A Research on the Mixed-Line Production Scheduling Problem of a Flow-shop System

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ABSTRACT

This paper is to establish and solve the re-scheduling problems under a flow-shop mixed-line production planning. A case study of the final stage, module manufacturing, of TFT-LCD is provided for illustration of the developed mechanism. In this research, the mixed-line production system and its rescheduling problems are discussed. The buffer management and the DBR scheduling methods based on the Theory of Constraints are used to detect, identify, and level the bottleneck problems in the system. The direct contribution of the results is to increase the production flexibility and mobility of the manufacturing scheduling system and to benefit the entire members of supply chain system. The simulation software, **Flexsim**, is used to construct and evaluate the developed model, some phenomena of simulated system performance on the maximum delay of orders, the total cost of delay, and make span are discussed.

Keywords: **bottleneck, DBR, mixed-line production, re-scheduling**.

INTRODUCTION

The mixed-line production is one of the trends of today's manufacturing system models and probably is also the useful way to meet the changing requirement from customers. The global supply chain system in the world makes the mixed-line system model even more important for industries. Enterprises and companies achieve the goal to meet customers' needs along with gaining profits and reducing costs by means of successfully planning and execution of supply chain management. Under the globalization of electronic system structure, the electronic and wireless communication industries can be seen as a structure of supply chain (Hvolby and Trienekens, 2002). The needs of different sizes of liquid crystal displays (LCD) or the flat panel displays (TFT-LCD, Thin Film Transistor Liquid Crystal Display, in particular) become today's major consumers' products through the global supply chain system. These needs of LCD are induced as living necessities of electronic devices and wireless communication products, e.g., laptop, digital camera, iPad, and iPhone, etc., in our daily life.

To meet the demand pattern of customers, i.e., high-variety and low-volume, the mixed-line production system and the pull phenomena concept are important. Thus, the last stage, the module manufacturing, of TFT-LCD industry is discussed to reveal the requirement of end customers. The mixed-line repetitive flow production is defined that different types of products are produced in the same production line. The transferring or set up time should be, but not necessary, short among different types of products. Those different types of products show in a crisscross pattern on the production line. Hall, in 1983, used four types of products, namely A, B, C, and D, as an example to describe this kind of production system. The production structure with four different types of products is A-B-C-A-B-C-A-B-A-D on a production line. This mixed flow represents that whenever the product *D* is finished, there have been already produced four *A*, three *B*, and two *C*.

The main production procedures of TFT-LCD industry include three major stages, namely the Array, Cell, and Module. The final part of production procedure, the so called Module, is the final assembly and is capacity and material oriented. Under the requirement of customers' orders for quantities and due-dates, to design a good scheduling is critical. Nevertheless, in today's environment of high-variety and low-volume demand, to model a mixed-line production system is also essential. How to resolve the above situation under longer scheduling process and unreliable production requirement is the major issue of this paper. Therefore, the intention of this research is to construct the model of scheduling and re-scheduling of a mixed-line production system for a flow shop manufacturing system. This mixed-line structure on a single production line can meet the requirement of customized demand and processes within the influence of supply chain configuration. This research intends also to apply the DBR (Drum-Buffer-Rope) scheduling technique derived from the theory of constraints (TOC) and the buffer

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management to study the mixed-line system under the consideration of due date, finish time, make span, and bottleneck shift phenomenon to scheduling orders and products. A real case in TFT-LCD industry using simulation software is also performed. The analytic results ensure that this provided model can provide a useful production control mechanism of the flow shop production system to enhance industries' abilities to meet customers' needs in the world.

LITERATURE REVIEW

For the production scheduling problems, an enormous amount of researchers have been dedicated in this area. Nevertheless, many of them basically focus on single or small range of system performance. The manufacturing system actually needs to be considered the entire interactions of planning and execution stages to reveal actual factors from different aspects. This research tries to cope with both the mixed-line and rescheduling structures; hence, several topics would be reviewed, including mixed-line and mix-model production, bottleneck and bottleneck shifting, and buffer management.

TFT-LCD manufacturing generally is a single production line for producing a certain size or item of product. In the past researchers were basically focused on single flow line rescheduling with concepts of Capacity Constraint Resource (CCR) by using DBR technique (Kuo, 2005) or on rescheduling timing and execution frequency problem (Wu and Lee, 1997; Varela et al., 2003; Lin, 2002). In TFT-LCD manufacturing, due to the limitation of factories space and expensive facilities investments, it is necessary to setup the mixed-line production to enhance productivity, efficiency, and to minimize total cost including setup cost, manufacturing cost and inventory holding cost (Chen, 2001 and 2003). For the rescheduling problems, Hu *et. al*. applied ant colony algorithm to schedule orders to fit into the smallest average flow time to let urgent orders be scheduled as early as possible. Itayef *et. al*. developed a two stages heuristic algorithm and in the first stage distributed fixed orders to jobs, then used the simulated annealing algorithm to optimize job sequences. Cui *et. al*. used the critical chain and TOC to develop six different heuristic methods to resolve rescheduling and the resources and job priority problems. Wang and Wang proposed a partial rescheduling by considering the rescheduling only at the period of machines breakdown and failure.

