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論文題目

# A Hybrid Model for Technology Assessment

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## Abstract

Technology assessment, which influences the advantages of firms or countries, is a multi-criteria decision issue. This study proposes a hybrid approach integrating the interpretative analysis, the fuzzy Delphi method and the analytic hierarchy process (AHP) to construct a technology assessment model for the emerging technology of organic emitting light diode (OLED) display. The interpretative analysis is used to identify the prospects and the problems within the development of aimed technology field. The fuzzy Delphi method is applied to integrate the experts' judgments toward the importance of technology assessment criteria. The AHP is adopted in this study to derive the weights of technology assessment criteria. The weights distributed to the prospects and the problems can serve as a reference for the industry applying this technology in order to make R&D planning and strategy. In this study, Taiwan is a research base for its OLED display industry which has occupied the third position in the global market since 2005. The purpose of this paper is to offer an example as to how a technology firm or even a country can evaluate or position certain emerging technology in the process of resource investment decision-making. Finally, some strategic and managerial suggestions according to the results are drawn in this research for related policy makers.



Keywords: technology assessment, interpretative analysis, fuzzy Delphi method, analytic hierarchy process

## 1. Introduction

Technology assessment is one of the most challenging decision-making areas in technology management that has drawn attention among researchers and practitioners in public and private domain (Tran & Daim, 2008). At organizational level, a company has to evaluate and then invest in a technology field with comparative advantage from various technology alternatives under multiple criteria and within a complicated environment (Yu et al., 1998). Technology-based enterprises rely on the renewal of existing technological resources and exploitation of new technologies to remain competitive and to sustain growth (McNamara & Baden-Fuller, 1999). This type of firm needs expert technological planning and strategizing to maintain its competitive advantages or to grasp new opportunities. Technology assessment helps these firms to determine a suitable technology field with advantage in a competitive environment (Clark, 1989; Morone, 1989; Torkkeli & Tuominen, 2002; Lee & Song, 2007). At the national level, evaluating and determining to support key emerging technologies helps countries to establish their strategic advantage in the international market (Khalil, 2000). These all need wise assessing and decision-making.

However, technology assessing is becoming more difficult due to the increasing complexity of technologies, convergence of technologies, abundance of technological options, rising costs of technological development, and the rapid diffusion of technologies (Berry & Taggart, 1994; Steensma & Fairbank, 1999; Lei, 2000). In addition, technology assessment is a multi-criteria decision-making challenge (Lamb & Gregory, 1997). To engage this kind of challenge, most technology assessment methodologies evaluate several technological alternatives against a set of criteria in order to select a suitable technology (Cho & Kwon, 2004; Tran & Daim, 2008). However, decision-makers might encounter an assessment of one specific technology for further R&D planning or strategizing to establish competitiveness and even an investment decision in the industry applying this technology. Under such context, the traditional technology evaluation techniques are not simply applied to evaluate only one specific technology field. Hence, an improved technology assessment method is suggested to develop in order to conduct the technology assessment.

To cope with the technology assessment of a specific technology, decision-makers need to widely gather and learn the information of the potential effects associated with the R&D of the targeted technology field, including the aesthetic, environmental, and social issues (Hellström, 2003; Palm & Hansson, 2006; Wilhite & Lord, 2006; Roelofsen et al., 2008). Thus, the first step is to identify the technology assessment criteria as positive prospects or negative problems in regard to the targeted technology. In this study, the technology assessment criteria are attributed to prospects or problems by clarifying the technological context and concerns existing in the development of

OLED display technology with interpretative paradigm.

After the identification of prospects and problems, the importance of technology assessment criteria are integrated by adopting fuzzy Delphi method which facilitates the survey of decision-makers' opinions economically and effectively (Ishikawa et al., 1993). After integrating important technology assessment criteria by fuzzy Delphi method, decision-makers have to evaluate the targeted technology based on a set of criteria (Torkkeli & Tuominen, 2002; Lamb & Gregory, 1997). The analytic hierarchy process (AHP) is a widely used tool for analyzing this type of problem. AHP, which uses pair comparisons and matrix algebra to identify and weigh the criteria, is a multi-attribute decision analysis tool. The AHP provides a systematic approach to identifying criteria, their relationship, and their weights on which to carefully base decisions (Winebrake & Creswick, 2003).

Technology assessment involves carefully appraising the technology fields with strategic importance and technological competitive advantage, while facing a brand new and emerging technology, such as organic light emitting diode (OLED). The OLED display is praised as the third generation display technology, after the cathode ray tube and the liquid crystal display. Since 2005, Taiwan's OLED display industry has occupied the third position in the global market, and has become increasingly competitive in the world (IEK, 2006). The original OLED patent, owned by Kodak, had been due for renewal in 2005. Kodak began to cross-license its key technology of OLED, thereby diminishing the technological barrier and attracting more competitors to this emerging technology.

We propose a hybrid approach comprising of interpretative paradigm, fuzzy Delphi method, and analytic hierarchy process to construct a technology assessment model for OLED display technology. Taiwan is a research base in this study. This is for the purpose of offering an example as to how to assess or position certain emerging technology in order to guide the further R&D planning and strategy. Finally, some strategic and managerial suggestions according to the results are drawn in this paper for related policy makers.

## 2. Literature Review

Practitioners, governments, and academics all agree that technology is a major source of competitive advantage for the technology-based industries and a country's economic development. Therefore, the objective of technology assessment is to widely investigate diversified perspectives of technological, economic, social, risk in order to facilitate the R&D planning and strategizing for the establishment of competitiveness. In this section, the background of technology assessment is reviewed, firstly. The existing technology assessment methodologies and criteria, then, are explored. The technology assessment criteria are identified as positive prospects and negative problems by interpreting the potential effects associated with the development of OLED display technology.

