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Product mix determination and capacity allocation for heterogeneous products in thin film transistor liquid crystal display manufacturing ☆

Y.T. Tai [a,*], W.L. Pearn [b], C.C. Chen [b]

[a] Department of Information Management, Kainan University, Taoyuan, Taiwan
[b] Department of Industrial Engineering & Management, National Chiao Tung University, Taiwan

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ABSTRACT

In the thin-film transistor liquid crystal display (TFT-LCD) manufacturing, the development of models to determine product mix and capacity allocation for a multi-stage, multi-site, and multi-generation company is very important. As rapid advancement of the electronic-paper display (EPD) technology, it is a trend of the coexistence of heterogeneous products involving LCD and EPD products. In the case we investigated, the TFT-LCD company merged an EPD company and incorporated their electro-phoretic technologies into their company. Notably, the manufacturing processes of the EPD products do not incorporate the process steps of liquid crystal injection and attachment of color filters. Consequently, to minimize the total cost, it is essential to decide the appropriate product mix and capacity allocation with considerations of the resource consumption of LCD and EPD products simultaneously. In this paper, we present mathematical models to determine product mix and capacity allocation, which involve three subsystems for TFT-LCD process with consideration of net demand, inventory level, yield rates, cost, margin, outsourcing allocation, cycle time, and panel conversion rate. To demonstrate the applicability of the proposed models, we present a real-world case taken from a TFT-LCD company located in the Science-Based Industrial Park at Hsinchu, Taiwan and perform sensitivity analysis to investigate the effect on the optimal solution.

1. Introduction

Recently, extensive applications of thin-film transistor liquid crystal display (TFT-LCD) products have been increasing rapidly, for example, tablet PC, smart phones, monitors, and LCD TVs. The TFT-LCD manufacturing process mainly consists of three basic stages: Array, Cell, and Module. Typically, in each process stage, there are multiple production sites with multiple process generations. It should be noted that the recently developed electronic-paper (e-paper) display has become an important product in visual display terminals (VDTs) because of its advantages in flexibility, reusability, light weight, and low power consumption (Wang, Hwang, & Kuo, 2012). Since electronic-paper display (EPD) becomes more popular in the reading-intensive handheld devices, some TFT-LCD companies have merged EPD companies and incorporated their electro-phoretic technologies into TFT-LCD manufacturing factories. Consequently, an efficient product mix determination and capacity allocation planning for heterogeneous products (LCD and EPD products) is essential for the TFT-LCD industry with multi-stage, multi-site, and multi-generation.

Notably, the manufacturing processes of the EPD products do not incorporate the process steps of liquid crystal injection and attachment of color filter. In other words, the front-end Cell process stage is not involved in the manufacturing process of EPD products. Consequently, to minimize total cost, it is important to decide an appropriate product mix and capacity allocation with considerations of the resource consumption of LCD and EPD products simultaneously. EPD products have various economic cutting ratios for the multi-generation factories. Based on the particular characteristic of EPD product's properties, we consider the essential material of EPD products which is referred to as front plane laminate (FPL), which is shown in Fig. 1.

Product mix determination and capacity allocation problem for heterogeneous products involving EPD and LCD products in TFT-LCD companies is very complicated since it is a multi-stage, multi-site, and multi-generation manufacturing environment. To solve the problem, the net demand, inventory level, yield rates, cost, margin, outsourcing allocation, cycle time, and panel conversion rate should be considered. In this paper, due to the discussion of heterogeneous products in TFT-LCD manufacturing, four process

☆ This manuscript was processed by Area Editor Manoj Tiwari.
* Corresponding author. Tel.: +886 3 3412500 6002; fax: 886 3 3412173.
E-mail address: yttai@mail.knu.edu.tw (Y.T. Tai).

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stages in the TFT-LCD manufacturing involves Array, front-end Cell, back-end Cell, and Module. In each process stage, various generations exist, which can be seen in Fig. 2. In Array and Cell process stages, there are a 2.5th generation in-house factory and three outsourcing factories involving 3.5th, 5th, and 6th generations in a real-world case. In each generation, due to the difference substrate size, the number of cutting piece is different. In addition, the manufacturing capability and capacity back up are not identical.

In this paper, to make decisions for proper product mix and capacity allocation, we propose three mathematical models, which involves FPL production planning model, capacity allocation models for Array and front-end Cell, back-end Cell process stages with consideration of the net demand, inventory level, yield rates, cost, margin, outsourcing allocation, cycle time, and panel conversion rate. To demonstrate the applicability of the proposed models, we present a case and perform sensitivity analysis to investigate the effect on the obtained solutions. This paper is organized as follows: Section 2 presents the existing research works and Section 3 presents the linear programming models for the problem. To demonstrate the applicability of the proposed models, we present a real-world application taken from a TFT-LCD company located in the Science-Based Industrial Park at Hsinchu, Taiwan in Section 4. Finally, Section 5 includes the conclusions.

