A Machine Setup Model for TFT-LCD Cell Back-End Process

Y.-C. Chang[1], P.-S. Chen[2], P.-C. Chen[1]
[1] Department of Industrial Engineering and Management, National Chiao Tung University, Hsinchu, Taiwan
[2] Department of Industrial and Systems Engineering, Chung Yuan Christian University, Chung Li, Taiwan
yungchiachang@mail.nctu.edu.tw, pingshun@cycu.edu.tw, hsu.c2688@msa.hinet.net

Abstract - **The cell process is the main part of thin-film transistor liquid-crystal display (TFT-LCD), and can be divided into front-end process and back-end process. Since the production machines of the cell process are the critical resources, maximizing the machine utilization and minimizing the loss of capacity become the major concern for production planning. This research studies the scheduling of machine setups in scribing and breaking station and in testing station (so called the cell back-end process). A customized machine-setup decision support system is proposed to assist shop-floor workers in the back-end process scribing and breaking station and testing station of a 5th generation TFT-LCD production facility to determine an appropriate timing to set up machines. Through a simulation study, it is found that the throughput of the proposed schedule and the machine setup effort in the bottleneck station are both outperformed the ones obtained by current methods employed in this facility.**

Keywords - **Machine setups, TFT-LCD cell process, scheduling, simulation**

I. INTRODUCTION

A Thin-film transistor liquid-crystal display (TFT-LCD) manufacturing process consists of three main processes – array, cell and module processes. The array process deals with TFT fabrication and the processing steps are similar to semiconductor wafer fabrication, but less complicated. The cell process consists of steps in assembling TFT-array substrate and color filter (CF) substrate. It is the critical part of the three processes and can be further divided into front-end process, dealing with cleaning, polyimide printing, rubbing and assembly, and back-end process, dealing with scribing and breaking, testing, polarizer attachment and laser repair. The module process assembles all the necessary parts, such as driver integrated circuit (IC), printed circuit board (PCB), backlight unit and frame, to make the final product.

Most existing literature about the TFT-LCD cell process mainly concerned the front-end process. Very few researches studied the back-end of cell process. Reference [3] developed a scheduling system for TFT-LCD cell process. The scheduling problem they discussed is a parallel-machine scheduling problem with sequence dependent setups. The objective is to minimize the mean flow time and maximize the production progressiveness. They proposed two heuristics for each production step of cell process. The first heuristic is applicable for the front-end of cell process, i.e., cleaning, polyimide printing, rubbing and assembly steps; and for the back-end process the other similar heuristic is employed. Reference [1] proposed an analytic framework for TFT-LCD production chain planning and scheduling and used a practical example of a Taiwanese company to verify their framework. They focus on discussing the strategic issues of production planning. Reference [2] presented a simulation analysis of the cell front-end process in TFT-LCD manufacturing, considering the effects of the lot release and dispatching rule.

A-company is one of the major TFT-LCD manufacturers in Taiwan. This study focuses on the scheduling of the machine setups in the cell back-end process for A-company's 5th generation TFT-LCD production facility (called A-facility hereafter). Fig. 1 shows an illustration of the cell back-end process in A-facility. The manufacturing of the cell back-end process consists of a set of serial workstations (or production steps) each of which contains several parallel machines. In the assembly station, the CF and TFT substrate are matched and then injected with the liquid crystal. The completed substrate set needs to go through the scribing and breaking (S&B) station to be cut into smaller pieces, called panels. The size of each panel depends on the type of product required. Each panel needs to be tested in the testing station. Failed panels are repaired in the laser repair station and then sent back to the testing station. For A-facility, some products need to go through polarizer attachment station and send back to the testing station, and others can be shipped out directly with no polarizer to a downstream manufacturing facility. That is, all panels are required to go through the assembly, S&B and testing stations but only part of panels need to be processed by polarizer attachment and laser repair stations. Besides, all work in process (WIP) is stored in stockers between workstations.