Mixed-line and Mix-model Production

Many researches mainly discussed on topics of the so called mix-model and mixed-line production problems. The mixed-model type of production system basically discusses on one production or assembly line with different production models. Different models, for example, continuous or intermittent production, can be applied on either the anterior or the posterior sector of a production line (Wang and Wang, 2011; Wu and Lee, 1997; Wu, 2001). Hall, in 1983, used four types of products, namely A, B, C, and D, as an example to describe this kind of production system structure. The production structure with four different types of products is A-B-C-A-B-C-A-B-A-D on a production line. This mixed flow represents that whenever the product D is finished, there have been already produced four A, three B and two C products. In this system, both bottleneck problem and utilization of the production system are the most important issues in this study. There are problems of having different setup time for changing products on the line or scheduling difficulties in this so called mixed-line production system. Researchers mainly focus on how to eliminate existing wastes in the production processes or to search the optimal solution of production sequences under dependent and independent conditions (Wu and Lee, 1997; Wu, 2001). This paper is then based on the total capacity concept and DBR technique, i.e., the theory of constraints, to study the influences by different batch feeding of materials and bottleneck shifting in a flow-shop mixed-line production system.

Bottleneck and Bottleneck Shifting

There are different interpretations for bottleneck. A bottleneck usually indicates the available capacity of a resource that limits or confines the outputs of a system or an organization. In a service or manufacturing system, bottleneck might be defined as the resource with the longest processing time, or the highest average utilization rate or loading, or by reducing processing time of the work station will reduce the entire average flow time of processes. In this paper, bottleneck can be defined in two different stages, the planning and shop floor execution stage (Wu, 2001; Wu et al., 1999). In the planning stage, bottleneck loading is based on the measured standard time and calculated by adding the needed process times; whereas in the shop floor execution stage, bottleneck can be detected by WIP phenomenon, quantities, and proceeding situation of buffers in front of resources.

Nowadays, the orders are mainly customized and the exact market requirement is mostly uncertain. Therefore, the main production scheduling might have to be rearranged due to reasons of orders being frequently cancelled, urgent orders arriving, shortage of raw materials, and so on. Rescheduling is one of the main methods to resolve request fluctuation and uncertainty. Unfortunately, bottleneck and bottleneck shifting are the major causes of rescheduling. Due to the frequent changes of customers' orders or requests and changes of work loadings, bottleneck station can be moved to another station and forms the so called phenomenon as bottleneck shifting or floating bottleneck. It is found that the buffer and buffer management are able to manage the production fluctuation by setting the buffer capacity and rescheduling (Kuo, 2005). The comparative between stages of production and factors for rescheduling is shown in Table 1.

Table 1. Causes of bottleneck shifting and factors for rescheduling

Stages and causes of bottleneck shifting		Factors for rescheduling
Stage of Production Planning	Capacity balance	Planned loading
	Combination of Products	1. canceling orders 2. order changes (including quantity or due date) 3. emergency or rush orders
	Materials input schedule	4. shortage of materials
Stage of Production Execution	Batch sizes	5. the process time is over or under estimated 6. rework
	Over pursue optimization of non-bottleneck resources	7. ahead of schedule or delayed
	Probability factors such as machine is down	8. mechanical failure or breakdown 9. quality problems
	Dispatching methods	

Source: Kuo (2005)

Performance of Mixed-line Production

Lawrence and Buss (1994) had shown how to find the shifting level of bottleneck β, $\beta = 1-(cv/\sqrt{n})$. It uses the β to remind managers that a resource or station tends to become bottleneck when β is high and is needed to put into control. Huang and Cheng (2001) had applied the intuition into WIP to identify the bottleneck shifting when WIP is out of a certain control limit. This method seems to be convenient for users, however, the response time is too long for those orders with urgent due date or those products with shorter manufacturing flow times. This is because bottleneck can be detected only after it had happened. In this paper, this problem can be controlled by applying buffer management technique to detect bottleneck at the check point time (CPT) to monitor the bottleneck shifting and eliminate bottleneck before it occurs. The schedule, quantities, and sequence of batch feeding of materials are influenced by the supply chain reaction and are also related to the response of customers' requests. The batch feeding of materials and products requirement will also create structural influence and change of the occurrence of bottleneck and bottleneck shifting. The important performance indices for mixed-line production system are the fulfillment of due date, minimizing make span and rescheduling (Kuo, 2005; Wu and Lee, 1997).

MODEL DEVELOPMENT AND ESTABLISHMENT

As mentioned earlier, bottleneck and bottleneck shifting might occur in two stages, namely the planning and execution stages. Both the theory of constraints and the concept of system output are limited by bottleneck constraints and are applied in this research for studying the mixed-line system. Our target is to put the planning stage into management to resolve bottleneck problem and enhance system productivity. For the entire research in this paper, the development is based on the total capacity of factory and applies the TOC to construct the production planning of a single mixed-line production system to enhance the production efficiency and prevent capacity waste. The DBR algorithm is then applied for the rescheduling plan of a mixed-line system under the affection of downstream customers' low-volume high-variety demand pattern and complex products combination.