2. Literature review

The existing literature works have been shown on various critical research topics regarding the TFT-LCD manufacturing industry. Lin, Chen, and Chen (2007) investigated capacity and product mix problem for TFT Array process stage involving multi-plants. Lin, Wang, and Peng (2008) presented the simulation analysis of the Cell process in a thin-film transistor liquid crystal display (TFT-LCD) manufacturing and considered the effects of the lot release times and dispatching rules. Lin, Chen, and Lin (2009) focused on the material planning problem in the TFT-LCD manufacturing industry. They proposed a single-period and multi-period critical material planning problem as mathematical models in order to optimize purchase quantity. Tsai and Wang (2009) constructed a generic three-stage model of multi-site available-to-promise (ATP) mechanism for assemble-to-order manufacturing. However, these research works only focused on a specific TFT-LCD manufacturing stage.

For multi-stage TFT-LCD manufacturing process, Jeong, Sim, Jeong, and Kim (2002) developed an ATP system for TFT-LCD manufacturing and proposed efficient heuristics for calculating unused production and for scheduling TFT-LCD module assembly processes for effective use of unutilized capacity. Lin and Chen (2007) developed a mathematical programming model considering variable time buckets, relevant constraints and characteristics for the supply network planning problem. Lin, Hong, Wu, and Wang (2010) considered several special production characteristics and developed an ATP model to compute delivery date and quantity of products. Lin, Wu, Chen, and Shih (2011) presented a strategic capacity planning problem in TFT-LCD industry under demand uncertainties. They provided a scenario-based two-stage stochastic programming model. Although multi-stage has been considered in these researches, in some research works, theory of constraints are incorporated and the Array stage is the bottleneck stage of the TFT-LCD production network. They focused on the multi-site TFT-LCD capacity planning problems in the critical manufacturing stage. However, when heterogeneous products coexist in a company and in-house and outsourcing should be considered simultaneously, the developed models may not be applied directly.

Chen, Huang, and Lai (2009) proposed a distributed production planning system for a multi-tier and multi-site production system by combining agent technology with advanced planning and scheduling (APS) system. This research took the Factory Planner which is a commercial packaged software developed by i2 as discussion basis. However, some small or moderate TFT-LCD companies may not use the costly commercial packaged software. They should develop their mathematical models to cope with the product mix and capacity allocation issues. Lu, Huang, and Tseng (2013) proposed an integrated algorithm that incorporates a genetic algorithm, a corner arrangement method, and a production plan model to solve cutting stock problem in the TFT-LCD industry more efficiently. To date, no research work has been done on the product mix planning and capacity allocation for the TFT-LCD companies involving heterogeneous products (LCD and EPD products) and having the characteristics of multi-stage, multi-site, and multi-generation.

3. Mathematical programming models

In this section, three mathematical programming models are proposed to obtain the appropriate product mix and capacity allocation for multi-stage, multi-site, and multi-generation involving FPL (front plane laminate) production planning, capacity allocation for Array and front-end Cell process, capacity allocation for back-end Cell process stage, as shown in Fig. 3.

In the proposed mathematical models, we consider two levels of demand including low season and high season. Due to the outsourcing contract limits, we set upper and lower bounds of outsourcing capacity level. That is, in the low season, company should place the contracted quantities to ensure the utilization of outsourcing factories. In the high season, the outsourcing factories need to reserve the contracted capacity for the TFT-LCD manufacturing company. In the case we investigated, the business strategies for FPL factory, Array, and front-end Cell process stages are make-to-stock. That of Module process stage is make-to-order.

In Fig. 3, we obtain the demand in Module process stage based on the forecast of finished goods, order, yield, and the inventory level. To fulfill the demand of the EPD product, we propose the first mathematical model, namely, FPL production planning model which is a linear programming model used to obtain the releasing quantity and the inventory level with the objective of minimizing the inventory and shortage cost. In the successive two mathematical models, according to demands on Module process stage, inventory level, yield rates, related cost, margin, outsourcing vendor, cycle time, panel conversion rate between Array and Cell process, we construct two linear programming models for Array and front-end Cell processes and back-end Cell process. These models can obtain optimal product-mix and capacity allocation planning at each site in each planning period. In the capacity allocation model for Array and front-end Cell processes, the main purpose is to allocate the optimal production quantity and to recommend outsourcing or in-house production quantity for the EPD and LCD products at each site with the objective of minimizing the total outsourcing cost, manufacturing

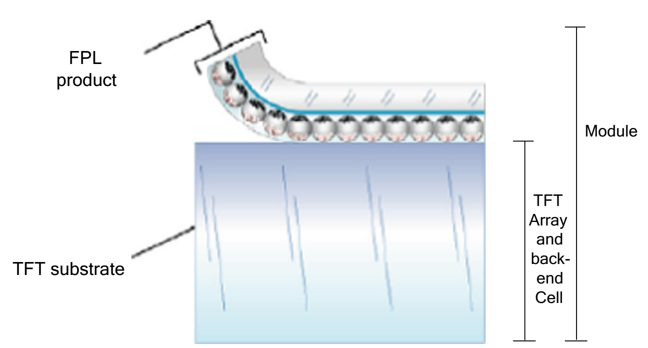

Fig. 1. Schematic of EPD product.