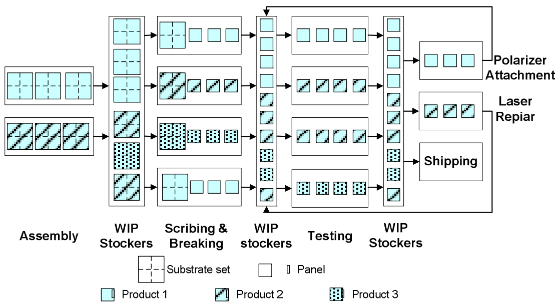

Fig. 1. An illustration of the TFT-LCD cell back-end process for A-facility.

Different types (or sizes) of products are manufactured in the same line, and changing the process requires machine setups, which usually take one to two hours. Frequently setting up machines not only results in loss of production capacity, but also may decrease the yield rate of the product.

After visiting A-facility, we found that the number of parallel machines in the S&B station or in testing station is significantly more than the number of machines in other workstations. There are 11 machines in the S&B station and 14 machines in the testing station, whereas no more than three machines in any other workstations. To set up a machine, it takes one hour in the S&B station or two hours in the testing station. Moreover, the number of setups that can be performed simultaneously in the S&B and testing stations is limited by the number of fixtures and the number of skilled shop-floor workers. Furthermore, the machine setup in the testing station has to be performed by engineers who usually work outside the fabrication area. In A-facility, the machine setup decisions are current made subjectively by the shop-floor supervisor. The decision quality highly depends on the experience and ability of these supervisors. However, when there are a certain number of machines and the setup time is long, even the most experienced staff cannot easily make appropriate decisions to avoid the unnecessary idleness of the machines. Although the WIP information is available in A-facility's real-time production information system, lack of decision support mechanism hinders supervisors from using such information to make better decisions. From the scheduling viewpoint, a lot of opportunities for improvement exist in the cell back-end process. Even a simple improved procedure can result in a significant improvement of the productivity. Therefore, the objective of this study is to design a customized machine-setup decision support system (DSS) for A-facility to assist its shop-floor workers in determining an appropriate machine-setup schedule in the S&B and testing stations.

II. DESIGN OF A CUSTOMIZED MACHINE-SETUP DECISION SUPPORT SYSTEM

The main purpose of this DSS is to shorten the idle time incurred by machine setups in the S&B and testing stations in order to increase the machine utilization and productivity. In order to effectively analyze this problem, the following assumptions are made to limit the scope of this study. (1) The capacity of warehouse and WIP storage area is sufficient. (2) The materials and transportation equipment are sufficient.

The maximum throughput of a system is determined by its bottleneck capacity. Thus, it is important to identify the bottleneck of a system before analysis. This study randomly selected one-month production data provided by A-company and analyzed the capacity and machine utilization for S&B and testing stations. The results are summarized in Table I, where the average machine utilization is calculated by the number of operating hours of the machines dividing by the total available working hours. The excess capacity represents the machine idle time. From Table I, we can find that the average machine utilization of the testing station is higher than that of the S&B station. Further, the excess capacity can only provide 1.67 setups for the machines in the testing station, meaning that the production planning and machine-setup schedule are very critical to the productivity of the testing station due to limited machine excess capacity.

TABLE I
CAPACITY AND MACHINE UTILIZATION FOR S&B AND TESTING STATIONS

Workstation	S&B	Testing
Average machine utilization	86.89%	88.67%
Excess capacity (hour/day)	5.43	3.34
Machine setup time (hour)	1	2
Number of setups per day provided by excess capacity	5.43	1.67

The proposed machine-setup DSS consists of three modules: data input module, machine-setup module and schedule output module. Data input module first reads and pre-processes data from the production information system for the machine-setup module, which generates appropriate schedules for machine setups by its built-in dispatching rule. The suggested schedules are displayed by schedule output module for shop-floor workers. The structure of the machine-setup DSS is illustrated in Fig. 2.

