives of (technical capacity B).

| Technical capacity (B) | 0.2671 | 0.2245 | 0.2771 | Defuzzied number |
|---|---|---|---|---|
| Correct product development direction B1 | 0.3648 | 0.2540 | 0.3932 | 0.0567 |
| Manufacturing equipment upgrading B2 | 0.3235 | 0.3840 | 0.3464 | 0.0724 |
| Innovation and R&D capabilities B3 | 0.3798 | 0.3620 | 0.2624 | 0.0814 |

### The overall FAHP layers' fuzzy weights

Multiply the weight of each layer, also known as the Eigenvector, by the upper layer's Eigenvector to obtain the global weight of each layer (the comprehensive Eigenvector). For example, the weights of the overall R&D capabilities of the first layer of the target layer are 0.2671, 0.2245, and 0.2271, the fuzzy weights of the technical capacity (B) perspective of the second layer are 0.3235, 0.3840, and 0.3464, and the technical capacity (B) 0.2245 is a multiplication of 0.0862 by 0.3840. The TFT-LCD industry key success factor assessment of FDAHP triangular fuzzy weight and the defuzzified numbers are obtained by equation (10). Table 8 illustrates examples of the triangular fuzzy weight vectors and integrated results of all perspectives of technical capacity (B) by FAHP.

The defuzzification and sequencing results of perspectives, by FAHP, are as shown in Table 9. The top three factors of expert weights are innovation and R&D capabilities (B3), the industry chain support (E3), and manufacturing equipment upgrades (B2) , respectively.

### Perspective sequencing of quantitative factors by gray sequencing analysis

By gray sequencing, and equations (11) to (16), select the top three TFT-LCD manufacturers, in terms of sales volumes, and analyze the TFT-LCD industry success factors by gray sequencing analysis, as shown in Table 10.

### Integration of semantics and quantification weight assessment

Finally, integrate the FDAHP (semantics) and gray sequencing (quantification) weight assessment, and list the TFT-LCD industry key success factors', ranked as shown in Table 11. The top three key success factors are innovation and R&D capabilities, industry chain support, and manufacturing equipment upgrades.

## CONCLUSIONS AND FUTURE STUDIES

Taking into consideration the FDAHP (semantics) and the quantification (real data) of gray sequencing, this study lists the priority sequencing of the TFT-LCD industry key success factors, as shown in the Table 11. The top three key success factors are innovation and R&D capabilities, the industry chain support, and manufacturing equipment upgrades, illustrated as follows.

### Innovation and R&D capabilities

Patents, including those related to manufacturing processes and products, are the main factors that affect product costs, quality, and characteristics. Such patents are mainly owned by Japanese players with advanced technologies. The TFT-LCD panel manufacturers in Taiwan have to pay large royalties to foreign companies, which cut profits considerably. Therefore, it is very important for high-tech companies in Taiwan to establish and upgrade their own patents. The TFT-LCD panel manufacturing industry's "R&D" can be roughly divided into:

a. Improvement in manufacturing processes: A good R&D result will take into consideration the manufacturing demands of product design to improve manufacturing efficiency and production performance, enhance product reliability, and lower production costs, as well as improving produce competitiveness.
b. New product development: the high standards and high quality products developed by panel manufacturers

**Table 9.** Defuzzification and sequencing results in perspectives by FAHP.

| **Quality capacity (A)** | | **Defuzzied number** | **Percentage** |
|---|---|---|---|
| High yield manufacturing capacity | A1 | 0.0698 | 5.82 |
| Percentage defective improvement capacity | A2 | 0.0632 | 5.27 |
| Long term reliability (stability) | A3 | 0.0598 | 4.99 |
| | | | |
| Technical capacity (B) | | | |
| Correct product development direction | B1 | 0.0567 | 4.81 |
| Manufacturing equipment upgrading | B2 | 0.0724 | 5.95 |
| Innovation and R&D capabilities | B3 | 0.0814 | 6.71 |
| | | | |
| Manufacturing and logistic support (C) | | | |
| Volume production capacity | C1 | 0.0673 | 5.61 |
| Product width | C2 | 0.0689 | 5.75 |
| Product depth | C3 | 0.0689 | 5.75 |
| Production management capacity | C4 | 0.0662 | 5.52 |
| Staff quality | C5 | 0.0567 | 4.73 |
| | | | |
| Market competition (D) | | | |
| Marketing channel control capacity | D1 | 0.0659 | 5.50 |
| Price competitiveness | D2 | 0.0643 | 5.36 |
| Delivery stability | D3 | 0.0636 | 5.30 |
| | | | |
| Service and support capabilities (E) | | | |
| Fund raising capacity | E1 | 0.0641 | 5.35 |
| Perfect logistics | E2 | 0.0612 | 5.10 |
| Industrial chain support | E3 | 0.0786 | 6.55 |
| Brand or corporate image | E4 | 0.0711 | 5.93 |

could win the recognition of customers, and would affect the market demands of the old products, leading to effects on profitability. To sum up, facing fast changing economic environments, “R&D” capabilities are a key factor for the satisfaction of customer demands, and thus, are increasingly important. According to data published by the ITIS (industry and technology intelligence services), from 2001 to 2004, the total number of patents owned by the top 5 TFT-LCD panel manufacturers in Taiwan is 319, which ranks fourth after LPL at 680, Sharp at 349, and Hitachi at 328. However, Taiwanese companies own less patents, on an individual basis, as Taiwanese companies mainly perform OEM (original equipment manufacturer) and ODM (original design manufacturer) business in the long term.

