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Full Length Research Paper

A study of supply chain replenishment system of theory of constraints for thin film transistor liquid crystal display (TFT-LCD) plants

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The thin film transistor liquid crystal display (TFT-LCD) including three fundamental process stages: array process, cell process and module process is generally called liquid crystal panel by consumers. Each process stage existing the variable manufacturing flow-process and characteristic of capacity results in acquiring individual objective in each plant, however, ignoring the demand in entire supply chain. For instance, array process and cell process enthusiastically pursue to reach maximal throughput contributed to have much more work in process (WIP) of the panel to Module process. However, the module process depends on the demand of final customers to assemble finished products. Therefore, the demand of customers and the supply from the upstream process exists asymmetrically to lead the inventory levels ineffectively for controlling. The theory of constraints supply chain replenishment system (TOC-SCRS) is supposed to apply the TFT-LCD plants, and is mainly discussed the inventory of TFT-LCD in each plant to study this model of replenishment. The inventory of TFT-LCD in each plant has three critical parameters: frequency of replenishment (FR), reliable replenishment time (RRT) and maximum inventory buffer. Furthermore, utilizing FR, RRT, and maximum inventory buffer parameters to calculate the replenishment quantity and delivery quantity. However, each inventory is related to each other between upstream and downstream. This study is concerned with TOC-SCRS to each inventory and uses the simulation model to simulate the variation of the each inventory to demonstrate the significance and feasibility of this proposed TOC-SCRS for TFT-LCD plants.

Key words: Thin film transistor liquid crystal display, theory of constraints, supply chain management, TOC supply chain replenishment system.

INTRODUCTION

In recent years, being driven by the demand of large-sized panel on LCD monitors, notebook computers and LCD TVs mainly, the flat-panel display industry has been gradually heading towards the peak. The TFT LCD (thin film transistor liquid crystal display, TFT-LCD) is a technology and capital intensive industry, its supply chain mainly consists of key component suppliers and panel makers. The key components include glass substrates, color filters, driver IC, printed circuit board, backlight modules and other related materials, while the panel makers are formed by three major manufacturing processes, namely the array process, cell process and module process respectively. Take the case of array process, owing to its expensive machine facilities, complicated process and the bottleneck machine (yellow area) with the characteristic of reflux, usually, its manufacturing lead time is unstable and requires a long time of about 5 to 7 days.

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The middle stage of cell manufacturing takes about 3 to 5 days; however, as it possesses a characteristic of assembling with color filters, any shortage of the required material in this stage will affect the assembly operation which prolongs the lead time and production. As to the final stage of module process, its manufacturing lead time is very short and takes only 1 to 2 days. What should be considered in this stage lies in whether the supply of materials could be in time. Currently, the global market demand for TFT-LCD has been growing and diversified, such as the desktop LCD monitors and notebook computers in information application and the LCD TVs, automotive-specific display in video application. However, customers in this industry tend to specify their own suppliers or components which often lead into a situation of the same product with different models after being sub-classified. Take the 17-inch LCD display for example, in the minor extent of variation, it has two models of 17 "WA01 and 17" WA02, whereas in the larger extent of variation, it becomes models of 17 "WA01 and 17" WXA01. At present, the TFT-LCD supply chain of the production planning is based on the make to stock (MTS) which develops the manufacturing process based on the demand obtaining from the prediction after being leveled.

This planning model is called MTS, namely make to stock. In the downstream module process, for avoiding the risk of over stock, it adopts the production strategy of MTO. Under different production planning, the goal of each process will be different. The production-oriented planning, for example, focuses on the quantity of output, whereas the planning of make to order concentrates on meeting the customers' specific demand in components and suppliers, in which the material supply and order delivery are the major concern.

Such condition of different goal of each process in TFT-LCD generates the following problems: (1) the difficulty in inventory control: as the production of current TFT-LCD is based on forecast demand, it is difficult to have an accurate prediction when the business cycle changes. (2) the lack of coordination among plants: owing to different production strategies and goal, each manufacturing process pursues its own goal without concerning the need of entire supply chain.

In a situation like this, it is necessary to have a mechanism to coordinate the supply chain between the upstream and downstream production in order to adjust the prediction when the demand of change occurs. Dr. Goldratt, in his best-selling business management novel, "It's Not Luck" (Goldratt, 1994), put forward the theory of constraints (TOC) which provides concepts and methods for the management in the supply chain. Currently, the most common replenishing models include the quantitative replenishment methods, such as s, S and the regular replenishment method, such as R, S, R, Q. In these two methods, the replenishment quantity (Q) or maximum stock level (S) is determined by the EOQ (economic order quantity) with the main considerations of cost like the costs of stock holding as well as the costs of order. The main concept of the theory of constraints in supply chain lies in the consideration of the consumption, which means the replenishment quantity is based on the consumed quantity and the frequency of replenishment.

As the TFT-LCD industry has developed into multi-site environment, as shown in Figure 1, the processes of manufacturing are no longer confined in a single plant, but rather formed by a number of plants. For instance, the array process can be divided into the array one, the array two and so on. Till now, there have already been many studies that explored the multi-site production planning, and this study will focus on the various upstream and downstream replenishment model of the supply chain in the TFT-LCD industry.

LITERATURE REVIEW

Introduction of panel process

Flat panel industry mainly consists of the upper stream process of array, the middle stream process of cell and downstream process of module. Upon the completion of the upstream array process, the product, a large glass substrate, is matched with the color filter in the front-end stage of cell process. It is then in the posterior stage of this process injected with liquid crystal and cut into small pieces of panel in accordance with the best quantity of each panel size can be obtained. Next, this small panel is delivered to the downstream process for the assembling of polarizer attachment, driver IC, printed circuit board, backlight modules, and then goes through the inspection tests upon completion. The glass substrate, the material of array process, after being cleaned, is covered by a film through the using the Chemical vapor deposition (CVD) and physical vapor deposition. Later on, the substrate is evenly coated by the photo resists and wears a mask for the blue-violet ray exposure. Next, through the contrast media, the exposed mask displays the photo resist layer pattern on the glass substrate. After that, the unprotected part of photo resist is removed and the required circuit pattern for processing is kept. Afore mentioned steps of cleaning, film, photo resisting, exposure, developing, etching are the majority of the array process which usually will rework for 5 to 7 times.

