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Predicting the development cost of TFT-LCD manufacturing equipment with artificial intelligence models

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ABSTRACT

Accurately and timely estimating product costs is extremely beneficial to corporate survival. This study assesses the reliability of multiple regression analysis (MRA), artificial neural networks (ANNs), case-based reasoning (CBR), and hybrid intelligence (Hi) to forecast costs of thin-film transistor liquid-crystal display (TFT-LCD) equipment. Newly completed equipment-development projects are provided by departments in a Taiwanese high-tech company, which is a top global producer of TFT-LCD equipment. The cross-fold validation method is applied to measure model performance, reliability, and prediction ease. Through comparison of various performance indices, the Hi method outperforms MRA, ANNs and CBR when used for cost prediction during conceptual stages. Although it is well developed in academia, artificial intelligence (AI) is rarely applied in practical project management. This study successfully describes an actionable knowledge-discovery process using a real-world data mining approach for the high-tech equipment manufacturing industry. Project managers (PMs) can benefit from applying the Hi approach to establish latent non-linear cost estimation relationships. The Hi approach is empirically proven an effective prediction technique for PMs considering overall evaluation criteria when determining the best selling prices of TFT-LCD manufacturing equipment to clients.

1. Introduction

The first impression of a display device is based on its design, quality and presentation in an advertisement. The span of devices ranges from simple displays in watches to complex technologies in computers. More than 500 million displays for televisions and computers were produced in 2008. Roughly 90% of these displays were cathode ray tubes (CRTs) in 1999. However, more than 60% of displays are now flat panels (e.g., liquid crystal displays (LCDs), plasma screens). The global market for panels, which was worth over US $70 billion in 2006, is predicted to reach US $92 billion in 2011 (ITIS, 2008). Therefore, thin-film transistor-LCDs (TFT-LCDs) now play a leading role in various flat-panel display devices (Menozzi et al., 2001), as TFT-LCDs have excellent features such as low profiles, low operating voltage, low power consumption, full-color capabilities, large visible area, and high-quality resolution.

Prices of TFT-LCDs are strongly influenced by the high degree of uncertainty in research and development (R&D). In practice, a flat panel's functions and specifications cannot be completely determined during the early R&D stages; thus, initial cost estimation (ICE) is generally based on the subjective judgment of experienced engineers. This ICE is only a quoted price for potential buyers and a comparative estimate for potential providers. Although knowledgeable sales managers or estimators may generate a good cost assessment via teamwork, professionals are difficult to train and are very mobile in the small- and medium-sized enterprises in Taiwan. Thus, this experience and project knowledge is hard to retain, resulting in such problems as loss of company credibility and potential customers.

The TFT-LCD industry, promoted by Taiwan's government in the Two Trillion Twin Stars plan, has developed rapidly in recent years. The TFT-LCD industry is second only to the semiconductor industry in driving Taiwan's economic growth. Notably, LCD production involves hundreds of complex processes. Each panel manufacturer typically has unique patented processes and production lines requiring diverse manufacturing equipment with a high degree of customization. The production of diverse panel sizes is generally in demand as the need for next-generation panels increases.

The technological environment has become increasingly competitive due to the rapid speed of globalization. Product cost estimation is a critical and important task for sales managers at high-tech equipment development companies to gain competitive advantage. As the time a panel manufacturer devotes to investment and production is critical, fast and accurate estimations are essential to successful delivery of devices in a timely manner, as is quality to customers in the increasingly competitive market environment.

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Despite significant advances in tools and techniques that assist in project management (PMI, 2004), project managers (PMs) in the engineer-to-order manufacturing industry still face problems associated with guesswork and subjective judgment that result frequently in inaccurate estimates. No concrete functional relationship exists between final cost and the basic cost drivers for equipment for manufacturing TFT-LCD panels. Thus, companies can lose market share and orders during the early marketing phase of attracting customers.

Although many studies of the TFT-LCD industry have analyzed raw materials, processes, supply chains, and marketing, TFT-LCD equipment cost forecasting has seldom been examined. Hence, this study reviews relevant literature and collected past projects with equipment specifications. Additionally, this study presents novel artificial intelligence (AI)-based prediction models for the TFT-LCD manufacturing equipment industry. The optimal estimation model must transform implicit corporation assets into explicit knowledge, provide a basis for bargaining between a manufacturer and buyer, and, consequently, avoid delays to production plans by reducing the time required by tedious price negotiation processes.