System Description and Model Formulation

The researched mixed-line system is adapted from the Module manufacturing portion of TFT-LCD industry. In TFT-LCD manufacturing processes contain three stages of *Array*, *Cell* and *Module*. The Module manufacturing process is located at the end of entire production flow and directly related to customers' requests and requirement. The "module" manufacturing process is a flow line production system as shown in Fig. 1. All products have to be operated along the same flow processes. The basic assumptions of this system are: 1. every single job can only be operated on one machine at a time; 2. each machine can only process one job at a time; each job can not be stopped once it is started processing, i.e., there is no preemption allowed; 3. there will be different setup times for different products when operated on the same machine; 4. the setup time will be different even when the operating sequence is different; 5. the re-entrant flow structure and product rework processes are not included in this research. The related descriptions and definitions of variables used are shown in Table 2.

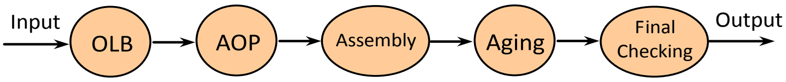


Figure 1. Production Processes

Table 2. Definition of Variables

i: product order number, i=1,2,3,…,n.
j: item number, j=1,2,3,…,m.
k: machine number, k=1,2,3,…,s.
Q_i: quantity of product order i.
O_{ij}: working (or manufacturing) order for item j of product order i.
Q_{ij}: quantity of working order O_{ij}.
MT_{ijk}: processing time of item of O_{ij} on machine k.
PT_{ijk}: total process time for O_{ij} on machine k.
i.e., $PT_{ijk} = Q_{ij} \times MT_{ijk}$
ST_{ijk}: setup time for O_{ij} on machine k.
WPT_{ijk}: total working time for O_{ij} on machine k, i.e., $WPT_{ijk} = PT_{ijk} + ST_{ijk} \times \beta_k$, where

$$\beta_k = \begin{cases} 1, \textit{if the consecutive working orders are} \\ \quad \textit{different on machine } k \\ 0, \textit{otherwise} \end{cases}$$

TUC_k: total available capacity time of machine k within planning period of time.
OST_{ijk}: start operating time of O_{ij} on machine k.
OET_{ijk}: end operating time of O_{ij} on machine k.
DD_i: due date of order i.
DT_i: delay time of order i, where
$DT_i = max(0, OET_{ijk} - DD_i)$, i=1,2,3,…,n.
α_i: delay cost of order i.
MR_j: allowance rate of j item on production line.
BS_k: machine k is the bottleneck station.
BT_{ij}: buffering time of O_{ij} on production line.
CPT: the rescheduling checking point time.
IST: ideal start time of bottleneck station.
ICT: ideal complete time of bottleneck station.

System Model Development and Establishment

The DBR, Drum-Buffer-Rope technique of TOC, and buffer management will be adopted for development and control of the mixed-line production system. The developed procedures and model showing as follows will help managers to detect production problems earlier, to evaluate the properness of those improving methods and to proceed rescheduling.

DBR Scheduling

Step 1: Detecting the constrained resource

This step is based on the average resource loading for detecting the constrained resource. The bottleneck workstation is the one that having the highest average loading at the total planned time span.

$$BS_k = Max \frac{(\sum_{i=1}^{n}\sum_{j=1}^{m} Q_{ij}) \times MT_{ijk}}{TUC_k}. \tag{1}$$

Step 2: Deciding buffer size

Buffer size is based on the buffer of bottleneck station. Here, we assume that bottleneck is the work station M, where M＝1,2,3,…,S and product item is 1, that is j＝1, then:

$$BB_{j=1} \text{（bottleneck buffer）} = \sum_{i=1}^{n} Q_{i1} \times \sum_{k=1}^{m-1} MT_{ijk} \times MR_{j=1}, \tag{2}$$

$$SB_{j=1} \text{（shipping buffer）} = \sum_{i=1}^{n} Q_{i1} \times \sum_{k=m}^{s} MT_{ijk} \times MR_{j=1}, \tag{3}$$

BB_{ij} =0; when M＝1 (i.e. the first station), (4)

SB_{ij} =0; when M＝S (the S^{th} station is the last station), (5)

BT_{ij} (buffer time)＝ $BB_{ij} + SB_{ij}$. (6)

Step 3: Design the production rhythm of bottleneck workstation

Designing the production rhythm of bottleneck workstation can not only determine how to arrange the production rhythm but also directly decide both the throughput of entire system and the cooperate sequence of non-bottleneck workstations. Among performance evaluation indices (described in next subsection), the minimal longest order tardiness is also selected to work as the basic criteria. The operation precedence can be determined by the following rules:

- EDD rule, which is based on the due date
- If due dates are the same, then follow the rule that selecting the order having the larger amount of tardiness cost processes first
- If all the due dates and tardiness costs of orders are the same, then processes the one with the longest process time first

Hence, the production rhythm of bottleneck station can be designed as follows (assume there is only one bottleneck station and is at the M^{th} station):

1. Calculate the ideal completion time of each working order at station M.

$$ICT_{ijm} = DD_i - \mathrm{SB}_{ij}, \tag{7}$$

where ICT_{ijm} (Ideal Completion Time) is the ideal completion time for O_{ij} at bottleneck station.