The *data input module* organizes and pre-processes required data for the machine-setup module. The required data include product related information (such as product type, number of panels generated by one substrate set for each type of product, processing time for each machine, etc.), the number of machines available in each station, the number of fixtures available for each type of product in each station and the planning horizon.

The *machine-setup module* consists of PD-PI algorithm and feasibility check algorithm. PD-PI dispatching algorithm is a combination of PD (product decreasing) algorithm and PI (product increasing) algorithm. In order to better explain the logic embedded in these two algorithms, we use "type x machine" to represent "a machine that has been set up to process product type x." In PD-PI algorithm, PD algorithm first checks if there is any product type that matches the conditions such that the number of corresponding type of machines can be decreased. The purpose of this algorithm is to locate the type of product whose WIP will soon be finished processing by the available machines. When a certain type of product is found by PD algorithm, PI algorithm is then applied to locate the type of product such that the corresponding type of machines can be increased. The purpose of PI algorithm is to locate the type of product such that the WIP of this type of product requires the longest time to process. The change of machine allocation generated by PD-PI algorithm needs to be further evaluated by feasibility check algorithm to find if there are enough fixtures available to perform the production task suggested by PD-PI algorithm.

The *schedule output module* provides the suggested schedule of machine setups for shop-floor workers. The output information includes the machine allocation in each time bucket and the trend chart for the work load in S&B and testing stations, respectively.

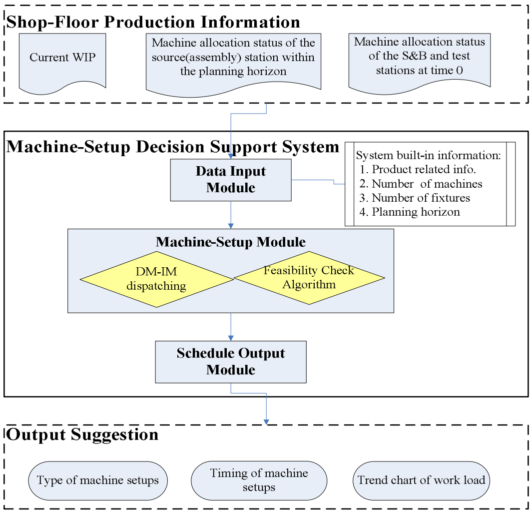

Fig. 2. Structure of the machine-setup DSS.

In PD-PI algorithm, the key performance indicator is the workload for each type of product in each workstation. The workload can be interpreted as the number of consecutive working hours required for a workstation to process a certain type of product. Let $W_{i,s,t}$ be the workload of product type i in station s at time t. $W_{i,s,t}$ can be calculated by (1).

$$W_{i,s,t} = \frac{V_{i,s,t}}{M_{i,s,t}\ O_{i,s}} \quad , \ \forall\, i,\ s,\ t\ . \qquad (1)$$

In (1), $M_{i,s,t}$ denotes the number of machines that can process product type i in workstation s at time t, $V_{i,s,t}$ represents the total amount of product i that are processed by machines in workstation s at time t and $O_{i,s}$ represents the average number of product i per hour that each machine can produce in workstation s. Here, $O_{i,s}$ is calculated by (2).

$$O_{i,s} = \left\lfloor \frac{3600}{p_{i,s}} \right\rfloor \quad , \ \forall\, i\,, s\ . \qquad (2)$$

where $p_{i,s}$ is the average time (in seconds) required by a machine in workstation s to process product i.