## 2.1. Technology Assessment

Technology as a major source of competitive advantage for manufacturing industries is widely accepted by practitioners, governments and academics. In order to realize this competitive advantage, it is vital to understand both the specific technologies, and the ways in which organizations can best manage technology (Phaal et al., 2001). Gregory (1995) has proposed that management of technology is comprised of five generic processes: identification, selection, acquisition, exploitation, and protection. Among these processes, technology identification and selection are defined as involving information gathering from various sources about the technology alternatives, and evaluate these technology alternatives against each other or some set of criteria (Lamb & Gregory, 1997).

However, evaluating the business effects of technologies is difficult, because a great deal of risk is involved and some of the effects may occur after a long period of time (Porter et al., 1991). In order to engage this challenge, technology assessment is performed to explore the impacts of introducing a new technology into the society or the industry. The concept of technology assessment was first developed in the U.S. in the late 1960s when demands were raised for greater social responsibility in technology development (Palm & Hansson, 2006; Tran & Daim, 2008). These demands were largely triggered by an increased awareness of serious social, economic, and industrial effects that were conceived to be caused by new technologies. The term "technology assessment" is said to have first been used in the Subcommittee on Science, Research, and Development of the House Science and Astronautics Committee of the U.S. Congress under its chairman, Emilio Daddario (US Congress, House of Representatives, Committee on Science and Astronautics, 1967). Congress needed an earlier awareness, an earlier warning, and an earlier understanding of what might be the social, economic, political, ethical and other consequences of the introduction of a new technology into the society or a substantial expansion of an existing technology. Consequently, technology assessment was conceived as a concept to assist in public policy informed the thoughts and deliberations of a wider public concerned with policy toward new technologies (Tran & Daim, 2008).

As early as Joseph Coates defined technology assessment "the name for a class of policy studies which attempt to look at the widest possible scope of impacts in society of the introduction of a new technology. Its goal is to inform the policy process by putting before the decision maker an analyzed set of options, alternatives and consequences” (Coates, 1976), and as recently as 2001 he redefined the concept along that line as “a policy study designed to better understand the consequences across society of the extension of the existing technology or the introduction of a new technology with emphasis on the effects that would normally be unplanned and unanticipated” (Coates, 2001). Under this context, the technology assessment terminology was meant to refer to public decision making and resource allocation (Tran & Daim, 2008).

## 2.2. Technology Assessment Criteria

The technology assessment involves different perspectives of diverse stakeholders, including practitioners, decision makers, researchers and R&D personnel in private and public sectors. In general, the concerns on technology assessment comprise of technological, economic, technology development, and risk aspects. Moreover, many methodologies used to conduct technology assessment problems have their own philosophic perspectives as mentioned in the previous section. Hence, the perspectives of these technology assessment methodologies should be taken into consideration as well.

These considerations mentioned above can be synthesized and at least distinguished into several aspects, such as technological merit, business effect, technology development potential, and risk. Furthermore, these considerations could be discriminated between positive prospects and negative problems existing in the technology development by interpreting related literature and secondary document in order to deeply analyze the potential effects associated with the development of OLED display technology. The content of these aspects and the corresponding criteria are illustrated as follows.

### 2.2.1. Technological Merit

Technological merit is one of the considerable aspects for assessing whether a technology has the potential to invest resource in. Take the Advanced Technology Program (ATP) of U.S. for instance, the technology programs subsidized by ATP should be innovative and advanced and create new technological opportunities in order to contribute to the new technology development of U.S. (ATP, 2010). The Department of Industrial Technology of the Ministry of Economic Affairs (2010) requires that the proposed R&D projects should exceed the level of existing technologies in the domestic industries and develop key or integrating technologies in order to improve the indigenous technology level. The assessment of Taiwan's important technology R&D programs includes the technological concern to evaluate their feasibility and the development value by comparing other competitive technologies (National Science Council, 2010). Hsu et al. (2003) indicate that the technological aspect is the major criterion in governmental technology assessment. In addition, other related researches also show that the consideration of technological prospect plays an important role in technology assessment (Yap & Souder, 1993; Lee & Om, 1996; Balachandra & Friar, 1997; Coldrick et al., 2005; Meade & Presley, 2002; Feldman & Kelley, 2003; Lee & Song, 2007).

According to literature review, the aspect of technological merit comprise of following criteria:

(1) *Advancement of technology*. It refers to the level of advancement of the proposed technology compared with existing technology. The development of advanced technology helps countries, indigenous industries and corporations to obtain technological benefit (Hsu et al., 2003; Huang et al., 2008). Hence, the advancement of technology is attributed to prospect of the technology assessment.

(2) *Innovation of technology*. Innovation of technology is the innovation level of the proposed technology. The technologies with innovation have the potential to produce brand new products or services and create competitiveness for indigenous industry and corporations further (Hsu et al., 2003; Huang et al., 2008; ATP, 2010). The innovation of technology, therefore, could be attributed to prospect on the technology assessment.

(3) *Key of technology*. This criterion is used to measure whether the proposed is critical for product of industry development. The indigenous industries and technology-based enterprises could establish their own technological competitiveness through acquiring the key technologies within a specific technology field (Huang et al., 2008). The key of technology should be ascribed to prospect of technology assessment since it is critical for the establishment of technological competitiveness.

(4) *Proprietary technology*. It evaluates whether the technology project will generate a proprietary technology position through the intellectual property rights. The more intellectual property rights originated from a specific technology, the more competitive this technology is (Lee & Om, 1996; Balachandra & Friar, 1997; Hsu et al., 2003; Huang et al., 2008). Thus, whether the development of technology will generate intellectual property rights should be prospect in technology assessment.

(5) *Generics of technology*. Generics of technology mean whether the proposed

technology is a generic technology to industry. A generic technology has the potential to be applied by the indigenous industries associated with related technology fields (Hsu et al., 2003; Huang et al., 2008). Therefore, the generics of technology could be regarded as a positive effect in the consideration of developing the targeted technology field.

(6) *Technological connections*. Technological connections are used to evaluate whether the proposed technology is applicable for many products; the more technological applications, the higher technological connections. A technology with higher technological connection will has more potential to benefit the indigenous industries and local economic development (Meade & Presley, 2002; Hsu et al., 2003; Lee & Song, 2007; Huang et al., 2008). Thus, the technological connections are regarded as positive effect in technology assessment.

