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A stochastic programming model for strategic capacity planning in thin film transistor-liquid crystal display (TFT-LCD) industry

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ABSTRACT

This paper studies strategic capacity planning problems under demand uncertainties in thin film transistor-liquid crystal display (TFT-LCD) industry. Due to the following trends, capacity planning has become a critical strategic issue in TFT-LCD industry: (1) complex product hierarchy and product types caused by a wide range of product applications; (2) coexistence of multiple generation of manufacturing technologies in a multi-site production system; and (3) rapid growing and changing market demand derived by the needs for replacing traditional cathode ray tube (CRT) display. Furthermore, demand forecasts are usually inaccurate and vary rapidly over time.

Our research objective is to seek a capacity allocation and expansion policy that is robust to demand uncertainties. We consider special characteristics of TFT-LCD manufacturing systems such as demand uncertainties, limited configuration flexibility, and cutting ratios. This paper proposes a scenario-based two-stage stochastic programming model for strategic capacity planning under demand uncertainties. Comparing to the deterministic approach, our stochastic model significantly improve system robustness under demand uncertainties.

1. Introduction

TFT-LCD (thin film transistor-liquid crystal display) has been widely used in computer and consumer electronic products in recent years. The manufacturing of TFT-LCD panel consists of three major manufacturing stages, namely the Array, Cell and Module stages. Typically, in each stage, there are multiple production sites. The Array process, which is similar to the reentrant semiconductor fabrication process, produces TFT panel glasses. The Array process is usually the bottleneck stage due to its high capital investments. The cost for a new generation array facility is several billion US dollars. Lithographic machines are the most expensive and usually the bottleneck station in the Array process. The Cell process combines TFT panel glasses with color filters and cuts the panel glasses into different sizes of LCD panels. Module process assembles LCD panels with other key materials to form the final product. Because Array process is capacity-constrained and capital intensive, an efficient use of the Array capacity is critical for TFT-LCD industry.

Capacity planning problems have become a critical strategic issue in TFT-LCD industry for the following reasons. (1) Complex product hierarchies and product types caused by a wide range of applications: TFT-LCD products are used in various applications, such as LCD monitor, Notebook monitor, and LCD TV. Products for each application are also differentiated by various sizes (e.g., 15, 17 and 19 inch). Each size is then differentiated by different display resolutions. (2) A multi-generation and multi-site production system generated by coexistence of multiple generations of manufacturing technologies. Production facilities which use different size glass substrate are called different generation sites. "Glass Substrate" is a key material used to manufacture various TFT-LCD products in the Array process. Higher generation sites use larger glass substrate and can produce different type of products. (3) Rapid growing and changing market demand caused by the replacement of the traditional Cathode Ray Tube (CRT). According to the market data provided by Display Search, Fig. 1, market demands are rapidly growing between 2004 and 2007, especially in LCD TV and personal computer monitor applications.

Strategic capacity planning is a critical issue for TFT-LCD companies due to demand uncertainties and rapid changing of product-mix in a multi-generation and multi-site production system. A company must simultaneously make capacity expansion decision and determine profitable product-mix. Capacity expansion in TFT-LCD industry can be categorized into three different levels, as shown in Table 1. The first level adds new production sites through the "New Site Installation" method. The second level procures new bottleneck machines to expand the bottleneck capacity of an existing site. TFT-LCD industry often encounters difficulties in the first and second level