PD algorithm can be described by the following two steps:

Step 1: Locate the candidate product type such that the number of machines processing such type of product can be decreased in workstation s at time t. Among the type of products that workstation s is processed at time t and the number of machines assigned to process such product types is greater than 1 (i.e., $M_{i,s,t} > 1$, for some i), locate the type of product (say product i_1) with the smallest workload. That is,

$$(i_1, s_1) = \arg\min \{ W_{i,s,t} \mid M_{i,s,t} > 1,\ \forall i \}\ . \qquad (3)$$

Step 2: Check if product i_1 meets (4) such that the number of machines processing such product can be decreased.

$$W_{i_1,s_1,t} < c_{s_1} + x\ . \qquad (4)$$

In (4), c_s is the time (in hours) required to set up a machine in workstation s and x is an allowance parameter which can be obtained by analyzing the historical production data. The value of x is chosen such that the total machine-setup time in both workstations is minimized.

PI algorithm is described by the following three steps:

Step 1: Locate the candidate product type such that the number of machines processing such type of product can be increased in workstation s at time t. Let product type i_2 be the type of product with the largest workload at time t in workstation s_2, i.e.,

$$(i_2,\ s_2) = \arg\max \{ W_{i,s,t}\ ,\ \forall i \}\ . \qquad (5)$$

Step 2: Check if product type j meets Condition I-1 described in (6). Here, product i_1 is the type of product suggested by PD dispatching algorithm such that the number of machines processing product type i_1 can be decreased. If Condition I-1 is satisfied, then go to step 3; otherwise, do not change the machine allocation in workstation s_2 at time t to avoid the situation when both $W_{i_2,s_2,t}$ and $W_{i_1,s_1,t}$ are small but the system suggests to alter the status of machine allocation.

$$W_{i_2,s_2,t} - W_{i_1,s_1,t} > D \ \text{(Condition I-1)} \qquad (6)$$

Step 3: Check if product type j meets Condition I-2 described in (7). Check if the WIP of product type i_2 at time t can be completed earlier if the number of machines processing product type i_2 is increased. If Condition I-2 is satisfied, apply the feasibility check algorithm; otherwise, do not change the machine allocation in workstation s_2 at time t.

$$W_{i_2,s_2,t} > W_{i_2,s_2,t+c_{s_2}} + c_{s_2} \quad \text{(Condition I-2)} \qquad (7)$$

PD and PI algorithms should be executed in an appropriate order to generate the suggested changes of machine allocation in S&B and testing stations, respectively, in each time bucket. As mentioned before, the testing station is the bottleneck and the machine setup in the testing station is more complicated and time-consuming than that in the S&B station. Whenever there is a need to set up a machine in the testing station, it is necessary to evaluate if it is possible to set up a machine in the S&B station to substitute the machine setup in the testing station in order to shorten the total setup time required by both stations as well as the number of time that engineers enter the fabrication area. The sequence of applying PD and PI algorithms is described in Fig. 3.

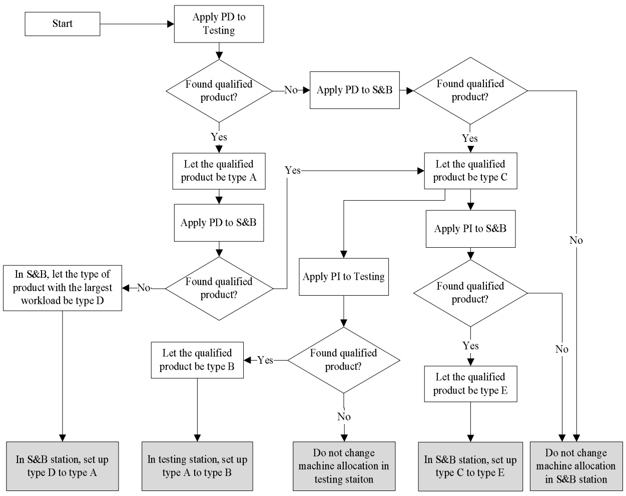

Fig. 3. Flow chart to illustrate the logic embedded in PD-PI algorithm.