The cell process is divided into forepart and back part. The forepart will assemble the glass substrate provided by the upstream suppliers with the color filers of home-made or purchasing from outside, and coat the TFT substrate and color film substrate with a layer of chemical film to form the polyemid, then match, seal and assemble these two substrates. The back part is to combine the two substrates more closely by using the high heat press, and remove the residuals of solvent and water vapor out of the seal by using the heat and vacuum. It will then fills the liquid crystal into the LCD panel, and seals it for avoiding

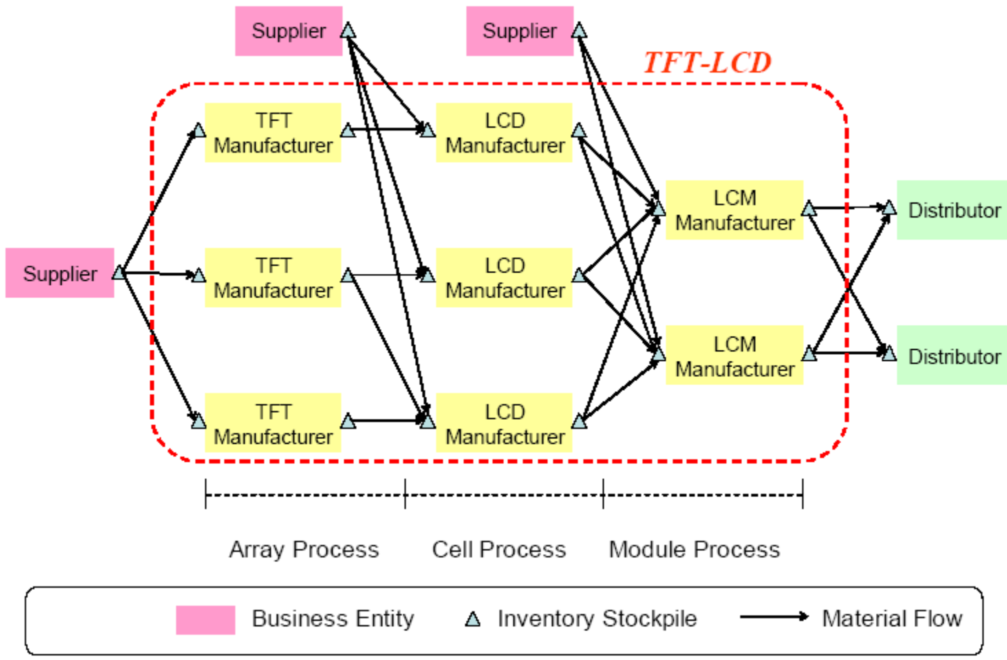

Figure 1. The environment of Multi-Site of the flat panel industry (Huangyan, 2003).

leakage. Later on, the panel will be cut in accordance with its dimension and then the entire cell process is completed after the inspection. The downstream process of module mainly composes of components assembling. First, it will attaché a polarizer on the panel produced by the middle stream process of cell and pack a piece of IC driver on it, and then assemble it with the printed circuit board and the backlight panel .The assemblage will then be locked with a steel frame, and inspected by the burn in test under the high temperature. In the final stage of this process, after the examination, the product is packaged and shipped.

TFT-LCD planning approach

At present, the entire production planning of the TFT-LCD plant can be divided into three stages of long-term, middle-term and short-term. The long-term planning mainly concentrates on the forecast of each customer's demand for each product, and then congregates and converts each forecast demand on the base of month (Lin et al., 2004; Lin and Chen, 2005). The middle term of sales and operation planning (S and Q), with the purpose to meet the goal of forecast demand, schedules the monthly production plan based on the projected demand and the feeding schedule provided by key material suppliers, procures the key material through the material control department, and transfers the information of future demand for material to the suppliers for reference. The final short-term production planning deals with the master production scheduling. It undertakes the monthly production plan from the middle-tern and uses the method of level out to develop the project of inputs and output. The TFT-LCD planning process can be divided into two categories, namely, Push and Pull. The push planning model uses the means of prediction to get the monthly production plan to satisfy the production goal without considering the customers' demand, whereas the pull planning model considers and places the customers' demand in the first priority. In current TFT-LCD planning process, the capacity- orientated array and cell plants belong push-based planning, while the goal-orientated downstream module plants are pull-based planning. The later will consider customer demand and place customers' satisfaction in the first priority. Currently, in the TFT-LCD industry, the array plant and group plants are push-based planning of capacity goal-oriented, while the downstream module plant is pull-based planning of material-oriented. .

Definition and classification of the supply chain

Lee and Kim (2002) suggested that the main programs of supply chain are production planning, control, distribution, and logistics. The production planning and control describes the entire manufacturing process, such as the processing and managerial designs like material control, schedule, inventory control etc. The distribution and logistics process is to decide how to obtain and transport products from the factory to the customers or whole-salers, including the in and out of inventory, transportation

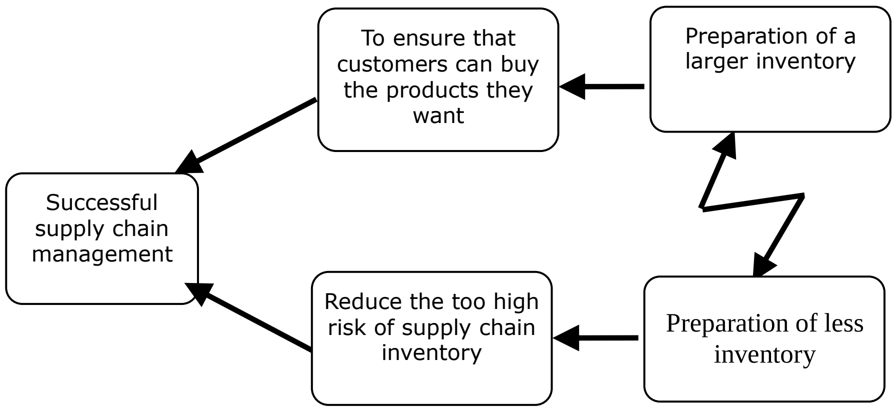

Figure 2. Conflict graph of supply chain management (Goldratt, 1994).

and product delivery (Bowersox and Closs, 1996). Beamon (1998) suggested that the supply chain shall include five major parts. To multi-class model, generally, it can be divided into four categories:

1. Deterministic mode: all variables in the mode are known. Williams (1981) used heuristic algorithms to solve the problems of production schedule and distribution in supply chain, and constituted it into an efficient supply chain network. This mode targets on inventory as a major factor, endeavors to reach the lowest cost of every node in the production and distribution. Based on EQQ, Cohen and Lee (1989) developed a mixed integer nonlinear program decision-making model which determines the maximization of profit (net profit after-tax) of resource allocation, production, and distribution planning for the enterprise in their global business operation under the consideration of the consistent constraints between the managerial resource, production, flexibility, demand, variable and logic.
2. Random mode: at least one variable is unknown, and assume that some certain variables follow a particular probability pattern. Cohen and Lee (1988) aimed at each node in the supply chain and established a material-based planning model, and also proposed four cost-based sub-models as follows: (1) Material Control: establishing material order quantity, order interval, the estimated lead time of all nodes, BOM, cost data and the response time needed by production. (2) Production control: determining each product's production quantity, lead time, and the response time of given materials. (3) Final goods inventories: determining the economic order quantity and volume for each product in accordance with the cost, demand, lead time, etc. (4) Distribution: establishing an inventory ordering strategy for various distribution points in accordance with the cost, transportation time, product demand, local area network, etc. Lee and Billington (1993), and Lee et al. (1993) developed a random, periodic stock checking, order-up-to inventory model to determine execution steps in the program of the supply chain system, it performs different operation and delivery processes in different target market structures in order to determine the best ordering policy of raw material.
3. Economic model: Christy and Grout (1994) constructed a framework based on economics and game theory to build the buyer – seller interactive relationship model of supply chain system. The goal of this model is to analyze which of the equilibrium solution will be close to convergence based on the size of risk arising from decision makings.
4. Analog mode: at least one variable is unknown, and assume that some of certain variables follow a particular probability pattern. Towill et al. (1992) used the system simulation approach to assess what kind of strategies are the most effective while the changes of demand is stable.