Data mining (DM) is a business intelligence tool used for exploring and analyzing data to identify meaningful patterns and rules. Several widely used DM techniques, namely, multiple regression analysis (MRA), artificial neural networks (ANNs), and case-based reasoning (CBR), have been applied to diverse cost management domains such as textiles and apparel (Camargo et al., 2003; Metaxiotis, 2004), machinery centers (Ciurana et al., 2008; Gang, 2005), software engineering (Berlin et al., 2009; Finnie et al., 1997; Marban et al., 2008; Mendes et al., 2002; Thomasson et al., 2006; Toussaint and Cheng, 2006), process vessels (Caputo and Pelagagge, 2008), building construction (Al-Sakran, 2006; An et al., 2007a, 2007b; Emsley et al., 2002; Kim et al., 2004; Marir and Watson, 1995; Nassif et al., 2007; Staub-French et al., 2003), infrastructure projects (Chou, 2009a, b), die manufacturing (Bouaziz et al., 2006), the automotive industry (Cavalieri et al., 2004), and product design (Asiedu and Gu, 1998; Bode, 2000; Seo et al., 2002; Tornberg et al., 2002).

However, these techniques have not been applied to cost estimation of TFT-LCD equipment development. This study assesses the ability of MRA, ANNs, CBR and proposed hybrid intelligent techniques to estimate cost with merely adequate knowledge of the TFT-LCD manufacturing process. By applying the AI model in practice, PMs can estimate equipment development costs early in the price quotation and negotiation stage, and thereby gain competitive advantage.

The remainder of this paper is organized as follows. Literature is reviewed in Section 2 to identify the techniques utilized and challenges in project cost estimation in the engineering industry. Sections 3 and 4 discuss the TFT-LCD manufacturing process and employ the research methodology, respectively. Section 5 examines the case of a Taiwanese high-tech company and presents analytical and model validation results. Section 6 gives conclusions, and presents research findings and managerial implications.

2. Literature review of cost estimation

Cost estimation methods can generally be categorized as analogous cost estimation (ACE), bottom-up estimation techniques, and computing technology combined with AI (Ben-Arieh and Qian, 2003; Bode, 2000; Camargo et al., 2003; Caputo and Pelagagge, 2008; Cavalieri et al., 2004; Duverlie and Castelain, 1999; Kwak and Watson, 2005; Marban et al., 2008; Metaxiotis, 2004; PMI, 2004; Tornberg et al., 2002). Table 1 lists the tools and techniques used by these methods in project phases.

2.1. Analogical and analytical techniques

Analogous cost estimating, also referred to as top-down estimating, uses values of such parameters as project length, size, duration, cost, and design complexity from a similar project to estimate the cost of a new project. This technique, which is commonly used to estimate cost early in a project's lifecycle when little information is available, requires sufficient knowledge and expert judgment (PMI, 2004). Notably, ACE is generally less costly and time consuming than other methods, but is also less accurate. Although project activities in two projects may be similar, differences in project background and environment, such as technology usage (Rogozhin et al., 2010), number of patents used in product development (Kee, 2010), clients (Hwang et al., 2008), new materials or equipment (Lin et al., 2009), can result in significantly different estimates.

The analytical technique of bottom-up estimation determines project cost by decomposing a process into manageable tasks, operations, or activities (PMI, 2004). Activity-based costing (ABC), a generic technique, calculates costs incurred as performing

Table 1
Cost estimation techniques at various product development phases.

Estimating techniques	Product life cycle			
	Initiation stage	Planning phase	Detailed design	Contracting & mass production
1. Analogous cost estimating Engineering experience & expert judgment (PMI, 2004)	✓	✓		
2. Bottom-up estimates Activity-based costing; ABC (Baykasoglu and Kaplanoglu, 2008; Ben-Arieh and Qian, 2003; Tornberg et al., 2002)			✓	✓
3. Artificial intelligence Artificial neural networks (Bode, 2000; Caputo and Pelagagge, 2008; Cavalieri et al., 2004)	✓	✓		
Case-based reasoning (Al-Sakran, 2006; An et al., 2007a; Duverlie and Castelain, 1999; Mendes et al., 2005; Toussaint and Cheng, 2006)	✓	✓	✓	
4. Multiple regression and parametric techniques Multiple regression and parametric cost estimating (Camargo et al., 2003; Caputo and Pelagagge, 2008; Cavalieri et al., 2004; Chou, 2009a; Duverlie and Castelain, 1999; Kwak and Watson, 2005; Marban et al., 2008)	✓	✓		
Feature-based estimation (Bouaziz et al., 2006; Ou-Yang and Lin, 1997)			✓	✓