## Industrial chain support

Service is not only general care and after sales guarantees. It involves the establishment of hardware and a professional image, as well as global support. As far as the TFT-LCD industry is concerned, it takes time to establish good services. With strong industrial chain support, a business could ensure high efficiency and better overall manufacturing processes, with higher flexibility than rivals. At present, industrial chains integrating flexible and efficient processes enable Taiwanese manufacturers a place in the market.

Industrial chain support includes new product development, simplification of manufacturing process and arrangement of manufacturing and production of key components and downstream channels and brand. Thus, the supply sources of key components can be controlled by the upstream manufacturers, and related costs can be greatly reduced. Therefore, companies need to stabilize the source of goods by transfer investment or strategic alliance. Downstream brands and customer relationship are also the operational keys. AUO company is supported by BenQ company and CMO company is supported by Nexgen company. CMO company also has the most diverse partners of panel. Besides Toshiba company and Panasonic company, HP company, Teco company and Sharp company, which are the two top LCD TV (television) companies in Taiwan, are also the clients. With Sony as a client, CMO company is expecting prosperous business. The characteristics and difference of two companies will be enhanced. As most companies

**Table 10.** TFT-LCD industry success factors by gray sequencing.

| | T1 | T2 | T3 | Gray sequencing calculation result | | Note to quantitative factor |
|---|---|---|---|---|---|---|
| Annual average sales volume | 650 | 500 | 400 | ($\Gamma_{ij}$) | % | NT$: 100 million (annual average sales volume) |
| High yield manufacturing capacity A1 | 86% | 80% | 78% | 0.881 | 6.1 | Manufacturing yield rate; the recent year |
| Percent defective improvement capacity A2 | 6% | 5% | 4% | 0.752 | 5.2 | Percent defective improvement capacity; annual average |
| Long term reliability (stability) A3 | 83% | 78% | 76% | 0.692 | 4.8 | Yield rate; annual average |
| Correct product development direction B1 | 10% | 16% | 19% | 0.711 | 4.9 | Estimated profit gap after introduction of new products; 20~30% |
| Manufacturing equipment upgrading B2 | 300 | 250 | 195 | 0.928 | 6.4 | Annual average manufacturing equipment upgrading costs: NT$:100 million |
| Innovation, R&D capabilities B3 | 158 | 92 | 71 | 0.962 | 6.6 | Number of annual average patents |
| Volume production capacity C1 | 650K | 550K | 420K | 0.798 | 5.5 | Volume production capacity of all the manufacturing facilities in recent years |
| Product width C2 | 4 | 3 | 2 | 0.909 | 6.3 | NB panel, monitor panel, tv panel, medium and small-sized panel. |
| Product depth C3 | 10 | 6 | 4 | 0.891 | 6.11 | Glass substrate size |
| Production management capacity C4 | 6 | 4.2 | 3 | 0.791 | 5.5 | Investment ERP system; NT$ 10 million |
| Staff quality C5 | 20% | 16% | 13% | 0.636 | 4.4 | Percentage of employees with graduate degree |
| Marketing channel control capacity D1 | 36 | 28 | 20 | 0.782 | 5.4 | Number of global operating facilities |
| Price competitiveness D2 | 5 | 6 | 2 | 0.782 | 5.4 | Types of lowest priced product/season |
| Delivery stability D3 | 1 | 3 | 3 | 0.688 | 4.7 | Delivery delay/season |
| Fund raising capacity E1 | 450K | 300K | 200K | 0.732 | 5.0 | Seasonal volume production of generation-5 factories |
| Perfect logistics E2 | 2100 | 1900 | 1800 | 0.741 | 5.1 | Worldwide retailers and after-sales service stations |
| Industrial chain support E3 | 90% | 75% | 70% | 0.943 | 6.5 | Percentage of industrial chain support by product |
| Brand or corporate image E4 | 6 | 3 | 1.5 | 0.887 | 6.09 | Production promotional costs/season; NT$10 million |

are facing competitions in different supply chains, the relationship between one component supplier and several clients will gradually transform from competition to cooperation. HannStar company invests in color filter companies such as Sintek company instead of self-constructed color filter companies in the vertical integration. AUO company also brings in filter manufacturers. Thus, to some degree, TFT-LCD industry in Taiwan has demonstrated professional work division of upstream and downstream industries and solid vertical supply chain system.