2. Calculate the process time of working orders at bottleneck station M.

$$WPT_{ijm} = ST_{ijm} \times \beta_k + PT_{ijm}. \tag{8}$$

3. Calculate the ideal start time of working orders at bottleneck station M.

$$IST_{ijm} = ICT_{ijm} - \mathrm{WPT}_{ijm}, \tag{9}$$

where IST_{ijm} (Ideal Start Time) is the ideal start time for O_{ij} at bottleneck station M.

4. Calculate the material planned starting input time to production system.

$$OST_{ijm} = IST_{ijm} - BB_{ij}, \tag{10}$$

where OST_{ijm} (Order Start Time) is the planned start input time for O_{ij} at bottleneck station M.

$$OCT_{ijm} = OST_{ijm} + WPT_{ijm}, \tag{11}$$

where OCT_{ijm} (Order Complete Time) is the planned complete time for O_{ij} at bottleneck station M.

5. Calculate the material planned starting input time to production system at the first work station.

$$OST_{ij1} = IST_{ij1} - \mathrm{BB}_{ij}, \tag{12}$$

where OST_{ij1} is the planned start time of O_{ij} for the first work station.

$$OCT_{ijs} = OST_{ij1} + WPT_{ijm}, \tag{13}$$

where OCT_{ijs} is the planned completion time of O_{ij} at the last work station.

Performance Evaluation Indices

Module manufacturing is the last and also the closest to customers' procedure of TFT-LCD industry. Therefore, how to satisfy customers' request of due date and demand quantities are one of the most important missions for module manufacturing companies. Hence, for the production scheduling, the first priority is often to meet the requirement of due date, then are the reasonable WIP inventory level and on time delivery. The following descriptions are the performance measurement indices with the sequence by importance.

1. To satisfy orders' due date: ***minimize the longest tardiness***, where the tardiness time is depicted by Fig. 2 and $t_i = Min(MaxDT_i)$ ， i=1,2,3……,n. (14)

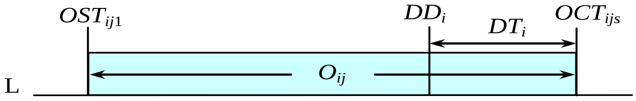


Figure 2. Delay Time of Working Order O_{ij}

2. To ***minimize total tardiness cost***, which is due date related,

$$e_i = Min\sum_{i=1}^{n}(\alpha_i \times DT_i) \text{ ， } i=1,2,3\ldots\ldots,n. \tag{15}$$

3. To ***minimized total flow time***, which is process time related,

$$P_{total} = Min(\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{s} WPT_{ijk}). \tag{16}$$

Buffer Management

Buffer management uses allowance time at each station for working orders to absorb the influences of accidences and statistic fluctuations. The buffer management of DBR production scheduling contains mainly three sections, namely the expediting zone, mentioned zone and ignored zone. In actual production, if the waited processing work orders exceed expediting zone, this means those orders are consuming allowance time and are very easy getting delay. Therefore, we set buffer in front of bottleneck station and design that buffer into four areas for managers to process orders reach to the expediting zone as shown in Fig. 3.

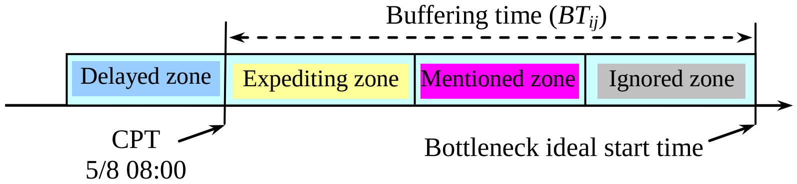


Figure 3. Structure of Buffer Management

When arriving the checking point, one has to detect whether there is any orders fell into buffer. The managerial meanings of buffer structure are listed in the following Table 3.

Table 3. Managerial meanings of buffer structure

Buffer areas	Managerial meanings
Delayed zone	When working orders in the buffer exceed the designed capacity, then it means those working orders are delayed and should be processed immediately.
Expediting zone	When within $CPT+\frac{1}{3}\sum_{i=1}^{n}\sum_{j=1}^{m}BT_{ij}$, there is a "hole" occurred, it means the working orders do not arrived as expected and too little amount of WIP before the bottleneck station. This zone represents that the previous station needs to expedite the processing of planned products.
Mentioned zone	When there is a "hole" occurred between $CPT+\frac{1}{3}\sum_{i=1}^{n}\sum_{j=1}^{m}BT_{ij}$ and $CPT+\frac{2}{3}\sum_{i=1}^{n}\sum_{j=1}^{m}BT_{ij}$, it means the previous station should make more planned products for fulfilling WIP and keep on monitoring the situation.
Ignored zone	When there is a "hole" occurred between $CPT+\frac{2}{3}\sum_{i=1}^{n}\sum_{j=1}^{m}BT_{ij}$ and $CPT+\sum_{i=1}^{n}\sum_{j=1}^{m}BT_{ij}$, it means the production system has just begun to operate, therefore, it is reasonable to keep producing and the working order might be arrived soon.