The replenishment strategies of TOC supply chain

Dr. Goldratt, in his book "It's Not Luck", put forward the theory of constraints (TOC) for the concepts and methods application in the supply chain. This theory proposes a win-win solution mainly for the conflicts that occur in the inventory management of supply chain (Goldratt, 1994). The process of the supply chain, as a whole, covers the range from raw material purchasing, processing, and delivering to customers through the distribution centers. The biggest profit in the supply chain of this process is to meet the customers demand quickly with the lowest cost. Inevitably, by this way, it will have to accumulate a large number of stocks to ensure that the final consumer can get the products which they want to buy. However, this kind of management is also apt to accumulate too many stocks in the points of sales which lead the entire supply chain expose to high risk, from the rising of inventory costs to the dull sales or products sold at a loss. Therefore, another method of inventory management is to prepare fewer stocks to avoid the cost loss of inventory owing to market changes. As shown in Figure 2, these

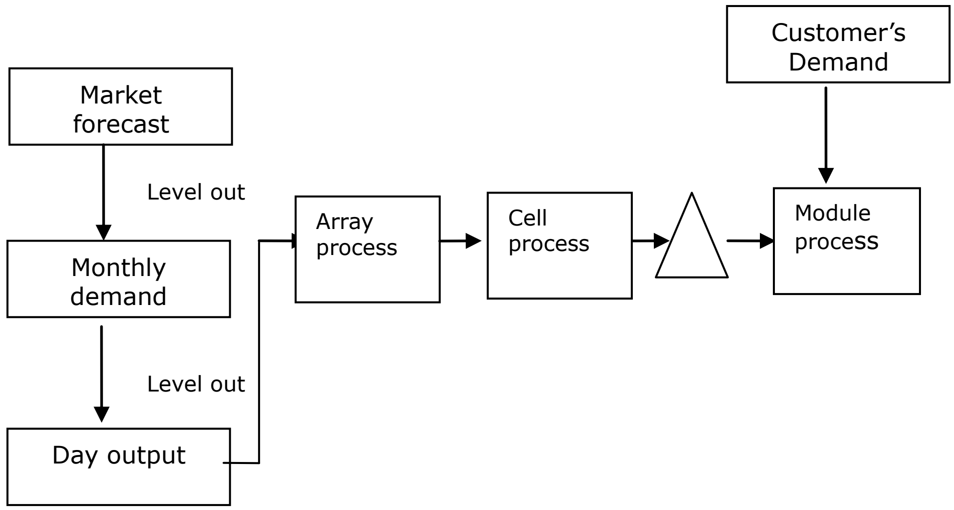

Figure 3. Panel plant production procedure.

two inventory management are confronted with dilemma and conflict. Now, the TOC supply chain solutions have been applied in a number of companies and have already improved the inventory turnover rate, out of stock rate and the efficiency of market reaction speed (Armentano et al., 1999; Blackstone, 2001; Hoffman and Cardarelli, 2002; Novotny, 1997; Patnode, 1999; Sharma, 1997; Waite et al., 1998; Watson and Polito, 2003; Wu et al., 2010a, b).

CASE STUDY

The problem definition and analysis

As technology advances, the final products in the TFT-LCD industry have increased broadly, such as TVs, LCD monitors and notebooks. Under the trend of product diversification, the product life-phase has been gradually shortened, thus the capability of continuously launching new products has become a key factor to the survival of plants. However, while launching new products, the current inventory condition of existing products must also be taken into consideration for the introduction of new products will inevitably affect the sales of existing product. The planning adopted by current panel industry belongs to stock type production; it is primarily based on the forecast from the sales department for different customers demand. After the congregating of all forecast demand, it will than be leveled out and converted into monthly output plan as well as the daily output plan. However, as the prediction is full of risk, the production based on the forecast demand in the current flat panel industry is not able to reflect the customers' actual needs effectively. If the demand change is too rapid, it will then make the whole panel plant expose to a high risk. Figure 3 In the planning approach of panel array plant (as shown in Table 1) it undertakes the annually forecasted demand of long-term planning and converts it into weekly demand. After that, it will confirm the orders with the downstream cell plants and determine the daily output plan. (Li, 2006). In the TF-LCD supply chain, the array process, cell process and modules process of TF-LCD act as the upper, middle and down streams respectively, and the glass substrate, color filter, polarizer, driver IC, printed circuit board, backlight module and other materials are indispensably key components in this system. However, under the stock-style production planning mode, it will result in some operation issues among the materials supply, the process of production and inventory control as follows:

1. Inventory accumulation: TFT-LCD panels are high-value digital products. Under the environment of high extent of customization and the complexity of product categories, the products are classified in different levels. The top level, based on the specific types, includes liquid crystal displays, LCD TVs, notebook computers and other products. The second level, based on dimension, is classified by the panel dimensions into 15-, 17-, and 19-inch and other product family. The third level classifies products in accordance with their resolution, and special characteristic of specific material such as XWA, XWQ. And the last level will subdivide products into different models of product family in accordance with the different components or vendors specified by a customer. Therefore, the classification of TFT-LCD panel products is all-inclusive. It can be imagined how complicated and difficult there is in the inventory control. So, under the stock-style production mode, the module process undertakes the semi-finished products processed by array and cell process and therefore accumulates the panel stocks in its inventory. However, as the finished product accumulated in inventory may not be the

Table 1. Production plan of array plant.

Monthly demand							
Product	**February**	**March**	**April**	**May**	**June**	**July**	**….**
15”	500	390	450	420	480	410	
17”	800	810	830	850	820	950	
19”	350	300	320	400	320	410	
Total	1650	1500	1600	1670	1620	1770	…

Daily output							
Product	**3/1**	**3/2**	**3/3**	**3/4**	**3/4**	**3/5**	**….**
15”	13	13	13	13	13	13	
17”	27	27	27	27	27	27	
19”	10	10	10	10	10	10	
Total	50	50	50	50	50	50	…

products needed by customers, and if it can not meet the needs of customers, these products will not be able to sell out, but also occupy the plant resources and erode its profit. In addition, with the fast boom cycle, the accuracy of the prediction methods which is used to evaluate the demand for each product is hard to achieve. Once the new products hit the market, the old products will inevitably face the threat of price cuts, and if the inventory levels of old products is too high, the plant will be subject to a large risk.