(7) *Technological extendibility*. The extendibility of technology refers to the extent to which the proposed technology has the potential for further technology development. A specific technology has more extendibility could positively affect future advanced technology development (Hsu et al., 2003; Huang et al., 2008). The technological extendibility is considered as positive prospect in technology assessment.

### 2.2.2. Business Effect

In addition to the prospected technological benefit, the potential economic benefit generated by new technologies is suggested to evaluate in order to determine whether the technologies benefit a country’s economic or industrial development. Thus, the assessment of Taiwan’s important technology programs considers the economic or business effect created by introduction of new technologies as well (National Science Council, 2010). The National Institute of Standards and Technology indicates that the technology programs subsidized by ATP should create large economic or industrial benefit to country (ATP, 2010). Yap and Souder (1993) suggest that any technology evaluation should consider whether the evaluated technology can succeed on business. Yu et al. (1998) argue that the business effect created by the technology development should be evaluated. The studies related to technology evaluation point out that the effects benefit corporations and economic/industrial development is one of considerable aspects on the evaluation of technology (Arbel & Shapira, 1986; Piipo & Tuominen, 1990; Garud & Ahlstrom, 1997; Hsu et al., 2003; Feldman & Kelley, 2003; Coldrick et al., 2005; Shehabudden et al., 2006; Huang et al., 2008). Based on the literature review, the concerns within the aspect of business effect are as follows.

(1) *Potential return on investment*. This criterion refers to the potential return on investment in the technology (Yu et al., 1998; Coldrick et al., 2005; Shehabudden et

al., 2006). The assessed technologies will create more benefit to industry or corporations if they have more expected return on investment. The potential return on investment, thus, can be regarded as prospect on technology assessment.

(2) *Effect on existing market share*. It is used to estimate whether the technology can enlarge the existing market share (Lee & Om, 1996; Coldrick et al., 2005; Huang et al., 2008). Once the indigenous enterprises' current market share is enlarged, more revenue is then generated. Therefore, the effect on local companies' market share originated from the evaluated technologies could be seen as positive prospect.

(3) *New market potential*, which considers whether the technology has the potential to create a new market (Lee & Om, 1996; Coldrick et al., 2005). The introduction or development of new technology is expected to create a new market applying the specific technology in order to bring positive effect on new industry and economic development. Hence, whether the application of new technology can create a new market is regarded as prospect in technology assessment.

(4) *Potential size of market*, which refers to the potential size of the market in which the products apply the technology (Huang et al., 2008). In addition to measure the capability of creating new markets, the potential size of market where the technology is applied should be estimated in order to determine if the market is valuable to investing in (Lee & Om, 1996; Balachandra & Friar, 1997; Meade & Presley, 2002; Huang et al., 2008). The potential size of market, thus, should be regarded as a positive attribute.

(5) *Timing of technology*, which refers to whether this is the right time to develop the technology (Balachandra & Friar, 1997; Meade & Presley, 2002; Huang et al., 2008). Yu et al. (1998) suggest that the introduction of new technology should consider when the right time to develop a specific technology is in order to occupy technological position with competitiveness. Since the right timing is critical to develop a specific technology, it is suggested to seen this criterion as prospect on technology assessment.

### 2.2.3. Technology Development Potential

The development of advanced technology usually encounters the problems of related technological resources availability which is critical to the feasibility of advanced technology development (Huang et al., 2008). National Science Council (2010) suggests that the aspect of technology execution is one of the evaluation criteria in the assessment of Taiwan's important technology programs. Take U.S. ATP for example, the assessment includes the consideration of whether the technology projects are possible to implement (ATP, 2010). Thus, it is necessary to consider the availability of related technological resources on technology assessment (Hsu et al., 2003; Huang et al., 2008). The suggested criteria within the aspect of technology development potential are presented as follows.

(1) *Technical resources availability*, which means access to which the technology can obtain technical resources. Some related peripheral technologies are necessary for successful development of a specific technology (Yu et al., 1998; Huang et al., 2008; ATP, 2010). The development of OLED display technology will encounter the problem of the availability of related technical resources. Thus, the availability of technological resources could be regarded as a problem in technology assessment.

(2) *Equipment support*, which measures the extents to technology that can be supported by necessary facilities. In addition to related technological support, the advanced equipment is necessary to facilitate some R&D of a specific technology (Huang et al., 2008). There is still no dominant manufacturing process to OLED display, which means the related equipment is diversified. The availability of key equipment will be crucial to the R&D of OLED display technology. In this study, the availability of equipment support, thus, is regarded as a potential problem in technology assessment.

(3) *Opportunity for technical success*, which refers to determine the opportunity of success for proposed technology and whether there is any similar successful technology. A technology without opportunity of success is not considered to invest R&D resources in (Huang et al., 2008). The OLED display technology is still a new one at the emerging stage currently. Many domestic flat display manufacturers involved the OLED display technology encounter some technological difficulties in the R&D. Therefore, the opportunity of technological success is necessary to evaluate and should be seen as a potential problem in technology assessment.

### 2.2.4. Risk

When assessing new technologies, decision-makers are faced with the potential risks within the technology development (Piipo & Tuominen, 1990; Bhat, 1991; Mustafa, 1991; Gaber et al., 1992; Williams, 1995; Garud & Ahlstrom, 1997; Leung et al., 1998; Henriksen & Traynor, 1999; Machacha & Bhattacharya, 2000; Elkington & Smallmman, 2002; Stewart & Mohamed, 2002). Most advanced R&D of advanced technologies is combined with high risks, therefore the risks associated with technology programs are another significant concern on technology assessment (ATP, 2010; Department of Industrial Technology of the Ministry of Economic Affairs, 2010). The examination of significant technology programs subsidized by Taiwanese government covers the risk evaluation (National Science Council, 2010).