Rescheduling

When considering under the supply chain structure, factors of rescheduling for production plan can be seperated into two dimentions, one is due date, and the other one is quantity. Materials will arrive within time planned when production planning is obtained by DBR, therefore, the inventory cost is not considered. The mechanism of rescheduling applies the DBR scheduling algorithm which is based on the bottleneck workstation as the critical scheduling target and uses buffer management to reduce the frequency of rescheduling. Here, rescheduling is designed into three basic execution principles: 1. scheduling evaluation; when schedule has performed for a period of time and need to reschedule, production manager has to evaluate the impacts to current schedule by rescheduling influence factors; 2. plan a proposal for rescheduling; prepare a feasible improvement proposal for rescheduling; 3. scheduling adjustment; after deciding to perform one of the feasible proposals, manager has to adjust the current schedule. Fig. 4 shows the factors and mechanism that this study used to evaluate whether to perform rescheduling or not.

CASE STUDY AND SIMULATION ANALYSIS

The case studied in this paper is the module shop in a TFT-LCD manufacturer. There are three assembly flow lines, T1, T2 and T3 in this module shop, all machines and facilities of these three lines are the same with each other. There are five work stations and the detail production processes are shown as in Figure 5. The product transfer batch size of production lines is set to 20. Currently there are six different batch sizes, namely 19 inch-A, 19"-B, 19"-C, 23"-A, 23"-B, and 23"-C respectively, of panels produced in this module shop. The processing time of different products in each workstation is shown in Table 4. If there is any delay order occurred, then the expected unit delay cost is shown in Table 5.

Currently, production schedule is planned according to EDD, the early due date rule. Products of 19 inches panels, i.e., 19-A, 19-B and 19-C, are manufactured at lines T1 and T2; where the 23 inches panels, including 23-A, 23-B, and 23-C, are manufactured only at line T3. The setup time is set to one minute if there is different size of panels operated consecutively. Forty orders were put into simulation designed by the package of "*Flexsim*" as shown in Fig. 6. The performance evaluation indices used in this paper are number of delayed orders, maximum tardiness time, maximum tardiness cost, and total completion flow time. There are basically three statuses, including processing, blocked, and idling in the production system. The system is analyzed for two different settings, one is operated under current production structure, that is processed one product at a time for one production line; the other one is processed under the mixed-line structure with different designed percentage of loading for each line. Both settings are simulated and compared with two conditions of using the early due date (EDD) rule and the proposed DBR method.