2. The inconsistent goals among plants: to upstream array and cell process, due to the expensive and long lead time of machine and other factors, these two processes therefore will focus on the production capacity as theirs main objective. As to the downstream module process, owing to what it concerns is on the material supply as well as the commitment to its customers, naturally, the goal of it will be set on the quick response and the meet of customers' needs. Therefore, the inconsistent goals among each process result in the ineffectiveness of the coordination and links among the plants. In the production planning, the array and cell process adopt the stock-style production model. Based on the predicted demand for production, these two processes will push the completed semi-finished products into the inventory area of module process. However, as the production model of the module process is to assemble products in accordance with customers requirement, the difference of production planning in each process will result in the failure of timely providing the accurate and required semi-finished panel products from upper stream array and cell process to module process. This situation makes the plants waste its capacity to produce unwanted product, thus resulting in inventory accumulation.

3. The lack of detailed control planning in material inventory: in the upstream array process, the main item it processes is the raw material of glass substrate. While the middle cell process undertakes semi-finished products of the processed glass substrate from the upstream array process, and assemble it with color filter. Finally, the module process assembles the semi-finished panel from cell process with the polarizer, driver IC, printed circuit boards, as well backlight module components, etc. Therefore, only the needed materials are well prepared can each process operate smoothly. However, as the production of each TFT-LCD panel is based on the demand projection, so each of the process will try to get the required material ready in accordance with the forecast demand, while the inventory material are provided by the supplier based on their feeding plan in accordance with the reference of each process's demand planning. This kind of planning lacks a clear mechanism in material inventory, and is likely to cause the shortage of materials supply, or the materials being piled up too much in the inventory, thus affects the plant's production operation. Take the cell process for example, as the production of the glass substrate and color filter production is based on the ratio of 3:3, if the color filters can not be timely supplied, it will not only waste the capacity of the cell process but also lengthen the manufacturing lead time. From this, we learn that the material inventory supply is very important. If just with the projected demand for stock preparation but without a mechanism to monitor the materials supply or replenishment, it is impossible to control the inventory material accurately, either too much inventory or materials supplying can not meet the requirement of production.

4. The planning phase is too long: at current stage, as the planning phase of the TFT-LCD panel plant is based on month, this leads to the un-ability of grasping the demand timely when significant changes occurs.

5. The low level of customization: by using the stock-style production model, it is easy to accumulate too many finished goods in inventory. Thus lead to a situation of satisfying customers' demand with stock goods and low flexibility in customers' products choice.

In order to solve the listed problems, all points of the TFT-LCD supply chain inventory, in terms of the inventory of the material, components, semi-finished product and finished products in all process, adopts the replenishment mechanisms, and apply the theory of constraints (TOC) supply chain replenishment system concept to develop a suitable TFT-LCD supply chain replenishment mechanism for the stock point (Pearn and Liao, 2006).

This study will describe how to apply the theory of constraints of supply chain replenishment on each stock of the TFT-LCD industry, and explore the replenishment time and the need for replenishment of the demand based on the consideration of the various processes as well as the correlation among industrial characteristics.

The application of TOC-SCRS to the structure of TFT-LCD plant

This study divided the TFT-LCD inventory into six large sectors, namely the raw material inventory of array, finished product inventory of array, raw material inventory of cell, finished products of cell, raw material inventory of module and finished goods inventory of module.

In the TFT-LCD supply chain, the modular process is the final stage which is also the process that most close to the clients.

This process undertakes semi-finished panels from upstream array and cell process and assembles the panels with other components to produce different models of goods which are also the final products of TFT-LCD panel. In the TFT-LCD supply chain, the real source of customer demand comes from the orders received by the module process, while the upstream array and cell process produce panels needed for semi-finished products only. Each process possesses its own goal and considers its own factors respectively.

Such as the production of array and cell process which are production-oriented, owing to the long lead time, they have to predict the end customer's needs to develop the production plans. But the demand obtaining by prediction is different from the actual customers demand, especially in the fast-changing business phases of the TFT-LCD panel industry, thus there will be a great risk to the TFT-LCD plant when the prediction is not accurate. Therefore, this study applies the concept of the theory of constraints (TOC-SCRS) and develop a replenishment mechanisms which is suitable for the inventory points of TFT-LCD supply chain from the most end of the module process after it receives the customers' demand and make replenishment requirement to the upstream process in order to meet customer needs with its inventory. This study will explore how to define the largest inventory stock, how long to raise the replenishment requirement to the upstream, how to determine the replenishment quantity and how long the goods will arrive after placing the replenishment order and so on. This study focused on the assessment of the largest buffer inventories, replenishment frequency, replenishment volume, and expected purchasing quantity, to develop a suitable inventory replenishment mechanism for inventory points in the TFT-LCD supply chain, and, through this mechanism, to work out production planning without using the mode of demand forecast. The mechanism used in this study will concentrate on the basic replenishment model, the assessment of the replenishment frequency, the evaluation of purchasing lead time, the replenishment of each inventory point and the production integration model, and inventory change simulation of five parts to construct the system of this study:

i. The basic replenishment model mainly focuses on the explanation of the application of TOC-SCRS mechanism. The purpose of it is to consider the correlation between all different types of product and the stock of each inventory points, so as to provide a basic replenishment mode which is suitable for all inventories.

ii. The assessment of the replenishment frequency is to offer the time point of how long the inventory should be replenished within a cycle. Because the inventory not only coves the replenishment between transportation, it also covers the replenishment between the productions. The replenishment between transportation can be self-assessed on the basis of the level of inventory; however, as the replenishment between the productions, owing to each inventory has its own stock of materials, components, half-finished goods, finished goods, etc., it has to assess the replenishment frequency of each product to decide how long the product is needed to be replenished under the consideration of the capacity.

iii. The assessment of the replenishment lead time is mainly used to assess the expected length of time that the ordered goods are to arrive. However, as there are two types of replenishments –the transportation and production in all inventories, and if only to explore the transportation replenishment between two inventories, the purchasing lead time will be the time required for the transportation; but if replenishment orders are placed to the process plants, it must consider the various processes required for the processing time, as well as the quantity of the required products. For example, if the product quantity is large, the processing time will be longer; on the contrary, if the demand is relatively small, the required processing time will be less.

iv. The replenishment of each inventory point and production integration model mainly provides the required replenishment quantity of each product and expected replenishment time (expect delivery time) to the plants of each process and designs feed-in mode based on different scheduled modes. However, as goods in such inventories are products processed by each process, itmeans that each process feeds in the required half-finished products, and manufactures products in accordance with the replenishment demand. The inventories of