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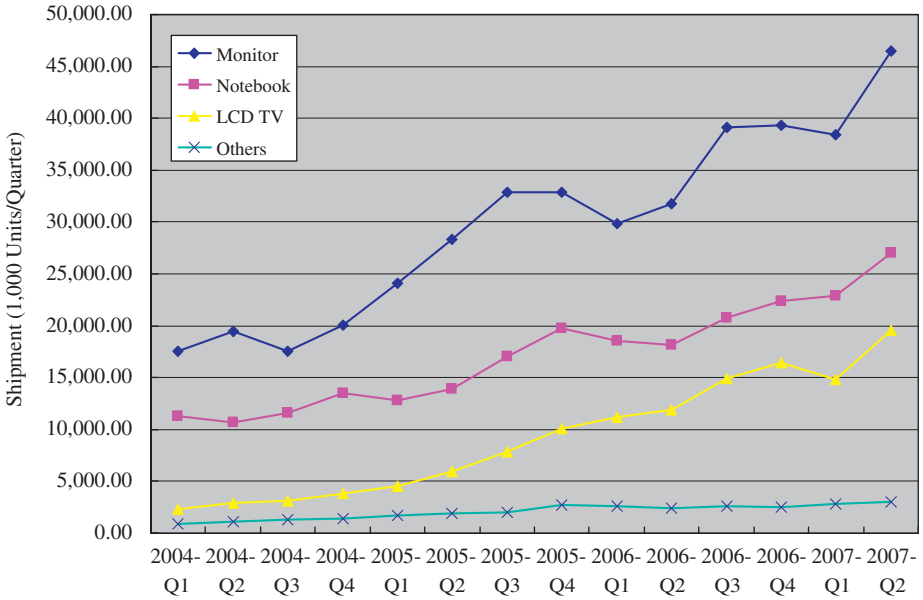

Fig. 1. TFT-LCD shipment quantities from 2004/Q1 to 2007/Q2 (*Source*: Display Search).

Table 1
Three capacity expansion levels in the TFT-LCD industry.

Level of capacity expansion	Decision issue	Impact capacity type	Investment cost	Installation/ procurement lead time
New site (factory) installation	1. What new generation site should be installed? 2. Where should the new site be installed? 3. How much capacity should be installed in new site?	Add "new production facility site"	80 billions ~100 billions	1.5 years ~2 years
New bottleneck machine procurement	1. Which site should be expanded its capacity? 2. How many bottleneck machines should be purchased?	Add "bottleneck machine capacity of an existing site"	200 millions ~300 millions	8 months ~12 months
New auxiliary tool procurement	1. Which site should be expanded its capacity of certain product group? 2. How many auxiliary tools should be purchased?	Add "auxiliary tool capacity of a product group at a production site"	10 millions ~20 millions	32 months ~4 months

capacity expansion due to various resource constraints. These difficulties include high investment cost, long construction and machine procurement lead-time, and space limitation of the existing site.

"New Auxiliary Tool Procurement" is the third level capacity expansion option. This paper considers the third level capacity expansion and can be modified for first and second level capacity expansion planning. New auxiliary tool procurement expands auxiliary tool capacity of a product group at a production site through acquiring new auxiliary tools of the certain product group The procurement of new Auxiliary tools can improve configuration flexibility (see [9]) of a production site when product-mix or demand forecasts are changed.

Despite the importance of strategic capacity planning in TFT-LCD industry, few papers study the capacity planning problems in a TFT-LCD production chain. Since demand forecasts are manually generated by marketing and sales personnel, the demand forecasts are usually inaccurate and change very rapidly. A strategic capacity planning model must include demand forecast uncertainty considerations to enhance the robustness of solutions. To our knowledge, none of the previous research considers demand uncertainties.

The research objective of this paper is to develop a capacity allocation and expansion model that is robust to demand uncertainties. We also consider special characteristics of TFT-LCD manufacturing systems such as short product life cycles, cutting ratios, production capacity/capability, production variable costs, inventory holding costs and high capacity expansion costs. When production is capacitated, it may not be possible to fulfill all demands without capacity expansion. Decision makers can acquire auxiliary tools for bottleneck machines to expand capacity of a certain product group. This paper proposes a scenario-based two-stage stochastic programming model for auxiliary tool capacity planning problems in TFT-LCD industry.

2. Literature review

Capacity expansion and allocation problems have been studied in many research papers without considering special characteristics of TFT-LCD industry, Chen et. al. [5]. Capacity planning problem in these literatures can be categorized into two major categories: single-site capacity planning problem and multiple-sites/supply-chain capacity planning problem. Through purchasing new machine or new auxiliary tool, single-site capacity planning problems focus on allocating and expanding capacity in a specific production site to meet future demand. Bard et al. [2] address the tool-set configuration design