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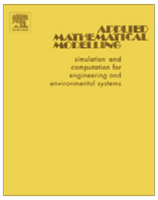

Stochastic multi-site capacity planning of TFT-LCD manufacturing using expected shadow-price based decomposition

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ABSTRACT

This paper presents a stochastic optimization model and efficient decomposition algorithm for multi-site capacity planning under the uncertainty of the TFT-LCD industry. The objective of the stochastic capacity planning is to determine a robust capacity allocation and expansion policy hedged against demand uncertainties because the demand forecasts faced by TFT-LCD manufacturers are usually inaccurate and vary rapidly over time. A two-stage scenario-based stochastic mixed integer programming model that extends the deterministic multi-site capacity planning model proposed by Chen et al. (2010) [1] is developed to discuss the multi-site capacity planning problem in the face of uncertain demands. In addition a three-step methodology is proposed to generate discrete demand scenarios within the stochastic optimization model by approximating the stochastic continuous demand process fitted from the historical data. An expected shadow-price based decomposition, a novel algorithm for the stage decomposition approach, is developed to obtain a near-optimal solution efficiently through iterative procedures and parallel computing. Preliminary computational study shows that the proposed decomposition algorithm successfully addresses the large-scale stochastic capacity planning model in terms of solution quality and computation time. The proposed algorithm also outperforms the plain use of the CPLEX MIP solver as the problem size becomes larger and the number of demand scenarios increases.

1. Introduction

TFT-LCD (Thin Film Transistor-Liquid Crystal Display) panel manufacturing has become a new high-technology industry due to the growing demand for TFT-LCD display application. The production of TFT-LCD panels involves the Array, Cell, and Module manufacturing stages. Multiple production sites that form a multi-stage and multi-site production network within each stage exist. The Array process, which is similar to, but less complicated than the re-entrant semiconductor fabrication process, makes the TFT panel glasses. It is usually a major bottleneck of production due to its high capital investments; the costs for a new generation Array facility can reach several billions of US dollars. The Cell process combines TFT panel glasses with color filters and cuts the panel glasses into different sizes of LCD panels. Finally, the Module process assembles the LCD panels with other key materials to form the final product. The Array process is capacity-constrained and capital intensive, its efficient use is critical for TFT-LCD industry.

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Capacity planning is a critical strategic issue in the TFT-LCD industry for several reasons. One, complex product hierarchies and product types have a wide range of application. TFT-LCD products are used in various consumer devices such as LCD monitors, Notebook monitors, and LCD TVs. These products are differentiated by size (e.g., 15 inch, 17 inch, and 19 inch) and each size is differentiated by display resolutions.

Two, a multi-generation and multi-site production system is generated by multiple generations of manufacturing technologies. Production facilities that use different sized glass substrates are called different generation sites. "Glass substrate" is a key material used to manufacture various TFT-LCD products under the Array process. Higher generation sites use larger glass substrates and can produce different types of products.

Third, market demand is rapidly growing and changing due to the replacement of the traditional Cathode Ray Tube (CRT). Market demands have rapidly grown between 2004 and 2007, especially in LCD TV and personal computer monitor applications, according to the market data provided by Display Search.

Fourth, demand forecasts are manually generated by marketing and sales personnel and are characteristically volatile and prone to inaccuracies. A strategic capacity planning model must include demand forecast uncertainty considerations to strengthen its solutions.

In this complicated environment, the TFT-LCD industry faces the capacity planning problem of balancing demand and supply. When production is capacitated, it may not be possible to meet market demand without capacity expansion. Thus, decision makers can acquire auxiliary tools for bottleneck machines to expand total capacity. The research objective of the current paper is to seek a sound capacity allocation plan and a capacity expansion policy hedged against demand uncertainties. Capacity allocation decision entails deciding on a profitable product mix and an optimum level of production for each product group at a given site in a particular period of time. Capacity expansion decisions must identify the procured amounts of new auxiliary tools and expanded quantities of product-group-specific capacity at a suitable site within a particular timeframe to meet projected demands.

To address such problems, this paper presents a two-stage scenario-based stochastic mixed integer programming model (SMIP). This model extends the deterministic multi-site capacity planning model proposed by Chen et al. [1] to discuss the multi-site capacity planning problem in the face of unpredictable demands. A three-step methodology is also proposed to generate discrete demand scenarios within the stochastic optimization model by approximating the stochastic continuous demand process fitted from historical data.

In addition, the proposed stochastic optimization model also considers the special characteristics of TFT-LCD manufacturing systems. These characteristics include short product life cycles, cutting ratios, production capacity/capability, production variable costs, inventory holding costs, and high capacity expansion costs (see [1] for detailed explanations).

Due to the computational complexity of the proposed model, the current paper seeks to develop an efficient expected shadow-price based decomposition (ESPD), a novel algorithm for the stage decomposition approach, to derive a near-optimal solution according to the specific properties of the proposed scenario-based SMIP model. Most studies in literature employ Lagrangian relaxation-based heuristics or soft computing, to tackle the stochastic capacity planning or capacity expansion problems [2–10]. However, these approaches may cause "infeasible" solutions with higher probability at the end when searching for an optimal solution from the "infeasible" domain. Therefore, they mostly design other problem-specific heuristics to correct the "infeasible" solutions; however, this alternative cannot guarantee the quality of the near-optimal solution obtained. In addition, some alternative decomposition methods, such as bender decomposition (BD) [11–13], disjunctive decomposition [14,15], stochastic branch-and-cut [16], Branch-and-Fix Coordination (BFC) [17], a mixture of BFC and BD [18], dual decomposition [19], and stage decomposition-based hybrid evolutionary algorithm [20] have appeared in literatures to solve the two-stage SMIP problems.

The proposed decomposition algorithm uses shadow-price information to break down the two-stage stochastic capacity planning model into two iterative phases: the scenario-dependent capacity allocation phase and the scenario-independent capacity expansion phase. According to the expected shadow price information from the first phase, the algorithm improves the objective value and searches optimal solutions from a good direction within "feasible" domains. Thus, the expected shadow-price based decomposition ensures finding a near-optimal feasible solution. Moreover, although the capacity allocation phase is a large-scale linear programming model with huge demand scenarios, this whole model can also be decomposed into a number of sub-models with individual scenarios. These capacity allocation sub-models can be solved synchronously based on parallel computing to reduce computational time and memory.

Lastly, the preliminary computational study indicates that the proposed decomposition successfully attacks the large-scale stochastic capacity planning model in terms of solution quality and computation time. In addition, CPLEX is the mixed-integer-programming (MIP) solver against which the computational comparison is performed. The developed algorithm would outperform the plain use of CPLEX solver as the problem size becomes larger and the number of demand scenarios increase.

The rest of the paper is organized as follows: Section 2 reviews some literature on capacity planning problems; Section 3 defines the stochastic multi-site capacity planning problem in TFT-LCD manufacturing and formulates as a two-stage stochastic mixed-integer linear programming model; Section 4 explains how to generate demand scenarios that serve as input to the proposed stochastic programming model; Section 5 develops an expected shadow-price based decomposition to solve large-scale capacity planning problems in efficient manners; Section 6 compares the proposed ESPD with the plain use of CPLEX solver to demonstrate that the proposed algorithm yields better results and solves large-scale problems; and Section 7 provides some concluding remarks.