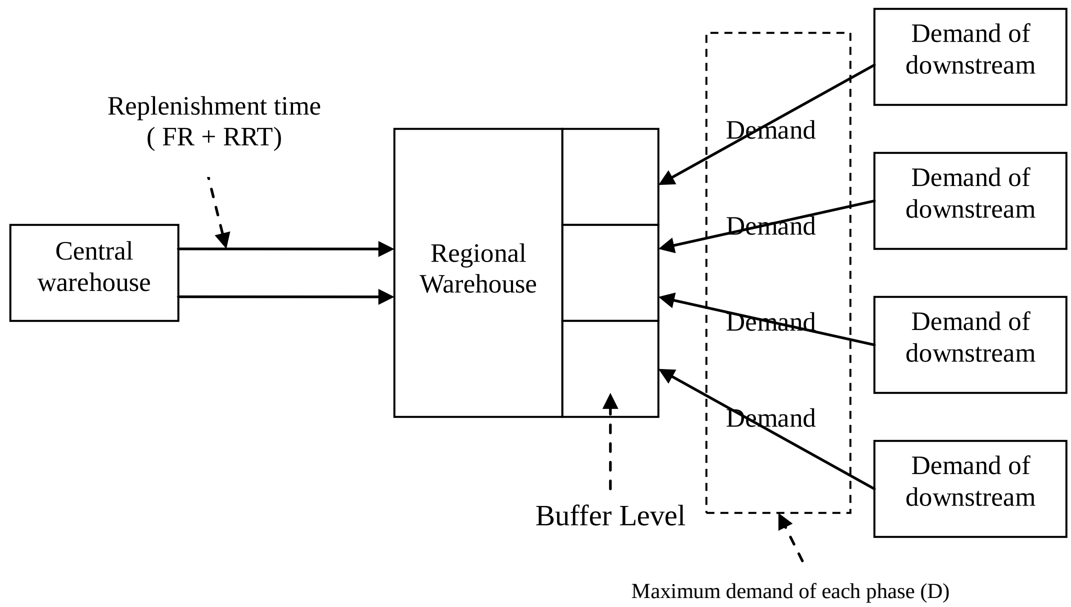

Figure 4. The replenishment mechanism of TOC-SCRS (Cole and Jacob, 2002).

raw material and components will replenish its stock to the upstream supplier based on the consumption of inventory in the production of each processing plant.

v. The inventory change simulation is to , through the calculation of each product's demand, expected replenishment quantity and final inventory, etc., provide the inventory control in order to monitor whether the inventory level of products are within the reasonable standard.

Basic replenishment mode

TOC replenishment mechanism of the supply chain is established on the concept of replenishment based on consumption. There are three parameters in this mechanism, namely the replenishment time of each product, the largest inventory, and back-volume (Figure 4). The replenishment time consists of the frequency of replenishment (FR) and the reliable replenishment time (RRT). The frequency of replenishment refers to the interval of time length of replenishment. For example, if a product A is replenished on the first day, the fourth day, the seventh days and so on every three days, the replenishment frequency is defined as 3 days. The reliable replenishment time is the waiting time of how long the ordered goods will reach the destination. For example, if an order for product A is placed in the first day and the goods are available in the fifth day, the product will be received in the first five days, and the reliable replenishment time will be 4 days. Buffer level, based on the sales record over a period of time, is to assess maximum sales quantity during the length of time in a continuous replenishment. For example, if the replenishment time for product A is five days, while the evaluated phase length is 20 days, then the cumulative sales for 5 days of the sales record over the past 20 days is the buffer level. As for the fill volume, it is the quantity of each replenishment order when the ordered quantity is the total quantity sold between the order of last time and the new one. In the six inventories of the TFT-LCD, we use p to represent the inventory, while the units which the inventory accommodates, is expressed as i. $p = 1$ represent the finished products in the module inventory. The inventory units are finished good which have already been processed by the module plants, such as the 17-inch monitor panels of WA1 models, 15-inch notebook computer of XA1 models and other; $p = 2$ represents the raw material in the module inventory. The inventory units are panel which have not been processed by the module plants yet, such as the 15-inch panels, 17-inch panels and other semi-finished products of panel; $p = 3$ represents the finished good in the cell inventory. The inventory units are the panels which have already been cut by cell plant. These inventory units are the same as the semi-finished products of the module plants, the only difference is the inventory locations, one is in cell plants while the other is in module plants; $p = 4$ represents the raw material in the cell inventory. The inventory units are the glass substrates which have not been cut and processed by the cell plant yet, such as the semi-finished products of 15- and 17-inch glass substrates; $p = 5$ represents the finished good in the array inventory. The inventory units, same as the raw material inventory in the cell plants, are un-cut glass substrates which have not been processed by the cell plants yet. In general, as the locations of array process and cell process are near, the processed glass substrates are stored in the array inventory. However, as there is still lead-time of the stock movement between

Table 2. The sales volume and accumulated sales volume of product 015XA1 over the past 16 consecutive days.

Product: 015XA1																
Period(day)	3/16	3/17	3/18	3/19	3/20	3/21	3/22	3/23	3/24	3/25	3/26	3/27	3/28	3/29	3/30	3/31
Demand/sales	300	0	200	800	900	0	500	500	400	900	800	0	500	300	1000	500
Consecutive 3 days sales			500	1000	1900	1700	1400	1000	1400	1800	2100	1700	1300	800	1800	1800

the two plants and the TFT-LCD supply chain has been developing into multi-site situation, namely that the array or the cell process are not in the same site, the inventory management has been getting difficult. Therefore, this study divided the inventory sites between array process and cell process into two parts: one is the array finished good inventory and the other is the cell raw material inventory. For p = 6 which represents the of raw materials inventory of array, these inventory units are unprocessed glass substrates provided by various raw material suppliers. The required parameters are illustrated as follows:

J: the evaluation of the numbers of total cycle. The unit is based on day; j: the cycle evaluation, j=1,2,….J; i : product range, i=1,2,…I; P: stocks category, 1 represents the finished goods stocks for the module, 2 represents the raw material stock for the module, 3 represents the finished good stocks for the cell, 4 represents the finished goods stocks for the module, 5 represents the finished good stocks for the array, 6 represents the raw material stocks for the cell; $D_{i,p,j}$: the stock demand of product i in phase j; product i with inventory p; $FR_{i,p}$: the replenishment frequency of product i stock p; the interval between each order, namely how long will the order be placed; $RRT_{i,p}$: the product i inventory p procurement lead time; meaning the time required to received the ordered goods, how long will it be available; $TRR_{i,p}$: the product i inventory p replenishment time, it is the replenishment frequency couples with the procurement lead time, that is $TRR_{i,p} = FR_{i,p} + RRT_{i,p}$.