Based on the review of related literature, the criteria of risk aspect are as follows.

(1) *Commercial risk*, which is the potential commercial risk of the applications. If the developed technology cannot be commercialized to generate revenue, the R&D resources invested in the previous stage will have no return (Yu et al., 1998; Shehabudden et al., 2006; Huang et al., 2008). Therefore, the commercial risk is attributed a negative impact in technology assessment.

(2) *Technical risk*, which is defined as the potential technical risk of the technology development (Yu et al., 1998). The evaluation of technical risk includes the successful experience of related technologies and the feasibility evidence (Huang et al., 2008). However, the development of emerging technology usually engages the technological uncertainty due to fewer similar R&D experience and feasibility evidence. Therefore, the technical risk could be attributed a negative problem in technology assessment.

(3) *Technical difficulties*, which estimates the extent to technology that cannot be successfully developed (Huang et al., 2008). When engaging more difficulties on R&D, the possibility of successful technology development will be decreased. The technological difficulties should be regarded as a negative impact in technology assessment.

## 3. Methodology

As mentioned before, the recent development of technology assessment is concerned with synthesized perspectives based on experts' opinions which would point out positive as well as negative aspects for the future development of the aimed technology. The purpose of all these implementation is to draw a conclusion as to a reference for R&D planning and strategy making to the aimed technology and the industry applying this technology. This research employs several methods in combination. The interpretative analysis is used to attribute the technology assessment criteria viewed as potential effects to positive prospects and negative problems. The fuzzy Delphi method effectively gathers experts' judgments to evaluate the importance of technology assessment criteria on the aspects of cost, risk, or benefit prospects and problems, and at the same time reduces the uncertainty and ambiguity existing in experts' judgments. The AHP leads to a multi-criteria decision-making model considering the importance, prospects, and problems with the evaluated technology in terms of its R&D related investment planning. The proposed technology assessment model and the applied methodologies are elaborated below.

## 3.1. The Research Process

The research process of this study is presented in Figure 1. In general, the process forms a successive chain, in which the former step outcome serves as one input for the latter step. Also additional input information from different sources is needed in all the steps. This way the information is refined step by step and thus the purpose of assessing a specific technology by an improved collaboration model is achieved.

In step 1, a specific R&D task may arise, such as the National Science and Technology Conference, or at industrial level, such as an industrial sponsor who are seeking the technological capability from R&D related academia. The researchers, the industrial sponsors, and other stakeholders related to the R&D tasks have to identify the specific technology to be assessed. In this study, the OLED display technology is adopted as a case to verify the proposed technology assessment model.

The development history and related theories of technology assessment are reviewed in step 2. In this step, the technology assessment criteria are extracted from related literature in the fields of technology assessment, technology evaluation, and technology selection. The OLED display industry development in Taiwan is briefly examined in this step as well.

In step 3, the technology assessment criteria extracted in the previous step are defined as prospects and problems by adopting interpretative analysis. The prospects and the problems of technology assessment on OLED display technology facilitate decision makers to understand the potential influence existing in future R&D by using the AHP in the following step.

The technology assessment model of OLED display technology is constructed in step 4. The importance of those technology assessment criteria gathered from the previous step is determined by using the fuzzy Delphi method in order to exclude some unimportant criteria. In the investigating process, the invited experts from academia and industry can replenish criteria that are neglected in step 2.

Further, the AHP is applied to obtain the weights of technology assessment criteria that are determined in the previous step. Both academia and industrial experts' judgments in regard to the targeted technology are critical because industrial experts can express their needs on that technology together with technological value evaluated by academic experts. The weights of these criteria represent what prospects should be pursued and what problems should be noted. This result can be conceived as guidelines to make a R&D plan or strategy.

According to the results obtained in step 4, the managerial suggestions for R&D planning or strategy are derived in step 5. Based on the derived implication or suggestions, R&D related academia could implement researches in the field of targeted technology and generate R&D outputs that meet the industry's needs.