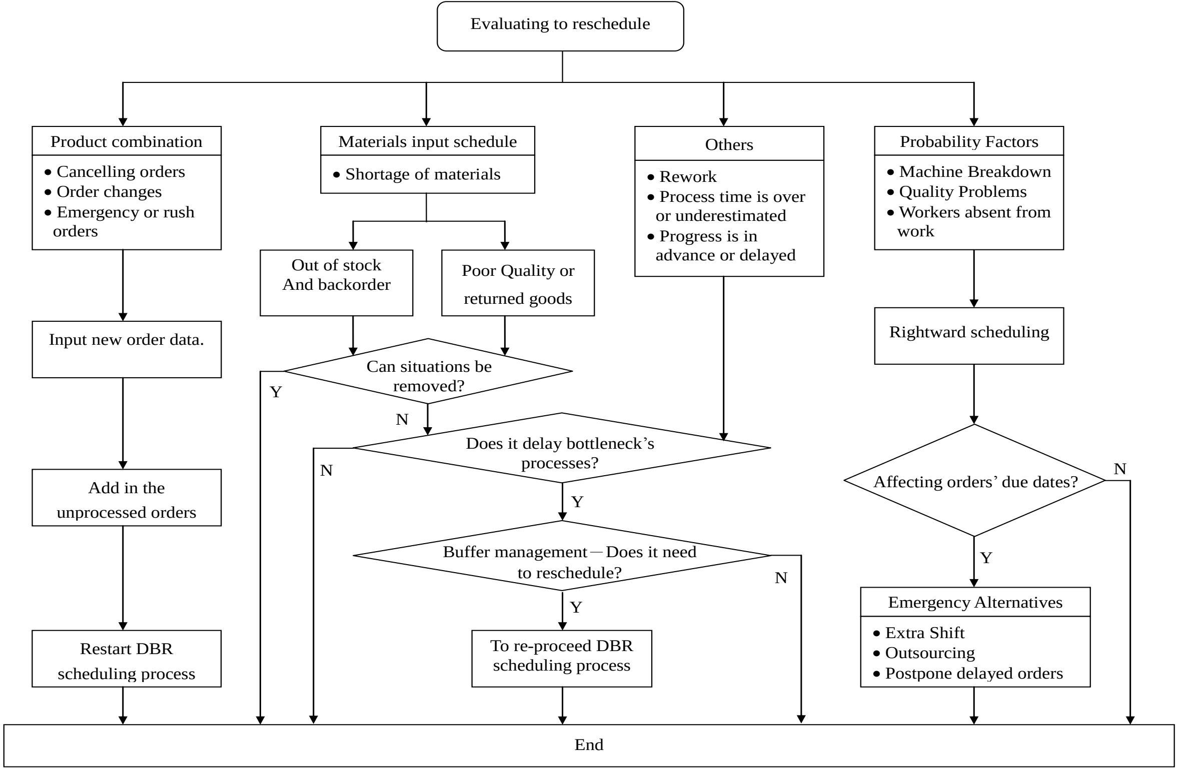
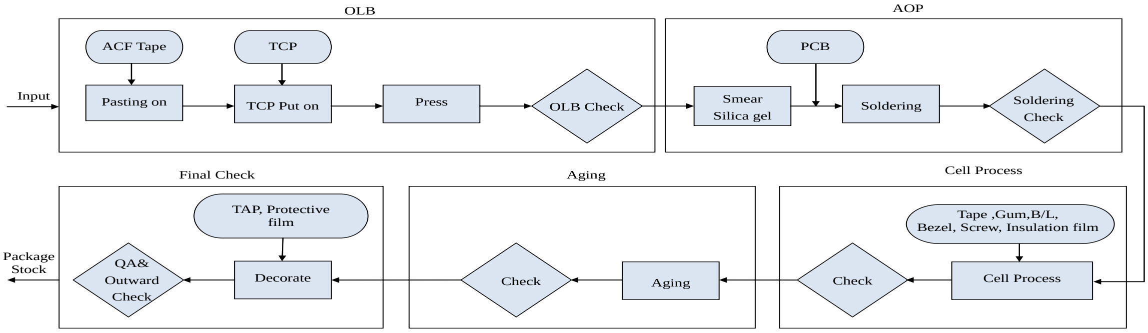


Figure 4. Evaluation Factors and Steps for Rescheduling



Source: from HannStar Display Corporation in Taiwan: http://www.hannstar.com/

Figure 5. Production Processes of the Case Studied

Table 4. Processing time of different products in workstations

Products	Processing time in work-center (unit:second/piece)				
Size	OLB	AOP	Cell Process	Aging	Final Check
19-A	30	56	49	74	31
19-B	30	56	49	74	33
19-C	30	56	49	74	35
23-A	62	51	44	245	31
23-B	62	51	44	245	31
23-C	62	51	44	245	30

Table 5. Unit delay cost for different products

Products	Unit delay cost(US$/piece)
19-A	0.5
19-B	0.6
19-C	0.8
23-A	1
23-B	1.08
23-C	1.2

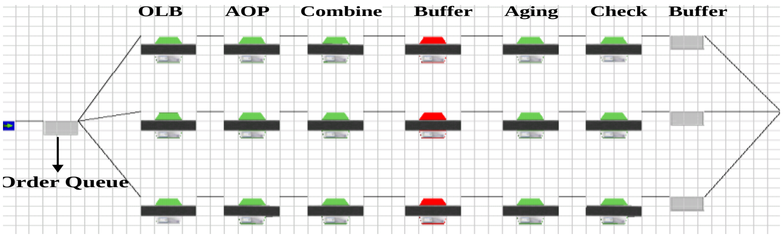


Figure 6. Simulation Model using the Software "*Flexsim*"

Simulation is performed under one product at a time for one production line by both EDD rule and DBR algorithm. Fig. 7 and Fig. 8 show the flow chart of proposed scheduling procedures using DBR algorithm. After performing production scheduling on current system using both EDD and DBR methods, the results in Tables 6 and 7 show that there are two delayed orders which cannot be fulfilled into production plan by using EDD rule. The percentage with respect to total amount of orders is 5 percent. However, all orders can be scheduled into production plan by applying DBR method, that is, no order is either delayed or not fulfilled. The effectiveness between those two methods is obvious. There still is time left as buffer to schedule those urgent orders.

Assisted by the simulation software "*Flexism*", further examinations and performance are designed for structural analysis. Designed scenarios include the followings: 1. each month's capacity loading is separated into three different pairs of designing, representing the capacity loading of the first half and the latter half of the month, pair loading design includes (30%-70%), (50%-50%), and (70%-30%); 2. total capacity loading of entire factory is designed into three different impact situation, namely 45%, 95%, and the 120% which representing over loading situation. Simulation was performed to collect four aspects of data, including the number of orders delayed, maximum tardiness, maximum tardiness (or delay) cost, and make-span for further performance evaluation. The results are shown in Table 8 and Table 9. It is found that the performances of the mixed-line system are better than the traditional flow assembly lines. Using DBR technique in the mixed-line system is better than using EDD method for the performance in both the completion time and production flexibility. Applying DBR method through the buffer management controlling technique can minimize the longest tardiness for customers' orders. This is not only to enhance satisfaction and service level for customers, but also to reduce improper capacity usage and increase capacity and ability for receiving and scheduling those urgent orders. Results also show that by applying DBR algorithm in scheduling, manufacturing system has more flexibility and ability under situations of capacity over loaded and frequent changing.