The required unknown parameters are illustrated as follows:

$S_{i,p,j}$: product i, inventory p, stock quantity in phase j; $Q_{i,p,j}$: product i, inventory p, procurement quantity in phase j; $R_{i,p,j}$: product i, inventory p, purchased quantity in phase j; $Buffer_{i,p}$: product i, inventory p, maximum stock buffer, the buffer stock for the greatest demand of the next replenishment in the regional warehouse. Each product in each inventory has its largest inventory buffer ($Buffer_{i,p}$), the assessment method is to collect each product's demand/sales dada over a period of time in the past, for example, j is the time point in the past, and If j = 1, it represents that there is 1 day before the current time point, if j =2 means 2 days before the current time point, and , in accordance with the length of replenishment time to calculate the accumulative demand/sales over the continuous length of replenishment time to identify the largest one (Equation 1):

$$Buffer_{i,p} = Max\left(\sum_{x=j}^{j+TRR_{i,p}-1} D_{i,p,x} \quad , \quad j = 1,..,(J - TRR_{i,p} + 1) \right) \qquad (1)$$

If the replenishment time of each product in the module inventory (p = 1) is known for 3 days, and the demand/ sales in the past 16 days is known, the equation (1) will find out the maximum demand/sales for 3 consecutive days. Take the 15-inch XA1 models of notebook computers for example, if the current date is 4/1, its maximum value from 3/24 to 3/26 of the continuous demand/sales are shown in Table 2. If the replenishment time of each product in the cell inventory (P = 5) is known for 6 days, as well as the demand/sales in the past 16 days, the equation (1) will find out the maximum demand/sales for 6 consecutive days. If 15-inch glass substrate, for example, and the current date is 4/1, its maximum value of 3/24 to 3/26 of the continuous demand / sales are shown in Table 3. After obtaining the largest buffer through equation (1), the purchasing quantity (Q_{ipj}) can be generated within the time length of each replenishment frequency (FR_{ip}), while the volume of procurement quantity is the continuous demand of each inventory product in the period of replenishment frequency. The calculation is shown in equation (2):

$$Q_{i,p,j} = \begin{cases} \sum_{w=j-FR_{i,p}+1}^{j} D_{i,p,w} \quad , \ if \quad \mod(j / FR_{i,p}) = 0 \\ 0 \qquad , \ else \end{cases} \qquad (2)$$

If the replenishment frequency of each product in the module inventory (p = 1) is known for 2 days, so is the demand/sales in the past 16 days, the equation (1) will find out the maximum demand/sales for 6 consecutive days. Take the 15-inch XA1 notebook computer for example, if the current date is 4/1, its procurement quantity for 16 days is shown in Table 4.

Replenishment frequency solution

But how to apply the TOC-SCRS mechanism to all inventories of the supply chain in order to provide suitable replenishment quantity and reasonable delivery date for the upstream process to produce? It relies on two factors:

Table 3. The sales volume and accumulated sales volume of 15-inch glass substrate over the past 16 consecutive days.

Product: 15-inch glass substrate																
Period(day)	3/16	3/17	3/18	3/19	3/20	3/21	3/22	3/23	3/24	3/25	3/26	3/27	3/28	3/29	3/30	3/31
Demand/sales	350	234	317	367	200	217	300	250	350	284	267	334	300	250	317	334
Consecutive 3 days sales						1685	1635	1651	1684	1601	1668	1785	1785	1785	1752	1802

Table 4. The calculation of procurement and replenishment for 015XA1.

Product: 015XA1																
Period(day)	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16
Demand	350	284	267	334	300	250	317	334	300	267	267	350	334	234	317	234
Procurement quantity		634		601		550		651		567		617		568		551

the replenishment frequency and the replenishment lead time setting. As the parameters setting of replenishment frequency and lead time of each inventory in The TFT-LCD supply chain are different, this research divide this issue in two parts to study: one of which considers only transpiration problem of the sale, while the other one considers the manufacturing capacity planning. Under both conditions, this study explored replenishment frequency and the replenishment lead time setting. First, we explored the replenishment frequency. If only to consider the sales or transportation between upstream and downstream, the replenishment frequency can be determined by self-evaluation without being affected by other factors, such as the replenishment request of raw material inventory by module proposes to the upstream finished goods inventory of cell, or replenishment request of the raw material inventory of array to the upstream supplier of raw materials. If, however, the replenishment involves the manufacturing, it will have the problem of production capacity, which often includes the required processing capacity, as well as production line replacement. While judging by the TOC-SCRS mechanism, each product replenishment rate will equal to the production line changing frequency, and this mechanism will target on the adequacy of manufacturing capacity for each production line replacement per day. However, the evaluation of the replenishment frequency for each is not all the same, like modular product, 15-inch notebook XA1 might be replenished every two days, and 3 days for WA2 model notebook computer.

In order to simplify this complexity, this study only explored the condition of products with the same replenishment frequency and is illustrated further.

Symbol definition

Input variables: I: the total number of commodity type; i: commodity types; j: an interim assessment of the number of days, unit: days; s: on behalf of the process, s = 1 for the module process, s = 2 for the cell process, s = 3 for the array process; H: the daily working time, unit: hour; $C_{s:}$ the working hours (capacity) per phase in s process, the $C_s = m_s \times j \times H$, Unit: hours; $D_{s,i}$: the average demand of each commodity in s process; $P_{s,i}$: the output/hour of the bottleneck machine for commodity i in s process;
$L_{s,i}$: the demand capacity/phase for commodity I in s process; $L_{si} = D_{si}/P_{si}$, unit: hour; $S_{s,i}$: the required time for bottleneck machine line replacement for commodity i in the s process, unit: hour; m_s: the number of the bottleneck machine in s process, unit: unit

Output variables: $f_{s,i}$: the replenishment frequency of i commodity with the same replenishment frequency in s process., namely, each f period of replenishment for each commodity.

By afore-mentioned way and in accordance with the previous time value, we can obtain the largest inventory buffers and the replenishment volume for each product with available replenishment frequency, as well as, under the condition of same replenishment frequency of each product, the satisfaction for the period requirement for each product in the capacity assessment period and the required capacity for each line replacement. In other words, the line replacement frequency is the least common multiple of the satisfaction for the required product capacity per phase adds the number of phase of the required capacity for the replacement line. If the working hours of panel factory are insufficient for the processes and replenishments of commodities, it means that the plant current demand load is greater than it can provide, thus it may need to assess to lengthen the replenishment frequency until meeting all various commodity replenishment one time. Under the condition of the same replenishment frequency and line replacement, the assessment of the replenishment for each commodity is as Equations (3) and (4):

Table 5. Cell plant product information (total demand/phase = 230 cartridges).