### Manufacturing equipment upgrading

The TFT-LCD industry is a capital and technology-intensive industry, which starts with array semi-conductor manufacturing technologies, then integrates cell LCD manufacturing technology, and adds module assembly technology in the later stages. Most TFT-LCD manufacturing technologies in Taiwan are transferred from Japanese companies. Major Taiwanese TFT-LCD manufacturers, their technology transferees, and technology introduction patterns: Japan is the birthplace of LCD panel manufacturing technology. In the beginning, Taiwanese panel manufacturers purchased manufacturing technology and equipment from Japan. Japanese companies were willing to transfer relatively outdated manufacturing technologies (generations 2 and 3 technologies).Most Taiwanese companies worked with Japanese companies to develop, or self-developed, new production technologies and equipment. W ith the continuous establishment of panel manufacturers and new generation

**Table 11.** Integrated qualitative and quantitative factor weight ranking.

| Factor | Integrated weight (%) | Resulting ranking |
|---|---|---|
| High yield manufacturing capacity A1 | 0.354 | 6 |
| Percent defective improvement capacity A2 | 0.273 | 12 |
| Long term reliability (stability) A3 | 0.238 | 16 |
| Correct product development direction B1 | 0.236 | 17 |
| Manufacturing equipment upgrading B2 | 0.381 | 3 |
| Innovation and R&D capabilities B3 | 0.445 | 1 |
| Volume production capacity C1 | 0.309 | 8 |
| Product width C2 | 0.360 | 5 |
| Product depth C3 | 0.353 | 7 |
| Production management capacity C4 | 0.301 | 9 |
| Staff quality C5 | 0.207 | 18 |
| Marketing channel control capacity D1 | 0.296 | 10 |
| Price competitiveness D2 | 0.289 | 11 |
| Delivery stability D3 | 0.252 | 15 |
| Fund raising capacity E1 | 0.270 | 13 |
| Perfect logistics E2 | 0.261 | 14 |
| Industrial chain support E3 | 0.426 | 2 |
| Brand or corporate image E4 | 0.363 | 4 |

the market size of LCD equipment continuously expanded. In 2004, a production capacity competition of panel manufacturers resulted in the creation of a number of generations 5 and 6 factories, and planned production lines, which led to a 98% rapid growth in the manufacturing equipment market, causing a TFT-LCD equipment market peak. Afterwards, as the panel market became gradually saturated, and generation 7 technologies were yet to mature, the returns on investments were affected. Therefore, the demands on LCD equipment gradually lessened to negative growth. The equipment in the emerging panel industry of Taiwan changed rapidly, and in a few years, panel manufacturers had upgraded equipment from generations 3, 4 and 5, continuing to the present with generation 7 upgrading to generations 7.5 and 8. Manufacturing equipment becomes larger and larger and can no longer be imported from abroad; therefore, manufacturing technology had to be self-developed by Taiwanese companies. Obtaining next generation production technologies and equipment has become an important factor to Taiwanese panel manufacturers to ensure continued participation fierce production capacity competition. In future studies, this method may be applied in other industry to obtain an overall assessment of expert opinions and real data; or integrate other semantics and quantification (real data) assessment methods to render different industrial success factor assessment results to be more convincing.

## REFERENCES


Buckley JJ (1985). Fuzzy Hierarchical analysis. Fuzzy Sets Syst., 17: 233-247.

Deng JL (1982). Control problems of grey systems. Syst. Control Lett., 1: 288-294.

Jin F, Liu P (2010). The multi-attribute group decision making method based on the interval grey linguistic variables. Afr. J. Bus. Manage., 4(17): 3708-3715.

Klir G.J, Yuan B (1985). Fuzzy Sets and Fuzzy Logic–Theory and Application. Prentice-Hall Inc., New Jersey.

Lin JY (2000). A study on the Environmental Quality Evaluation Method for Industrial Parks. J. Publ. Affairs Rev., 1: 63-90.

Lin LZ, Hsu TH (2008). The Qualitative and Quantitative Models for Performance Measurement Systems: The Agile Service Development. Qual. Quant., 42(4): 445-476.

Lin WC, Yahalom S (2009). Target performance management for an international shipping harbor: An integration activity-based budgeting with a balanced scorecard approach, the case of Keelung Harbor. Afr. J. Bus. Manage., 3(9): 453-462.

Liu W, Liu P (2010). Hybrid multiple attribute decision making method based on relative approach degree of grey relation projection. Afr. J. Bus. Manage., 4(17): 3716-3724.

Rong C, Takahshi K, Wang J (2003). Enterprise waste evaluation using the analytic hierarchy process and fuzzy set theory. Prod. Plan. Control, 14: 90-103.

Saaty TL (1980). The Analytic Hierarchy Process. McGraw-Hill: New York.

Soh S (2010). A decision model for evaluating third-party logistics providers using fuzzy analytic hierarchy process. Afr. J. Bus. Manage., 4(3): 339-349.