Conclusions

This research studied the last procedure of TFT-LCD industry, i.e., module manufacturing, for the mixed-line production system by applying both the DBR technique of theory of constraints and buffer management. For choosing module manufacturing, it is because that this procedure is closely related to the customers' requests. Under the impacts of fluctuant demand of market and the problems induced by supply chain reactions, applying mixed-line production system is one of the feasible solutions. Though there is doubt of increasing setup time to reduce the production performance, we confirmed that mixed-line system can achieve better performance than current flow line system by using both DBR and buffer management techniques.

From the results shown by case simulation, this research has the conclusions as followings: 1. performances of the mixed-line system are better than the traditional flow assembly lines; 2. Using DBR technique in the mixed-line system is better than using EDD method for the performance in both the completion time and production flexibility. Orders which cannot be scheduled into production plan can now put into master production schedule. 3. Basically both EDD and DBR methods are the scheduling methods using the due date as main performance index. We found that by applying DBR method through the buffer management controlling technique can minimize the longest tardiness for customers' orders. This indicates that DBR scheduling method is better than traditional EDD scheduling method.

Table 6. Scheduling status with current EDD method

Production Line	Station Status	OLB	AOP	Assembly	Aging	Final Quality Examination
T1	Processing	40.6%	75.7%	66.2%	99.9%	44.2%
	Blocked	59.4%	24.3%	33.7%		
	Idle			0.1%	0.1%	55.8%
T2	Processing	40.6%	75.7%	66.2%	99.9%	44.2%
	Blocked	59.4%	24.3%	33.7%		
	Idle			0.1%	0.1%	55.8%
T3	Processing	25.4%	20.9%	18%	99.9%	12.4%
	Blocked	74.6%	79.1%	81.9%		
	Idle			0.1%	0.1%	87.6%

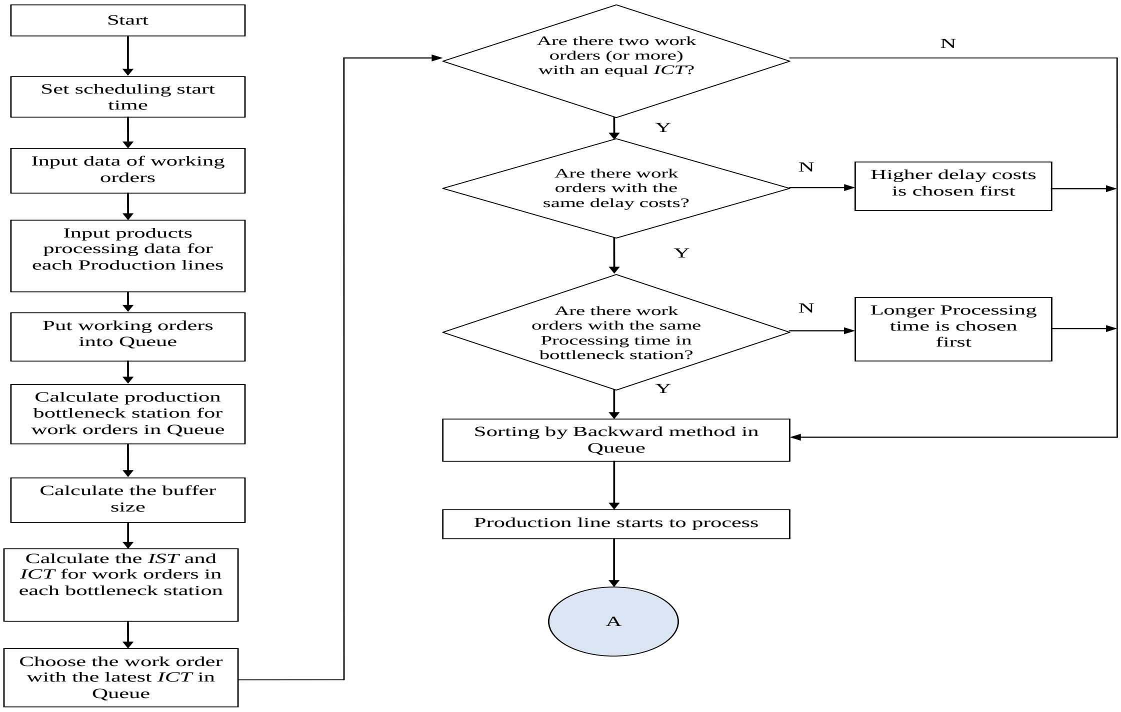


Fig. 7. The Flowchart of Scheduling Procedures using DBR algorithm (Front Portion)

