MULTI-CONWIP FOR ORDER RELEASE AND WIP CONTROL IN COLOUR FILTER FABS

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ABSTRACT

Colour filter (CF), a key step of capital- and technique-intensive TFT-LCD industry, produces colour on glass substrates, counting around 20% of the total cost. It is critical to reduce the cost of CF production where order release and Work-in-Process (WIP) control are two important but correlated issues. This study proposes a Modified Multi-CONWIP strategy that can control WIP, reduce cycle time, increase throughput. An AutoMod simulation model was developed based on a 4.5th-generation CF fab and is used to evaluate the performance of different control strategies.

Keywords: TFT-LCD; colour filter; simulation; order release; work-in-process

INTRODUCTION

Thin Film Transistor - Liquid Crystal Display (TFT-LCD) industry is both capital-intensive and technique-intensive. In years, TFT-LCD gradually replaces Cathode Ray Tube (CRT) and has been widely used in computers and consumer products nowadays. The manufacturing of TFT- LCD consists of four major processes: array, colour filter (CF), cell, and module. CF and array processes fabricate colour layer and transistors on glass substrates, respectively. Then, cell process combines colour filter substrate and array substrate to fill in liquid crystal between them. The assembled substrates are then cut into units with different sizes according to customer demands. Finally, module process assembles additional components, such as backlight and driver integrated circuits (IC), to become glass panels.

In these four processes, CF is the key element of TFT-LCD manufacturing counting around 20% of the total cost of those 26 to 42-inch TFT-LCD. Thus, it is critical to reduce the cost of CF production by increasing the manufacturing efficiency. As show in Figure 1, CF has eight major steps: Black Matrix (BM), Red (R), Green (G), Blue, (B), Indium Tin Oxide (ITO), Multi-Domain Vertical Alignment (MVA), Photo Spacer (PS), and Final Inspection (FI). A BM is formed first to protect backlight and the Red, Green, and Blue colour mixture with pattern that is sequentially coated on the glass substrate surface. A transparent conductive ITO layer is then formed and MVA is applied for vertical alignment pattern. Photo spacer is used to set the cell gap between colour filter glass and TFT array glass. Finally, FI is implemented to ensure the function and quality

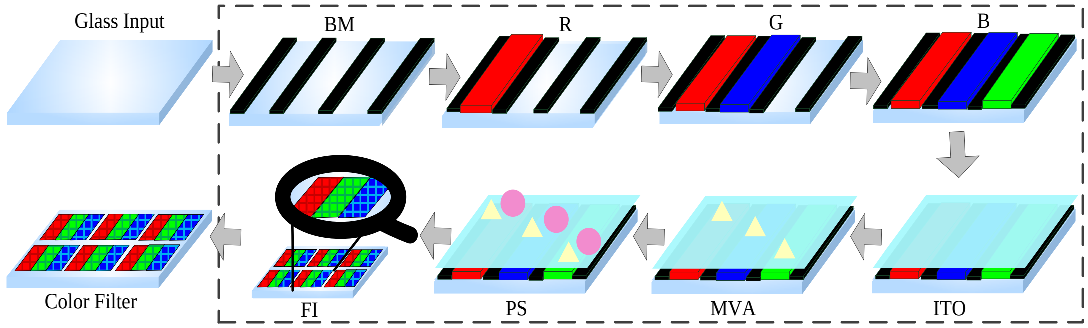

Figure 1 A Typical CF Process Including Eight Major Steps.

In this study, we illustrate using a 4.5th-generation CF fab with two production lines connecting to one MVA station. A typical process flow starts from the release of glass substrates to the production line and ends at final inspection. The production capacity of the CF fab is about 150,000 to 200,000 pieces of glasses per month, depending on the complexity, yield, and processing time of the products. To manage the risk and to ensure the improvement of implementation in TFT-LCD fabs, an AutoMod simulation model will be developed to evaluate the proposed method.