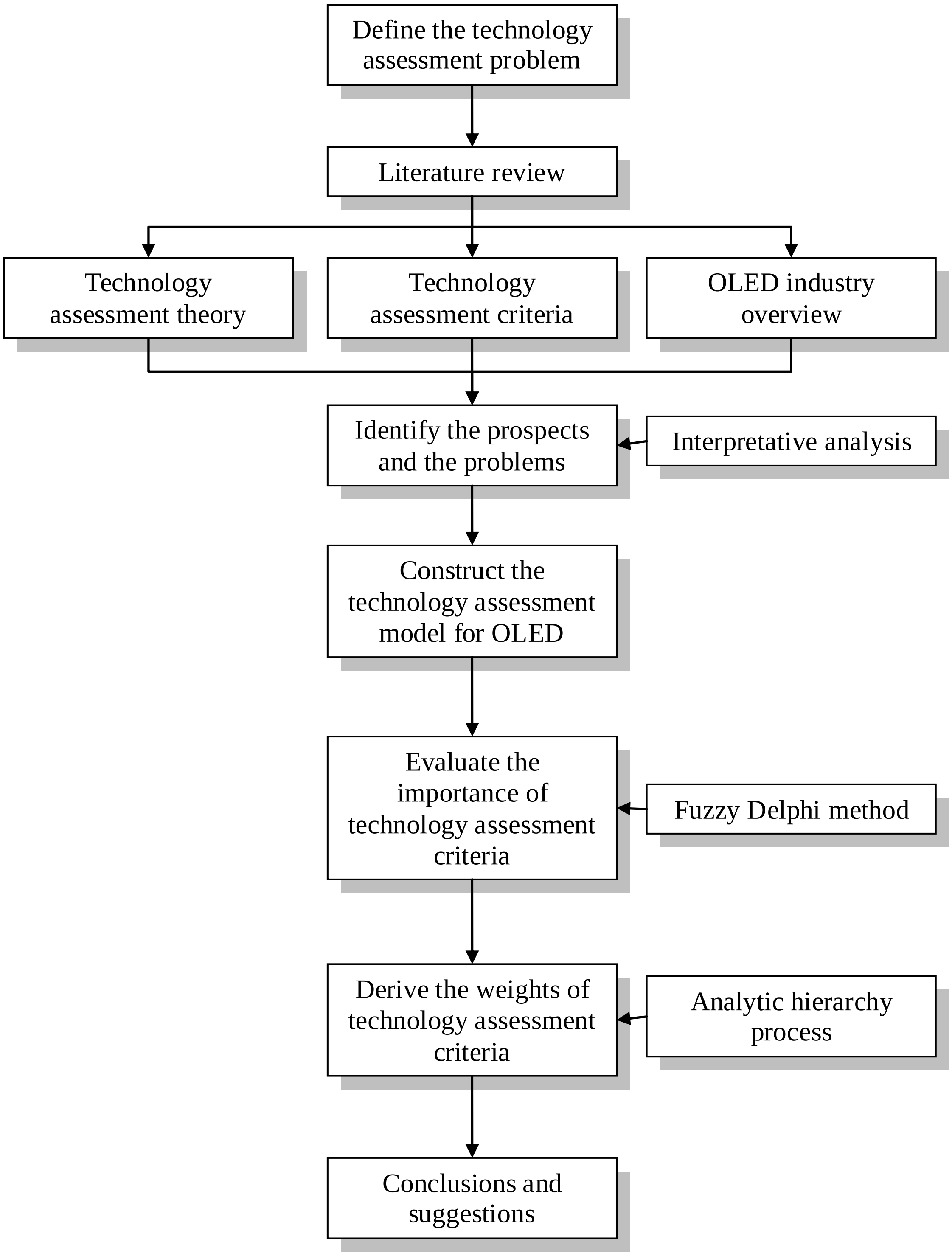


Figure 1. The research process

## 3.2. Interpretative Analysis

Thinking in the Western world is characterized by a basic dichotomy. Bernstein (1983) argues that there is uneasiness expressed by the opposition between objectivism and subjectivism. Contemporary thinking has moved between objectivism and subjectivism. Based on Cartesian dualism which sharply differentiates between the physical as external reality and thinking as internal world, this division is reflected in two basic paradigms of scientific thought and methods: the objective, deductive and often called quantitative and the subjective, interpretative and frequently labeled qualitative paradigm (Mayrhofer, 2009). From a subjective, interpretative point of view the world is subjectively constituted and socially pre-interpreted, formed by the observation schemes. The methods used within this paradigm usually have to meet specific criteria like openness, communicativity, contextuality or search for meaning (Lamnek, 1988).

In this research, the technology assessment criteria represent the potential effects existing in the R&D of OLED display technology. However, in order to clarify the consequences caused by the development of OLED display technology, it is necessary to identify the prospects and the problems associated with the development of OLED display technology. Thus, the technology assessment criteria are attributed to prospects and problems by clarifying the socioeconomic and technological concerns that the OLED display technology development may encounter with the interpretative paradigm. The prospects and the problems evaluated by AHP in the following step can be regarded as a reference to R&D planning or strategy for the field of OLED display technology.

## 3.3. Fuzzy Delphi Method

Many published studies on technology assessment have developed a wide variety of models related to experts' judgments (Baker, 1974; Liberatore & Titus, 1983; Schmidt & Freeland, 1992). In order to integrate experts' opinions and identify a critical set of criteria for technology assessment, the Delphi method developed by Rand Corporation is a widely used technique (Dalkey & Helmer, 1963; Lee & Kim, 2001; Bañuls & Salmeron, 2007; Bañuls & Salmeron, 2008; Chen et al., 2008). The Delphi method aims to improve group decision making by seeking opinions without face-to-face interaction. Several features characterize the Delphi method and distinguish it from face-to-face group interrogative methods, including anonymity, iteration, controlled feedback, statistical group response, and stability in responses among the experts on a specific issue (Cyphert & Grant, 1971; Uhl, 1983; Cochran, 1983; Dailey & Holmberg, 1990; Whitman, 1990; van Zolingen & Klaassen, 2003).

Although the Delphi method provides a chance to completely integrate diverse experts' opinions, it is time-consuming, costly, and has a lower questionnaire return rate because it tries to obtain converged results through repetitive surveys. In addition, the problems of ambiguity and uncertainty still exist in experts' responses (Hwang & Lin, 1987; Chang et al., 2000). Ishikawa et al. (1993) introduce the fuzzy Delphi method to avoid the above defects using fuzzy logic. The fuzzy Delphi method can converge experts' responses with fewer survey rounds and effectively conduct their ambiguity and uncertainty (Klir & Folger, 1988). Furthermore, recent studies have widely adopted the fuzzy Delphi method together with AHP to conduct decision making at a different stage, such as the e-marketplace (Büyüközkan, 2004), public transport system project selection (Hsu, 1999), and managerial talent assessment (Huang & Wu, 2005). This study employs the fuzzy Delphi method to integrate experts' opinions on technology assessment criteria.

The process of the fuzzy Delphi method is briefly explained as follows. The experts' opinions in the technology assessment criteria collected by the questionnaires are identified by the triangular fuzzy number in Equation 1:

$$\tilde{W}_k = \left(a_k, b_k, c_k\right) \tag{1}$$

where $\tilde{W}_k$ is the fuzzy number of the criterion *k*, $a_k$ is the minimum of the experts' evaluation, $b_k$ denotes the average of the experts' evaluation, and $c_k$ denotes the maximum of the experts' evaluation.

The center-of-gravity method is in common use (Klir & Folger, 1988). Where $S_k$ denotes the clear value in Equation 2:

$$S_k = \frac{a_k + b_k + c_k}{3} \tag{2}$$

Finally, researchers select the proper criteria according to the needs of the study. The principles are as follows:

(1) If $S_k \geq \lambda$ then accept criterion *k*, where $\lambda$ is the threshold value suggested by experts.

(2) If $S_k < \lambda$ then omit criterion *k*.