III. SIMULATION ANALYSIS

The proposed DSS is implemented by constructing macros embedded in Microsoft Excel by VBA (Visual Basic for Application) language in order to be compatible with A-company's current shop-floor system. To investigate the effectiveness of the machine-setup schedules suggested by the proposed DSS, a discrete event simulation model, constructed based on the real setting in the fabrication area in A-facility, was used to evaluate the system performance. The simulation model was built and executed in eM-Plant, the object oriented simulation tool. To simplify the simulation model, the following assumptions are made: (1) The type and number of machines and the corresponding time for each machine to process a certain type of product are known. (2) The number of fixtures available for each type of product is known. (3) The manufacturing facility operates 24 hours a day (by two 12-hour shifts). (4) The planning horizon is one day divided into 24 time buckets.

Fig. 4 is an illustration of the simulation model of the cell back-end process in A-facility. Five workstations are included in this simulation model: assembly, S&B, testing, polarizer attachment and laser repair stations. The machine-setup decisions in S&B and testing stations are suggested by the proposed DSS. The rest three stations are modeled as sourcing stations that provide WIP to S&B and testing stations.

In the simulation scenario, the input materials are substrate sets that have been matched, hot-pressed and injected with liquid crystal in the assembly station. Seven types of product are produced. The number of panels can be cut from one substrate set of each type of product is organized in Table II.

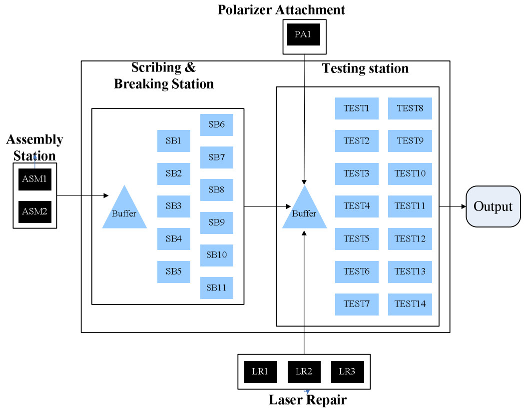

Fig. 4. Simulation model of the cell back-end process.

TABLE II
NUMBER OF PANELS CAN BE CUT FROM ONE SUBSTRATE SET OF EACH PRODUCT TYPE

Product type	A	B	C	D	F	G	H
Number of panels can be cut per substrate set	16	16	12	12	12	12	8

Moreover, the number of machines in each of the five workstations included in the simulation model is organized in Table III. The machines in each workstation are regarded as independent parallel machines.

TABLE III
NUMBER OF MACHINES IN EACH WORKSTATION

Workstation	Assembly	S&B	Testing	Polarizer Attachment	Laser Repair
Number of machines	2	11	14	1	3

The setup time for a machine in the S&B station is one hour and the setup time for a machine in the testing station is two hours. The numbers of fixtures available for different product types in S&B and testing stations are organized in Table IV.

TABLE IV
NUMBER OF FIXTURES AVAILABLE

Workstation \ Product type	A	B	C	D	F	G	H
S&B	9	3	11	4	11	5	6
Testing	0	4	9	7	11	7	7

In the simulation study, the material release schedule is based on the estimated production planning of the assembly station. Moreover, the existing method employed to determine the machine setup schedule is modeled as a myopic minimum setup time (MST) rule. Based on MST rule, machine setup will not start until at least one machine is idle. Due to the limited skilled manpower to set up machines, the existing method allows at most one setup in S&B station and at most two machines to be set up in testing station simultaneously at any time. The simulation model is verified by the animation and step trace functions provided by eM-Plant software to ensure that the model is correctly constructed. The simulation model is also validated using the historical production data and the system throughput difference between the real and simulated system is within 5%.

The input data of the simulation analysis is based on the actual production history provided by A-company. Since the planning horizon is one day, each simulation run requires one-day production data. The main performance measure of this analysis is chosen as the setup time required for the bottleneck station (i.e., the testing station) in order to fully utilize the production capacity. Another performance measure is defined as the system throughput.