In the production, there are three typical types of products with different process routines (please refer to **Error! Reference source not found.**). Products A, B and C have 8, 7 and 6 steps, respectively. The typical batch size of an order ranges from 300 to 3,000 glasses and a cassette can store 50 sheets of glasses. Workstations are connected with the stockers, and different workstations share the same stocker. Glasses are stored in cassette that is either stored in stockers or in processing at a workstation. After the completion of one operation, a cassette is first moved to the stocker and then further moved to the workstation for next processing when it is available.

Table 1 Three Product Types Information (SOC: Spacer on Colour Filter).

A	MVA	BM→R→G→B→ITO→MVA→PS→FI
B	SOC	BM→R→G→B→ITO→PS→FI
C	Non-SOC	BM→R→G→B→ITO→FI

To avoid the deadlock or WIP congestion, it is crucial to control the lot release based on current WIP level to balance the number of cassettes, the number of loaded cassettes, the number of shelves of the stockers, and the number of loaded shelves. In practice, the shelves cannot be fully loaded to reserve space for the loaded cassettes to be transited from the workstation of previously finished process to the stocker and then to the workstation for next process. In general, the number of shelves of the stockers is about 20% more than the number of cassettes. Cassettes are stored in both stockers for temporary storage or waiting and workstations when the glasses are under processing. Insufficient empty cassettes may cause the delay of the lot release to the production lines. When deadlock or WIP congestion happens due to inappropriate shop floor control, operators need to manually dispatch cassettes from overly loaded stockers to lightly loaded stockers and this process will waste the workstation capacity and decrease the utilization. The studied CF fab has seven stockers and more than seven hundred cassettes.

In CF production, order release and Work-in-Process (WIP) control are two important but correlated issues. Overloaded order release results in high WIP that in turn leads to long cycle time. As lean production with WIP control is widely used in industry to reduce WIP level and reduce the production cycle time, it is of the interest to investigate the order release policy with WIP control to increase the system throughput as well as reduce the cycle time and WIP level in the studied colour filter fab. Traditionally, Kanban and constant WIP (CONWIP) are two most common pull strategies to control certain WIP level and determine order release policy. However, it is difficult to directly apply these two strategies to complex and real manufacturing systems such as TFT-LCD manufacturing, semiconductor assembly and testing and lamp production lines [1, 2]. Therefore, a Multi-CONWIP strategy that separates the whole production line into several loops and controls their WIP levels is derived and outperforms the traditional Kanban and CONWIP systems. This research further extends the Multi-CONWIP concept to propose a Modified Multi-CONWIP strategy and applies it to the real CF fab. The Modified Multi-CONWIP strategy controls the WIP level from two layers: (1) first layer controls fab's WIP (system WIP) with CONWIP strategy, and (2) second layer controls stocker's WIP with Multi-CONWP strategy. Finally, through the simulation model of the CF fab, the different performances of four control methods including Kanban, CONWIP, Multi-CONWIP, and Modified Multi-CONWIP proposed in this study are discussed and compared under various WIP level settings and product mix ratios. The experimental results demonstrate that the Multi-CONWIP and Modified Multi-CONWIP strategies can well control WIP quantities, reduce cycle time, increase throughput and outperform the Kanban and CONWIP systems.

MULTI-CONWIP FOR ORDER RELEASE AND WIP CONTROL

This study proposes CONWIP and Multi-CONWIP approaches based on the drum-rope-buffer concept of theory of constraints [3] that an order was released to the fab when current WIP level is below the threshold. That is, when glass substrates finishes their last production route, a request will be sent to the control center to release new lots of glass substrates to the first stop (i.e., BM in this study) until WIP level exceeds the WIP threshold. Based on the concept of Lean production, high WIP causes production congestion and increases cycle time [4].

