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Capacity planning in thin film transistor – Liquid crystal display cell process

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ABSTRACT

The cell process in a thin film transistor-liquid crystal display (TFT-LCD) manufacturing is characterized as a complicated multi-stage and parallel-machine production system. This system has multiple products, sequence-dependent setup times, multi-step production, multi-objective, and matching constraints between color filter lines and array lines. This complex and capital-intensive production environment needs an efficient capacity planning decision that determines the order release schedule, estimated machine start and finished time of each order, and machine allocations to improve the performance of the entire production process. This research first proposes a finite capacity planning system (FCPS) to cope with the capacity planning problem faced by the TFT-LCD cell process based on the pull philosophy and assumption of finite capacity. A modified multi-objective genetic algorithm (MOGA) embedded in FCPS is also developed to efficiently generate the order release decision, which simultaneously minimizes the machine workload balance, makespan, and lateness. The preliminary experiment identifies the fine MOGA tuning parameters using a two-level factorial experimental design. Finally, the full factorial experiment evaluates the significance and robustness of the proposed modified MOGA algorithm compared with other competitive algorithms under various circumstances.

1. Introduction

The demand for thin film transistor-liquid crystal display (TFT-LCD) panel, initiated by the replacement of cathode ray tubes (CRT) with flat panel display, has been rapidly growing because of its wide usage in monitor devices, LCD televisions (TV), mobile phones, and tablet personal computers (PC). Total sales of 10-inch TFT-LCD and the above occupy more than 50% globally on an annual basis compared with other flat panel display product categories [23]. The average size of LCD TV panels increased significantly in 2013, with the average size at 38.8 inch, up from 36.6 inch in 2012 [19]. Based on the market research in 2013, it was expected that the penetration rate of light-emitting diode (LED) backlights for LCD TV grew 40% and surpass cold cathode fluorescent (CCFL) backlights in 2014 with more than 50% penetration rate. Although the demand is prospective, the global production capacity for large-size TFT-LCD panels (10 inch and above) grew only 3.4% in 2013, which represents the lowest growth rate for the industry.

Low production capacity growth rate indicates that capacity planning or capacity allocation, instead of the capacity expansion, plays a dominant role. Nowadays, the capacity expansion becomes difficult because of the challenging issues related to the product hierarchy complexity, and coexistence of multiple generations of manufacturing technologies [9]. Additionally, TFT-LCD has also been denoted as a complex manufacturing process because of its short product life cycle, complicated cutting ratio, limited production capacity and capability, high production variable cost, high inventory holding cost, and high capacity expansion cost [8]. High utilization is regarded as the essential aspect to be competitive in the global market [26]. Furthermore, the improvement of efficiency, productivity, product reliability enhancement, and cost reduction plan are also considered as the way to achieve competitiveness [38].

TFT-LCD manufacturing process consists of four main stages: color filter, array, cell, and module. Most of TFT-LCD manufacturing companies focus only on the throughput improvement for the array process [34]. However, TFT-LCD cell process holds an essential and critical role in the entire TFT-LCD production network. Cell process consists of many assembly steps to join the color filter and array substrates from previous two processes, which provides the LCD panels to module process for meeting customer demand. The

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TFT-LCD cell process faces several production problems such as high work-in-process (WIP), long cycle time, long setup time, and customer order delay. Moreover, the challenging barriers of the cell process are the multi-stage and parallel-machine production system with multiple products, sequence-dependent setup times, multi-step production, multi-objective, and matching constraints between the color filter line and array line. An efficient capacity planning decision under this complex and capital-intensive production environment can yield performance improvement for the entire production process.

The capacity planning problem is initiated by determining the order release schedule for all machines in the production system. Lin et al. [25] validated that the lot release decision significantly affects the cell process performance under different operating conditions, especially on the reduction of setup and cycle times. Order priority decision based on dispatching rules typically finds a good solution which are near the optimum, easy to implement, and faster to compute [2]. Moreover, common dispatching rules are excellent in certain cases, such as Critical Ratio (CR), which is excellent at on-time delivery performance [14]. However, the general conclusion on order release rules is that no rule performs consistently better than all other rules under a variety of shop configurations, operating conditions, and performance objectives [15]. It is very challenging because the assignment of the release priorities of all orders, based on some combinations of job characteristics and common system parameters, is categorized as an NP-hard problem [20,40]. Genetic Algorithm (GA) is one of the common meta-heuristic tools for solving these complex optimization problems [7,12,17].