### 3.4. Analytic Hierarchy Process

Since the introduction of AHP in 1976, it is widely used in the research fields of technology assessment (Tran & Daim, 2008), such as technology choice in the less developed countries (Ramanujam & Saaty, 1981), communication technology (Prasad &

Somasekhara, 1990), soap-making technology (Raju et al., 1995), hydrogen fueling systems (Winebrake & Creswick, 2003), healthcare technology (Sloane, 2004), the internet (Malladi & Min, 2005), desalination plants (Hajeeh & Al-Othman, 2005), operation system (Tolga et al., 2005), and R&D projects (Wang et al., 2005). In this study, the AHP is utilized to construct a technology assessment model due to its wide applications in this type of multi-criteria decision-making problem.

A literature review, brainstorming, and the Delphi method can be used to search for the criteria when establishing a hierarchical structure. After that, the criteria are mutually compared for $n \times (n-1)/2$ times if there are $n$ criteria. A nine-point scale recommended by Saaty (1980) is adopted to obtain experts' opinions—with preferences between alternatives given as equally, moderately, strongly, very strongly, or extremely preferred (with pairwise weight of 1, 3, 5, 7, and 9, respectively)—and values of 2, 4, 6, and 8 as the intermediate values for the preference scale. A matrix can be formed to represent the pairwise comparisons as Equation 3:

$$\boldsymbol{A} = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \tag{3}$$

where $a_{ij}$ represents the value of geometric mean that experts compare the criterion $i$ with criterion $j$.

To estimate the relative weights of the criteria in this matrix, the priority of the criteria is compared by computing the eigenvalues and eigenvectors with the following Equation 4:

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

where $\boldsymbol{w}$ is the eigenvector of the matrix $\boldsymbol{A}$, and $\lambda_{\max}$ is the largest eigenvalue of the matrix $\boldsymbol{A}$. The eigenvector $\boldsymbol{w}$ can be obtained by Equation 5:

$$\boldsymbol{w} = \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n} \Bigg/ \sum_{i=1}^{n} \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n} \tag{5}$$

where $n$ is the number of criteria being compared in this matrix. The largest eigenvalue $\lambda_{\max}$ of $\boldsymbol{A}$ can be estimated by using Equation 6:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(\boldsymbol{A}\boldsymbol{w})_i}{w_i} \tag{6}$$

The consistency of the matrix is done by examining the reliability of judgments in the pairwise comparison. The Consistency Index (CI) and the Consistency Ratio (CR) are defined as Equations 7 and 8:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{7}$$

$$CR = \frac{CI}{RI} \tag{8}$$

where $n$ is the number of criteria being compared in this matrix, and RI is the Random Index. The average consistency index of a randomly generated pairwise comparison matrix of similar size is shown as Table 1.

Table 1. Random index (RI)

| *n* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 |
| *n* | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
| RI | 1.45 | 1.49 | 1.51 | 1.53 | 1.56 | 1.57 | 1.59 | |

## 4. Data Analysis

The fuzzy Delphi method integrates experts' opinions without modifying their original thought, processes the fuzziness within their thoughts and, moreover, lowers survey costs. AHP forces experts to consider the targeted issues systematically. This study proposes a hybrid approach integrating the fuzzy Delphi method and the AHP to construct a technology evaluation model for OLED display.

Our hybrid approach is that after sifting through important technology evaluation criteria by the fuzzy Delphi method, decision-makers can evaluate the certain technology such as OLED display within a hierarchical structure of the AHP and obtain the weighted results as a reference of their decision-making on important technology project investments. Comparing to other single technology evaluation tools the proposed joint approach should be more efficient, since the fuzzy Delphi method makes the AHP assessment more capable and proficient, while the multi-criteria decision-making for technology evaluation and consideration is conducted by the related policy makers.

Taiwan is a research base in this study for its OLED display industry has occupied the third position in the global market since 2005 and has become increasingly competitive in the world (IEK, 2006). The following deciphers our empirical analyses.

## 4.1. Define the Technology Assessment Objective

Defining the technology evaluation objective requires identifying the scope for which the technology will be assessed. This study focuses on assessing OLED display technology for OLED panel manufacturers in Taiwan to determine whether this new technology is worthwhile for all concerned. The technology assessment criteria both need to be carefully explored for this emerging display technology.

## 4.2. Explore the Criteria of OLED Display Technology Assessment

Explore the technology evaluation criteria for OLED display. The OLED display technology assessment criteria induced from the previously discussed studies as shown in section 2.2. The interpretative analysis is used to attribute these criteria regarding the potential effects caused by the OLED display technology development to prospects and problems in this step.

## 4.3. Integrate the Important Criteria of Technology Assessment

This study applies snowball sampling to survey 6 experts from academia and 5 experts from industry to evaluate the importance of the criteria explored in the previous step. The importance of the criteria is measured using the linguistic scales and their corresponding fuzzy numbers: (0.7, 0.9, 0.9) - extremely important, (0.5, 0.7, 0.9) - important, (0.3, 0.5, 0.7) - normal, (0.1, 0.3, 0.5) - unimportant, (0.1, 0.1, 0.3) - extremely unimportant.