Two commonly used pull-type strategies are Kanban and CONWIP. Kanban implements the well-known just-in-time (JIT) production [5] while CONWIP asserts the constant WIP in production line to achieve target throughput. CONWIP not only minimizes WIP but also satisfies demands. Thus, the CONWIP strategy can be read as a single-stage Kanban strategy. That is, CONWIP strategy only uses one set of system cards to manage the whole system WIP. In contrast, Multi-CONWIP strategy manages system configurations between CONWIP and Kanban strategies in the way that more than one but less than the number of total workstations sets of cards are circulating in different sections of the production line.

AUTOMOD SIMULATION MODEL

The layout is presented at Figure 2 where the simulation is at a full automation manufacturing environment using industrial data from a CF fab, where cassette is the smallest lot of moving unit; a lot has 50 sheets; FIFO dispatching rule is adopted; and flow shop system is used. Mean time between failure (MTBF) and mean time to repair (MTTR) are collected from historical data. All of the steps operate 24 hours a day and seven days a week.

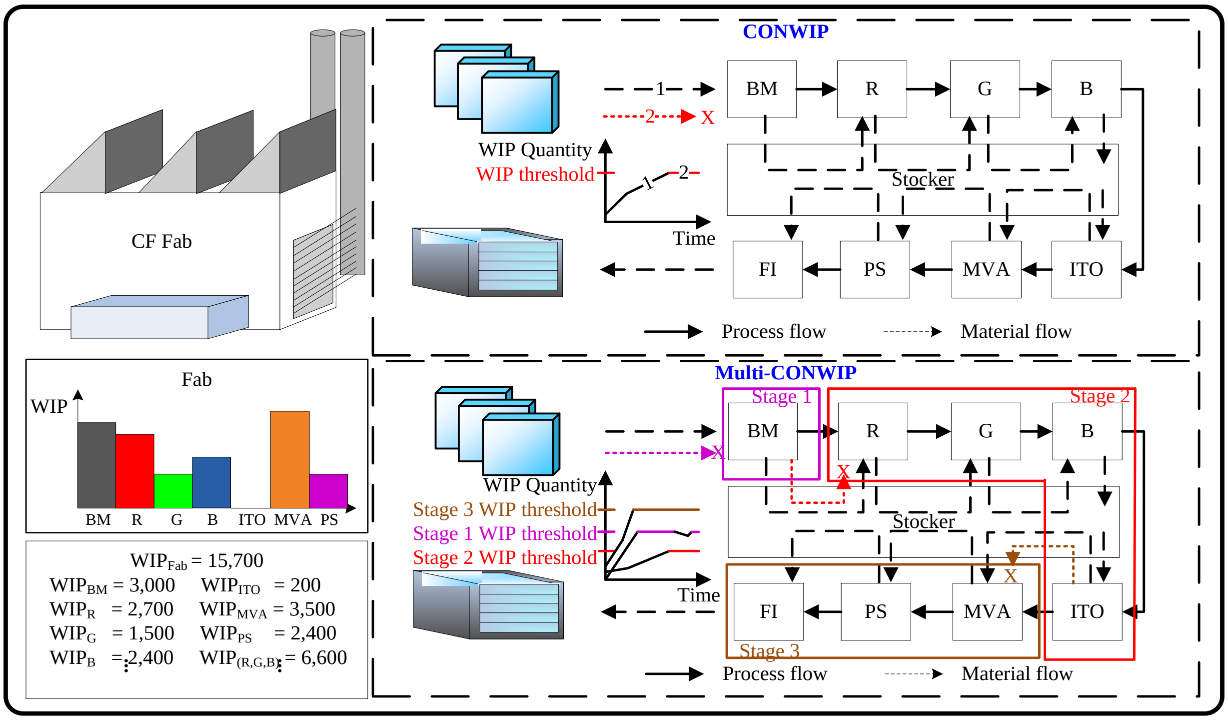

Figure 2 CF Fab Layout in Simulation for CONWIP and Multi-CONWIP.