The current research first applies and extended the finite capacity planning system (FCPS) framework proposed by previous researches [3–5] into the TFT-LCD cell process environment. Although the previous works have discussed capacity planning system (CPS) [3–5] in the semiconductor manufacturing, FCPS developed from this study not only modifies the module algorithms (e.g. WPM, WAN, LRM, etc.) of the original CPS according to the characteristics and layouts of Cell process but also provides several advanced order priority rules such as MOGA, lot release time heuristic [25], and CR for generating the best order release schedule. The decision makes can choose the best order priority rule or develop new rule within this FCPS framework to generate best capacity plan. This is also the main contribution of this research and different from previous literature. On the basis of pull philosophy and assumption of finite equipment capacity, FCPS extracts the master production schedule (MPS), work-in-process (WIP), process routing, processing time, setup time, number of machines, and order priority sequence/release decision as the main input and produces the output. The output includes order release time, earliest machine start and finished time, machine allocation, machine workload, and order completion time. This capacity planning problem becomes a multi-objective optimization problem because machine workload balance, makespan, and lateness must be simultaneously considered as the main performance. Another contribution of the present research is the development of modified Multi-Objective Genetic Algorithm (MOGA) embedded in the FCPS to efficiently generate the optimal order release schedule. Modified MOGA uses the CR rule for producing better initial order priorities. This modification is expected to enhance the searching performance of the original MOGA. The preliminary experiment identifies the fine MOGA tuning parameter using a two-level factorial experimental design. The computational experiment evaluates the significance and robustness of proposed algorithm performance compared with other competitive algorithms by full factorial experimental design.

The rest of the paper is organized as follows: Section 2 reviews the relevant literature. Section 3 introduces the cell process and identifies the capacity planning problem. Section 4 presents additional details about the FCPS framework and the proposed MOGA algorithm. Section 5 provides the experimental design and results to address the significance and robustness of the proposed modified MOGA algorithm within the FCPS. Finally, Section 6 draws conclusions and provides future research directions.

2. Literature review

In this section, researches related to capacity planning are first reviewed. After that, the order release and scheduling problem in TFT-LCD manufacturing are also surveyed.

Matsuura et al. [27] depicted that two approaches exist in capacity planning or production planning: finite loading and infinite loading. The finite loading approach considers the workload status in setting planned lead times for the jobs to avoid exceeding the machine capacity determined in advance. The finite loading approach is usually used in the capacity-constrained production system. The infinite loading approach does not take the workload status into account to determine the planned lead times based on job operation times. For example, material requirement planning (MRP) is one of the infinite loading approach. Leachman et al. [22] generated capacity-feasible production schedules for a worldwide manufacturing network and quoted product delivery dates in response to customer inquiries. Hood et al. [18] proposed a capacity planning method that accepts uncertainty and uses stochastic integer programming to find a tool set robust to changes in demand. Chen et al. [3] developed a capacity planning system (CPS) that considers the capacity and capability of equipment for multiple semiconductor manufacturing fabs. Wang et al. [36] proposed a method that utilizes simultaneous resources and task allocation in semiconductor testing industry to support decisions regarding equipment investment alternative procurement. Chen et al. [4] developed a capacity requirement planning system (CPRS), based on the assumption of infinite capacity of twin fabs of wafer manufacturing. Chen et al. [5] presented an infinite capacity planning system (ICPS) for IC packaging fab that considers dual resources. Geng and Jiang [14] indicated that spreadsheet, simulation-based method, and integer programming are typically used in capacity planning optimization for semiconductors. Wang and Chen [37] proposed an ant algorithm for solving a set of nonlinear mixed integer programming models to maximize the profit of individual factories. The proposed method allows a mutually acceptable capacity plan of resources for a set of customer tasks to be allocated by the two negotiating parties. Each party has private information regarding company objectives, cost, and price. For the TFT-LCD manufacturing, Chen et al. [8] first studied capacity planning problem in the Array process to determine the profitable “product mix” and “production quantities” of each product group across various generation sites in a particular period and the optimal “capacity expansion quantity” of specific product groups at a certain site. Chen et al. [9] proposed a complete capacity expansion and allocation model that considers the investment of both bottleneck machines and auxiliary tools for TFT-LCD multi-site manufacturing. However, both studies [8] [9] only focus on capacity expansion or investment issues in the multi-site environment without considering detail capacity allocation including order release decision or machine scheduling in certain processes. Missbauer and Uzsoy [28] reviewed the basic formulations of load-dependent production planning problems and focus on models that support decisions on production volumes and order release over time and highlight the related issues on determining planned lead times. Kacar et al. [21] compared the performance of three algorithms including a clearing function model using two different methods for estimating the clearing functions, and two iterative algorithms that combine linear programming and simulation models for production planning with