The important criteria are sifted from the evaluation result by employing the fuzzy Delphi method. The sifting threshold value will affect the number of criteria. If the threshold value is higher, there will be fewer remaining criteria so that the following research may be affected. Therefore, this study adopts 0.6 as the threshold value suggested by experts because it is the mean of the minimum value of “important” (0.5) and the maximum value of “normal” (0.7). The result is shown in Table 2:

Table 2. The fuzzy Delphi sifting result of OLED display evaluation criteria

| **Scale** | **Criteria** | **S** | **Result** |
|---|---|---|---|
| Technological merit | Advancement of technology | 0.76061 | |
| | Innovation of technology | 0.66364 | |
| | Key of technology | 0.66970 | |
| | Proprietary technology | 0.76061 | |

| | | | |
|---|---|---|---|
| | Generics of technology | 0.63333 | |
| | Technological connections | 0.65152 | |
| | Technological extendibility | 0.66364 | |
| Business effect | Potential return on investment | 0.54242 | Cancel |
| | Effect on existing market share | 0.67576 | |
| | New market potential | 0.68182 | |
| | The potential size of market | 0.66970 | |
| | Timing for technology | 0.65758 | |
| Technology development potential | Technical resource available | 0.56061 | Cancel |
| | Equipment support | 0.57879 | Cancel |
| | Opportunity of technical success | 0.53030 | Cancel |
| Risk | Commercial risk | 0.74849 | |
| | Technical risk | 0.74242 | |
| | Technical difficulties | 0.58485 | Cancel |

According to the results of the criterion sifting, the five criteria—potential return on investment, technical resource availability, equipment support, opportunity of technical success, and technical difficulties—are canceled. The reasons are based on the in-depth interview with experts:

(1) Every OLED panel manufacturer is presently without revenue. Due to future potential, if a firm determines to invest in this technology, it should prepare for a loss in the short term. Therefore, the potential return on investment is not the most pressing issue in the near future.

(2) Once a firm has decided to invest in OLED display technology, it will endeavor to support the technical resources and the necessary equipment. Therefore, technical resources available and equipment support are not of great importance, according to the experts' concerns.

(3) OLED display is an emerging technology within recent years. Most OLED display manufacturers lack experience, especially in mass-production. Hence, the OLED display manufacturers have had to explore this technology with limited similar experience; therefore, the opportunity of technical success is not the main concern.

In addition, insufficient technical personnel support and financial risk are suggested in the in-depth interviews with experts:

(1) OLED, which was first developed by Kodak, is an emerging display technology. In Taiwan, the OLED display manufacturers are patent licensed by Kodak or CDT and lack experienced technical personnel; therefore, insufficient technical personnel support is suggested. Due to the facilitation of experienced technical personnel support, the OLED display technology could be more successfully developed. Therefore, the insufficient technical personnel support can be regarded as a problem in the development of OLED display technology.

(2) Some OLED display manufacturers, such as Pioneer in Japan and Opto Tech in Taiwan, abandoned their businesses in this market owing to continued financial loss. Financial risk should be considered when investing in this type of emerging technology. The financial risk could be viewed as a problem since its negative impact during the development of OLED display industry.

### 4.4. Obtain the Weight of Criteria by AHP

After verifying the importance of criteria, the OLED display technology evaluation hierarchy has been constructed as above. This survey is aimed to understand experts' perceptions regarding the weights of evaluation dimensions along with criteria while planning projects toward investing in OLED display technology in the position of government or related industries. The snowball sampling employed 6 experts from academia and 5 experts from industry, and the weights of criteria are obtained by adopting the AHP. The CI and CR for technological merit, business effect, risk, and the entire hierarchy are smaller than 0.1, indicating the experts' judgment with consistency. The result of the AHP survey is shown in Table 3.

Table 3. The weights of OLED display technology evaluation

| Scale | Weight | Criteria | Local Weight | Global Weight | Attribute |
|---|---|---|---|---|---|
| Technological merit | 0.22421 | Advancement of technology | 0.11656 | 0.02613 | + |
| | | Innovation of technology | 0.12448 | 0.02791 | + |
| | | Key of technology | 0.22781 | 0.05108 | + |
| | | Proprietary technology | 0.19596 | 0.04394 | + |
| | | Generics of technology | 0.06935 | 0.01555 | + |
| | | Technological connections | 0.13014 | 0.02918 | + |
| | | Technological extendibility | 0.13570 | 0.03043 | + |
| | | CI=0.01503, CR=0.01139 | | | |
| Business effect | 0.36079 | Effect on existing market share | 0.23421 | 0.08450 | + |
| | | New market potential | 0.20445 | 0.07376 | + |
| | | The potential | 0.24348 | 0.08785 | + |

| | | | | | |
|---|---|---|---|---|---|
| | | size of market | | | |
| | | Timing for technology | 0.31787 | 0.11469 | + |
| | | CI=0.00138, CR=0.00153 | | | |
| Risk | 0.20423 | Commercial risk | 0.27181 | 0.05551 | - |
| | | Technical risk | 0.24869 | 0.05079 | - |
| | | Financial risk | 0.47951 | 0.09793 | - |
| | | CI=0.00408, CR=0.00703 | | | |
| Insufficient technical personnel support | 0.21077 | Insufficient technical personnel support | 1 | 0.21077 | - |
| Overall CI=0.007651, Overall CR=0.008501 | | | | | |

Note: "+" is prospect; "-" is problem.

As shown in Table 3, the dimension weight implies how the experts consider each evaluation dimension's relative importance; the criterion weight can be regarded as the individual evaluation product for each evaluation criterion. The discussions relating to the above survey results are as follows:

(1) The prospects have total weighting of 0.585 which exceeds the problems with weighting of 0.415, as shown in Table 3. This result implies that there are potential and opportunity for Taiwan's industry to invest in OLED display technology field.

(2) According to the investigation of weights (relative importance) of the OLED display appraising dimensions in this research, "business effect" ranked first in terms of importance or advantage, and the weight of dimension is 0.36079. "Technological merit," "insufficient technical personnel support," and "risk" were then evaluated as the second, third, and fourth contributory facets in terms of deciding whether to invest in the technology OLED display, respectively. Indeed, from the perspective of R&D manufacturers and the government, future substantial commercial or economic benefits resulting from the new targeted technology are often considered one of the most critical decision-making factors in terms of whether it is worth investing in the new technology (Lee & Song, 2007; Link et al., 2002; Raafat, 2002; Chan et al., 2006). OLED display, as the third generation of display technology, following TFT-LCD (Chen & Huang, 2007), can be used in microdisplays of mobile phone handsets and handheld devices as well as large-screen displays, such as in televisions. The expected economic and industrial benefits generated can be considerable. However, due to the fact that the history of OLED display technology is not long, the development of this technology is still not mature as TFT-LCD technology. There are expected technological benefits associated with the

development of OLED display technology because the technological opportunities usually exist in such an emerging technology.