EXPERIMENTS

The experimental design includes three factors, i.e., Control Strategy (CS), CONWIP Level (CL), and product mix ratio (PM),. The CS has seven levels: (1) CONWIP, (2) Multi-CONWIP by stocker, (3) Multi-CONWIP by available shelf of stocker, (4) Multi-CONWIP by process, (5) Modified Multi-CONWIP by-stocker, (6) Modified Multi-CONWIP by available shelf of stocker, and (7) Modified Multi-CONWIP by process. CONWIP level has two levels: high and low. Different CS levels use different approaches to estimate CL for each control strategy. There are three product types here. We choose two types of product mix (50%, 25%, 25%) and (34%, 33%, 33%) to reflect the normal production combination. The AutoMod simulation model was developed to replicate a real production system and to evaluate the performance of production by adjusting the levels of WIP. Throughput, cycle time, and averaged WIP are key performance indices to evaluate strategies. The threshold of WIP was set by the rule of Little's Law, indicating the WIP level that can be calculated as the multiplication of throughput and production cycle time [4].

Table 2 Summary of Experimental Design.

Factor	Level	Description
Control System (CS)	1	CONWIP
	2	Multi-CONWIP by Stocker
	3	Multi-CONWIP by Available Shelf of Stocker
	4	Multi-CONWIP by Process
	5	Modified Multi-CONWIP by Stocker

	6	Modified Multi-CONWIP by Available Shelf of Stocker
	7	Modified Multi-CONWIP by Process
CONWIP Level (CL)	1	High
	2	Low
Product Mix Ratio (PM)	1	50%, 25%, 25%
	2	33%, 33%, 34%

As mentioned, CM and CE are CONWIP strategies of WIP control for maximum throughput and order release control under expected throughputs. The simulation results from experimental designs are analyzed using descriptive statistics and analysis of variance (ANOVA). All ANOVAs are run by Minitab. The significance level for all statistical analysis is 0.05. Summarized in Tables 3(a)-(c), only the main effects of CS and PM are significant in throughout; CS, CL, and PM are all significant in both cycle time and WIP. That is, factors of CS, CL and PM are significant in all performance indexes except CL to throughput. CONWIP control level directly results in WIP level in the production line. It reduces the time for waiting and subsequently cut the cycle time. However, the level is not crucial to the throughput although it does affect the cycle time and WIP when product mix is different.

Table 3 (a) ANOVA Table with Respect to Throughput.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CS	6	5821466786	5821466786	970244464	14.55	0.002
CL	1	4600804	4600804	4600804	0.07	0.802
PM	1	2821039375	2821039375	2821039375	42.31	0.001
CS*CL	6	664078571	664078571	110679762	1.66	0.277
CS*PM	6	1601925000	1601925000	266987500	4.00	0.058
CL*PM	1	1775089	1775089	1775089	0.03	0.876
Error	6	400036786	400036786	66672798		
Total	27	11314922411				

Table 3 (b) ANOVA Table with Respect to Cycle Time.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CS	6	2.65198	2.65198	0.44200	11.27	0.005
CL	1	0.54238	0.54238	0.54238	13.83	0.010
PM	1	8.83891	8.83891	8.83891	225.46	0.000
CS*CL	6	0.47632	0.47632	0.07939	2.02	0.206
CS*PM	6	0.08286	0.08286	0.01381	0.35	0.885
CL*PM	1	0.15952	0.15952	0.15952	4.07	0.090
Error	6	0.23523	0.23523	0.03920		
Total	27	12.98720				

Table 3 (c) ANOVA Table with Respect to WIP.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CS	6	118680401	118680401	19780067	9.91	0.007
CL	1	35203886	35203886	35203886	17.64	0.006
PM	1	225359932	225359932	225359932	112.90	0.000
CS*CL	6	20518957	20518957	3419826	1.71	0.265
CS*PM	6	5975291	5975291	995882	0.50	0.791
CL*PM	1	18135041	18135041	18135041	9.08	0.024
Error	6	11977040	11977040	1996173		
Total	27	435850548				

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