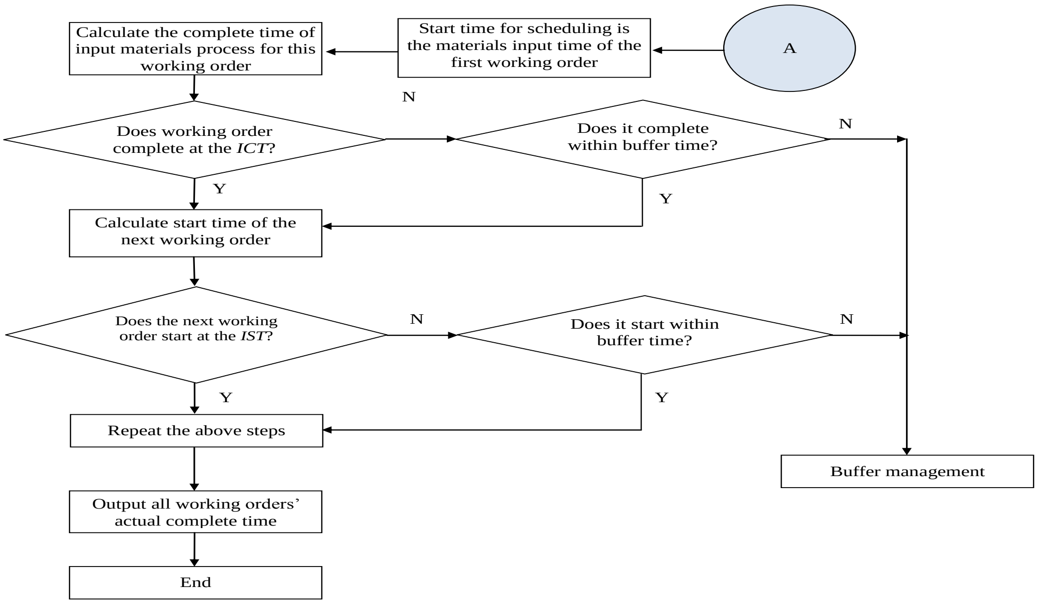


Figure 8. The Flowchart of Scheduling Procedures using DBR Algorithm (Ccontinue)

Table 7. Scheduling status with current DBR method

Production Line	Station Status	OLB	AOP	Assembly	Aging	Final Quality Examination
T1	Processing	61.7%	96.8%	84.5%	99.6%	31.8%
	Blocked	38.2%				
	Idle		3.1%	15.4%	0.3%	68.1%
	Setup	0.1%	0.1%	0.1%	0.1%	0.1%
T2	Processing	61.7%	96.8%	84.5%	99.6%	31.8%
	Blocked	38.2%				
	Idle		3.1%	15.4%	0.3%	68.1%
	Setup	0.1%	0.1%	0.1%	0.1%	0.1%
T3	Processing	61.6%	96.8%	84.5%	99.6%	31.9%
	Blocked	38.3%				
	Idle		3.1%	15.4%	0.3%	68%
	Setup	0.1%	0.1%	0.1%	0.1%	0.1%

Table 8. Table of performance assessment indices

Index of performance	Product type	Non mixed-line production	Mixed-line production	
		EDD	EDD	DBR

assessment	Capacity loading	30% | 70%	50% | 50%	70% | 30%	30% | 70%	50% | 50%	70% | 30%	30% | 70%	50% | 50%	70% | 30%
Number of Orders delayed	45%	0	0	0	0	0	0	0	0	0
	95%	17	6	11	13	3	9	11	1	7
	120%	23	21	16	24	28	24	13	14	24
Max. tardiness (day)	45%	0	0	0	0	0	0	0	0	0
	95%	9.65	9.83	16.32	4.62	0.92	5.54	3.68	0.27	4.60
	120%	21.17	21.17	24.00	10.27	6.84	10.29	8.52	3.28	10.28
Tardiness or delay Cost (USD)	45%	0	0	0	0	0	0	0	0	0
	95%	32060	11580	22060	25460	6800	16060	20860	3600	12460
	120%	44340	32360	36420	46740	42420	45520	31340	18720	45520
Total completion time (day)	45%	23.89	21.32	18.75	23.45	20.79	18.14	21.45	20.87	18.20
	95%	39.56	39.74	29.92	34.54	30.83	29.07	34.60	31.19	29.17
	120%	51.08	51.08	53.92	40.18	36.76	35.99	39.44	27.46	37.02

Table 9. The performance evaluation results

Production system without applying the mix-line production model		
Scheduling method applied	EDD	DBR
Number of orders delayed	8.7% (2/23)	8.7% (2/23)
Tardiness	358,940(second)	39,560(second)
Tardiness cost	4,800(US dollar)	4,800(US dollar)
Makespan	2,943,740(second)	2,948,360(second)

Production system applying the mix-line production model		
Scheduling method applied	EDD	DBR
Number of orders delayed	0	0
Tardiness	0	0
Tardiness cost	4,800(US dollar)	4,800(US dollar)
Makespan	2,537,760(second)	2547020(second)

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