Fig. 5 organizes the total machine setup time required in the testing station by the existing method and by the proposed study. Five simulation runs using five randomly chosen production data sets (sample) are performed. In Fig. 5, we can find that the proposed method can significantly reduce the total machine setup time required in the testing station for every sample. Further analysis is made on the machine setup time required by each workstation, as shown in Fig. 6. Fig. 6 shows that the main machine setup effort lies in the testing station. Since the machine setup in the testing station is more complex than that in the S&B station, the proposed method is designed to substitute the machine setup in testing station by the machine setup in S&B station. Moreover, Fig. 6 also displays that the proposed method successfully reduces the total setup time in the testing stations by increasing the machine setups in the S&B station, especially for samples 1, 2, and 5.

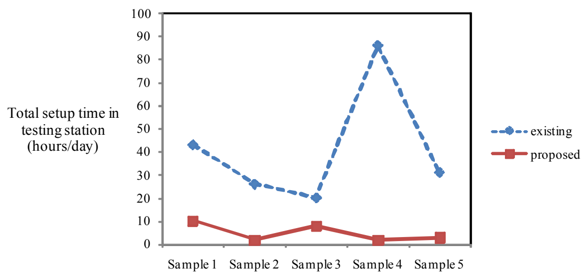

Fig. 5. Machine setup time required in the testing station.

Fig. 7 displays the increment on throughput by using the proposed method compared with the existing method. In Fig. 7, we can find that the proposed method does increase the system throughput significantly in every sample except in sample 5. After carefully examining the production data in sample 5, we found that the initial loading in the testing station in sample 5 is significantly lower than that in other samples. This situation makes some machines in the testing stations idle. Thus, the changes made to the machine setup decisions by the proposed method do not have significant effect on the system throughput. However, although the system throughput generated by the two methods using production data in sample 5 are close, the total machine setup time in the testing station by the proposed method is still significantly lower than by the existing method.

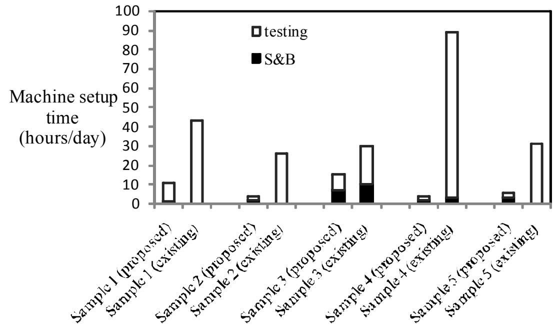

Fig. 6. Total machine setup time required in the S&B and testing stations Machine setup time required in the testing station.

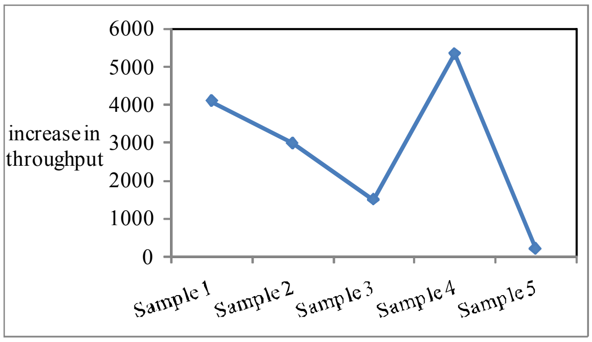

Fig. 7. The increment on throughput by proposed method compared with the existing method.

IV. CONCLUSION

This paper proposes a customized machine-setup DSS to assist shop-floor workers to determine appropriate machine-setup schedule in the scribing and breaking station and the testing station of a 5th generation TFT-LCD production facility in Taiwan. This DSS contains three modules, including data input module, machine setups module, and schedule output module. Real production data are used to verify the effectiveness of the proposed system through a simulation study. The results show that the schedule by the proposed DSS outperforms the existing method in terms of the machine setup time in the bottleneck station and the system throughput.

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