Item \ Dimension	15"	17"	19"
Average demand /phase (cartridge)	50	150	30
Time needed for line replacement of bottleneck station (h)	2	2	2
Commodity output per hour (Pi)	5	5	5

$$f_{s,i} \times (j \times H - \sum L_{s,i}) = f_{s,i} \times (j \times H - \sum (D_{s,i} \times 1/P_{s,i})) \geq \sum S_{s,i} \quad (3)$$

$$f_{s,i} \geq \frac{\sum S_{s,i}}{(j \times H - \sum L_{s,i})} \quad (4)$$

However, as most bottleneck machines in panel factory belong to multi-machine style, so equation (3) needs to be amended in the required time for machine replacement. Firstly, we calculated the required machine units each time required by each product replenishment (production) as $L_{s,i} / (j \times H)$, and then obtained the new machine replenishment frequency. The basic formula for equations (5) and (6):

$$f_{s,i} \times (C_s - \sum L_{s,i}) \geq \sum (S_{s,i} \times \left\lceil \frac{L_{s,i}}{j \times H} \right\rceil) \quad (5)$$

$$f_{s,i} \geq \frac{\sum (S_{s,i} \times \left\lceil \frac{L_{s,i}}{j \times H} \right\rceil)}{(C_s - \sum L_{s,i})} \quad (6)$$

If the panel cell plant (s = 2) works 24 h a day and produces three dimensions (inch) of goods with 2 units of bottleneck machine, the production information is shown in Table 5. While considering the cell process of glass substrate with color filter, it should be in the proportion of 1:1, such as the 15-inch products require 50 cartridges which represent the processes of 25 glass substrates and 25 cartridge color filters respectively. Assuming the replenishment frequency of each commodity is the same, then its replenishment frequency is as in Table 4.

As the average daily demand of capacity of (50 +150 +30) × 1 / 5 + [2 × (10/24+30/24 +6/24)] = 54 is larger than the plant's daily production capacity ($C_2 = m_2 \times j \times H$) of 2 × 24 = 48 h, the commodities can not be replenished in a day. Thus, through equation (6), we can obtain each dimension commodity replenishment frequency fs, i ≧ 2 × (10/24+30/24+6/24) / (2 × 24 - 46) = 4, which represents each produced 4 days average demand for each dimension commodity in every 4 days.

Solution for the replenishment lead-time

The afore-mentioned explanation, under the consideration of the incapability of a plant in providing once time capacity for both process and replenishment, lengthens the replenishment frequency to obtain the appropriate replenishment frequencies and learn how long and how much volume in each commodity replenishment. In the replenishment mechanism of TOC supply chain, the replenishment time consists of the replenishment frequency, and replenishment lead-time which is also depended on the size of the replenishment frequency, such as if the replenishment frequency is 1 day, then the fill volume will be of 1 day demand; while the replenishment frequency is 3 days, then the fill volume will be the sum of the cumulative 3 days demand. However, when the replenishment frequency elongated, the replenishment lead time will be followed by changes, such as an array of flat panel industry where the production process cycle time was 6 days, group processes and systems for four days, the module manufacturing process for 2 days. The known production cycle time in the MTS production mode, is proceeded in accordance with the forecast production demand and the consideration of the capacity. However, in TOC supply chain replenishment mechanism, it depends on the replenishment frequency to decide when the plants will receive the production instruction. If the replenishment frequency is 1 day, it means that the plant will receive the production instruction everyday, and if the replenishment frequency is 3 days, it represents that the plant will receive the production instruction every 3 days.

Replenishment frequency, however, also affects the replenishment lead time. For example, to an array process plant with 1 day replenishment frequency which receives 1 day production demand and an array process plant with 3 days replenishment frequency which receives 3 days production demand, both of their replenishment lead-times are different. Therefore, in this chapter we explored the relationship between the replenishment frequency and how to set the replenishment lead time under a given replenishment frequency. If a cell process plant operates 24 h per day with two units of bottleneck machines in the same replenishment frequency of dimension, the data of its production for three dimensions are shown in Figure 4.

According to Equation (6), the obtained replenishment

Table 6. Cell plant product information (total demand/phase = 180 cartridges).

Item \ Dimension	15”	17”	19”
Average demand / phase (cartridge)	40	110	30
Time needed for line replacement of bottleneck station (h)	2	2	2
Commodity output per hour (Pi)	5	5	5

Table 7. The calculation results of replenishment quantity for the 15-inch panel (replenishment frequency 1 day).

Period (day)	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16
Quantity of demand (unit)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Order quantity	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40

Table 8. The calculation results of the replenishment quantity 15-inch panel.

Period (day)	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16
Quantity of demand (unit)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Order quantity	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Expected fill quantity					40	40	40	40	40	40	40	40	40	40	40	40

Table 9. The calculation results of replenishment quantity for the 15-inch panel (replenishment frequency 4 day).

Period (day)	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16
Quantity of demand (unit)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Order quantity				200				200				200				200

frequency is 1, which implies that the production of average demand can be completed within a day (Table 7). And based on 4 days of production cycle period, we can set a 4 days replenishment lead time for cell process plant as the reference of delivery time point (Table 8).

According to Table 4, as the calculated replenishment frequency for each dimension is 4, it means that a four-day average demand will be generated every four days (Table 9). It is different from the 1 day replenishment frequency which will receive the demand for 4 days in the fourth day. However, in the production cycle time for 4-day but with less product output, the replenishment lead time for every dimension commodity will be more than 4 days.If a plant receives a demand of order which it can afford, it will be able to complete this order production in its average production period. But if the demand of orders received is higher than its cycle production capacity, the replenishment lead time will no longer be its production cycle time, and it needs to assess to stretch the replenishment lead-time. While in assessing the setting for the replenishment lead-time, the drum-buffer-rope (DBR) approach to assess the time spent on various orders on the bottleneck station will be firstly applied, and then followed by Schragenheim and Ronen (1990)’s capacity-constrained resource (CCR) buffer and the shipping buffer methods. The general formula proposed by Daniel and Guide (1996) in determining the size of buffer value is based on timing the processing time by a multiple value. However, as there is a characteristic of Reentry exists in the array process of the flat panel industry, there will be an predictive Rod buffer installed two bottleneck stations.

Symbol definition

s: process classification, namely the array process, cell process and module processes.

i: product categories; $D_{s,\,i}$: the product *i*'s demand in the *s* process; $n_{s,\,i}$: the number of days required for the demand of the product *i* in the *s* process; $S_{s,\,i}$: the production line replacement time for product *i* in the *s* process; CP_s: the processing time of the bottleneck station in the *s* process; CB_s: the CCR buffer values; SB_s: the Shipping buffer

Table 10. The buffer time of each process (h).

	Bottleneck buffer	Interval buffer 1	Interval buffer 2	Interval buffer 3	Interval buffer 4	Shipping buffer
Array process	3	3.5	3.5	2.5	2.5	9
Cell process	1	x	x	x	x	20
Module process	1	x	x	x	x	1

Table 11. The processing time of bottleneck machine in each process.

	Bottleneck machine	Input unit
Array process	30	Cartridge
Cell process	12	Cartridge
Module process	0.5	Piece

values; RB_s: that Rod buffer values (the array process only); *k*: the multiple value of buffer size, this research adopts the proposal of Schragenheim and Ronen (1990) of the shop floor environment to obtain the three time values in accordance with the past experience of the lead time distribution; $BT_{s,i}$: the total processing time of product *i* in the bottleneck station in the *s* process; $CT_{s,i}$: the cycle time of product *i* in the s process.