(3) As for business effect, “timing of technology” is currently the most advantageous factor because OLED display technology is classified as a newly-developing technical industry. Its total evaluation product is 0.11469 (= dimension importance percentage 0.36079 × criterion functioning percentage 0.31787 under the dimension). Many firms are now investing in R&D for OLED display technology, in order to accumulate R&D and manufacturing experiences for themselves, so they will be able to plunge into mass production when the OLED display technology matures in the future. “Potential size of market” is the second reason for investing in the OLED display technology. OLED display is now used in microdisplays, such as in the panels and sub-panels in mobile phone handsets and MP3 player and car dashboard displays. Moreover, in 2008, Sony launched the OLED television. The potential market for OLED display technology readily exists as long as there is a need for displays. Moreover, several studies indicate the introduction of new technology should consider when the right time to develop a specific technology is in order to capture the technological position with competitiveness (Balachandra & Friar, 1997; Yu et al., 1998; Meade & Presley, 2002; Huang et al., 2008). This argument is echoed by the result of this study.

(4) In terms of technological merit, “key of technology” is the most gainful factor if deciding to invest in OLED display technology. For flat panel industry players in Taiwan who have spent their existence doing Original Equipment Manufacturing (OEM), the ear of ferment technology OLED display is key for them to overcome the industry stereotype of OEM. Moreover, due to the fact that OLED display technology is still in its developmental stage, technically, there is plenty of room for improvement. The acquisition of patents, therefore, is relatively easy, and thus, “proprietary technology” is the next profitable factor to be considered in the dimension of technological merit. In addition to being display technology, with the features of luminescence and power-efficiency, OLED can also serve as a sort of illumination technology. Besides, its technological flexibility may make itself become possible technology making electronic paper. Related investments in OLED are therefore thought to help develop other related technology in the near future. In this sense, technological extendibility was assessed as the third beneficial criterion in the same dimension. Moreover, the technological competitiveness of aimed technology is also highlighted in related literature (Hsu et al., 2003; Huang et al., 2008).

(5) In terms of risk, “financial risk” must be considered first in deciding whether to invest in R&D of OLED display technology. As examples, including Optotech

shutting down operations of its loss-making OLED division and AUO and Teco's decision to back out of OLED R&D and manufacturing, indicate, there are still significant financial risks in this sector that must be considered (IEK, 2008). "Commercial risk" is another factor affecting the launch of OLED display technology because OLED is not yet a mature technology and continues to face competition from the mature TFT- LCD technology. The similar result is shown in Yu et al. (1998) and Shehabudden et al. (2006)'s researches as well.

(6) Overall, technical personnel support, timing of technology, and financial risk ranked first, second, and third in all criteria, respectively. With OLED an emerging technology area, the adequacy of technology professionals' support directly determines the success of the technology development. Moreover, OLED display technology, instead of OEM, is considered to be taking a chance to increase the margin for the flat display industry in Taiwan. Therefore, the R&D resources should be invested to make the essential first move, thereby creating an advantage when a technology is emerging. As such, timing with technology ranks second. Finally, the OLED display technology is still in the emerging stage, so it is important for the manufacturers in this industry to carefully evaluate the financial risk involved.

## 5. Conclusions and Suggestions

Technology assessment, which is a multi-criteria decision-making issue, influences an enterprise or a country's technological advantages. An enterprise can waste its resources and lower its comparative advantages by investing in wrong technological alternatives at the wrong time or by investing too much in the right ones. On the other hand, a firm/country can lift its competitive advantages by investing in emerging technologies offering bright prospects (Yu et al., 1998; Lee & Song, 2007). Therefore, research and development in emerging technologies should be planned through a carefully designed structural process.

This study suggests a hybrid technology assessment approach integrating the interpretative analysis, the fuzzy Delphi method and the AHP approach. When policy makers and R&D planners design R&D programs in emerging technology fields, this proposed model can help to clarify the prospects and the problems existing in the development of aimed technology and facilitate R&D planning and strategy making as well as investment decision in the industry applying this technology.

Besides, using Taiwan's OLED display technology as an example, this study has generated a conclusion comprising several strategic suggestions and managerial implications as follows.

(1) Technology assessment involves decision making based on multiple criteria (Yap & Souder, 1993; Gerdsri & Kocaoglu, 2007). Based on literature, the assessment criteria in the general technology assessment model this research constructs can be used as the assessment of technology R&D plan. Further research can extract more evaluation criteria through expert interviews, Delphi method, or fuzzy Delphi method to deliver technology evaluation models subject to specific technologies. Though this evaluation model applies best to emerging technology, it can still be considered a performance measure of technology when applied to more mature technology.

(2) The whole approach developed by this study can serve as a reference for construct an evaluation framework to evaluate other technology fields in order to propose some guidance for R&D planning or strategy making in the industry applied the aimed technology.

(3) Past papers related to technology assessment are simply socioeconomic or technological based models evaluating the expected technology itself, as reviewed in the previous section. The technology assessment model delivered by this study adopts a synthesized view integrating the socioeconomic and technological views for large-scale and technology development planning, which provides an applicable reference for deciding whether to invest in the R&D of a new technology based on suggestions from industry, government, and experts during the era of ferment when technical uncertainty is still high and estimation of traditional cash flow evaluation remains difficult.

(4) The traditional MCDM techniques conducting the technology assessment problems evaluate several technological alternatives to determine a best one. However, the traditional MCDM methodologies are not proper while decision-makers intend to recognize the potential effects associated with the development of a targeted technology. This study improves the AHP through discriminating between prospects and problems caused by the development of a targeted technology to resolve this drawback.

(5) The weights distributed to the prospects and the problems can serve as a reference of whether the R&D investment in the new technology is worthwhile for all concerned. Future research can adopt the approach proposed in this study to evaluate the worth of R&D investment in other targeted technologies.

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