The time spent for product of each bottleneck machine in each process is the product demand volume multiple the processing time of bottleneck machine, as shown in Equation (7):

$$BT_{s,i} = D_{s,i} \times CP_s \qquad (7)$$

The assessment method for a product cycle time in each process is to accumulate the bottleneck buffer, interval buffer, and shipping buffer and multiples it with K time value, and then adds each product's processing time in the bottleneck machine, as Equation (8) shows:

$$CT_{s,i} = k \times (CB_s + SB_s + RB_s) + BT_{s,i} \qquad (8)$$

Unlike the array process which the existing phenomena of the reflux are characteristic, the cell and module processes do not have to install the interval buffer. Regarding the bottleneck machines, the input units in the array and cell processes are based on cartridge (a cartridge loads 20 glass substrates), while in the module process, the input unit is the cut panel (piece) which it undertakes from the cell process. The buffer time and bottleneck process time of each process is listed in the Tables 10 and 11.

Take the cell process for example, according to the data shown in Table 6, to the case of the demand quantity for 15" per phase is 40 cartridges, 110 cartridges for 17", and 30 cartridges for 19", and based on the calculation of equation (7), the required processing time for each product can be obtained as follows:

$BT_{\text{Cell},15''} = 40 \times 12 = 480$ (min) = 8 h

$BT_{\text{Cell},17''} = 110 \times 12 = 1320$ (min) = 22 h

$BT_{\text{Cell},19''} = 30 \times 12 = 360$ (min) = 6 h

According to equation (8), the cycle time of each product can be obtained through the accumulation of the buffer times and multiply it by three times of value, and then couple with the time spent by each bottleneck machine. The calculation is as follows:

$CT_{\text{Cell},15''} = 3 \times (1 + 20 + 0) + 16 = 71$ (h), about 3 days

$CT_{\text{Cell},17''} = 3 \times (1 + 20 + 0) + 22 = 85$ (h), takes about 4 days

$CT_{\text{Cell},19''} = 3 \times (1 + 20 + 0) + 6 = 69$ (h), about 3 days

As Table 4 expressed, the required demand for each phase of 15" is 50 cartridges, 150 cartridges for 17" and 30 cartridges for 19". However, owing to the replenishment that occurs every 4 days, therefore, when the cell process receives the requirement, the demand quantity will change to 200 cartridges for 15", 600 cartridges for 17" and 120 cartridges for 19". According to equation (7), the total processing time of product can be obtained as follows:

$BT_{\text{Cell},15''} = 200 \times 12 = 2400$ (min) = 40 h

$BT_{\text{Cell},17''} = 600 \times 12 = 7200$ (min) = 120 h

$BT_{\text{Cell,19"}}$ = $120\times12=1440$(min) = 24 h

Similarly, the cycle time of each product in each process can also be obtained from the calculation of equation (8):

$CT_{\text{Cell,15"}}$ = $3\times(1+20+0)+40=103$(h) , takes about 5 days

$CT_{\text{Cell,17"}}$ = $3\times(1+20+0)+120=183$(h) , takes about 8 days

$CT_{\text{Cell,19"}}$ = $3\times(1+20+0)+24=87$(h) , takes about 4 days

However, this is just to consider a single bottleneck machine. As most of the bottleneck stations in the panel plants are multi-machines, equation (8) is modified as follows:

$$n_{s,i}\times(H\times j\times m_s)\geq\sum(S_{s,i}\times\left\lceil\frac{L_{s,i}}{j\times H}\right\rceil)+\sum BT_{s,i} \quad (9)$$

By equation (10), we can get the total required time for processing all of the products in each of the bottlenecks, least of ns, i days:

$$n_{s,i}\geq\frac{\sum(S_{s,i}\times\left\lceil\frac{L_{s,i}}{j\times H}\right\rceil)+\sum BT_{s,i}}{(H\times j\times m_s)} \quad (10)$$

According to equation (11), we can obtain the cycle time for each product by adding the three times value of total buffers to number of days for processing all of the products in each of the bottlenecks obtained from equation (10):

$$CT_{s,\text{i}}=k\times(CB_s+SB_s+RB_s)+n_{s,i} \quad (11)$$

Based on the data of Table 4 in which the replenishment time is 4 days and the demand for 15' has changed into 200 cartridges, 600 cartridges for 17"-inch, and 120 cartridges for 19', the cycle time for each product of each process can be obtained through the calculation of equation (9). From equation (10), for 200 cartridges of 15", 600 cartridges of 17", and 120 cartridges of 19", the total required processing time of bottlenecks machines in the cell process takes at least 4 days:

$$n_{s,i}\geq\frac{2\times(1+2+1)+[(200+600+120)\times12]/60}{(24\times1\times2)}=4$$

Based on Equation (11), we can figure out the cycle time for all products in each process as;

$CT_{\text{Cell,15"}}=CT_{\text{Cell,17"}}=CT_{\text{Cell,19"}}$

$3\times(1+20+0)+(4\times24)=159$ (h) (it takes about 7 days).

The calculated cycle time for all products in each process, as shown in Equation (12), is equivalent to the replenishment lead time of each process. The cycle time of modular process is equal to the replenishment lead time for finished goods inventories; similarly, the cycle time of cell process is equal to the replenishment lead time for finished goods inventories; the cycle time of array process is equivalent to the replenishment lead time of the array of finished goods inventories:

$$RRT_{i,p}=CT_{s,i} \quad (12)$$

After obtaining the replenishment lead time of each process, we can assess the expected time point for replenishment when each of the process plants receive the production demands and add it with the production lead time for replenishment. From equation (13), we can learn that the replenishment volume is the continuous replenishment demand within the period of replenishment frequency:

$$R_{i,p,j}=Q_{i,p,j-RRT_{i,p}} \quad ,j=1,2,...,J \quad (13)$$

Therefore, based on Table 4 which shows 4 for the calculated replenishment frequency for all products and 7 days for the replenishment lead time, we can obtain the expected purchase quantity. Take the 15" for example, the calculation is shown in Table 12.

The integration models of replenishment and production

In the TOC-SCRS mechanism, the inventories of finished goods in the array, cell and module processes are closely related. The main function of TOC-SCRS is to assess the required time of the production for product processing in each process and the total time of production line replacement is overloading or not. If it is not, the replenishment frequency can be set as 1, in other words, making the replenishment requirement everyday. If the load is over the capacity, the plan can appropriately lengthen its replenishment frequency so as to adjust the availability of each product processing and production line replacement all for once. Therefore, the assessing of the replenishment frequency in the three major inventory will be different in accordance with the variation of each own demand volume and replenishment frequency. Although each of the inventories in the TFT-LCD supply

Table 12. The calculation of order quantity for 15" commodity (4 days of replenishment , 7 days of lead time).

Period (day)	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16
Demand (unit)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Order quantity				200				200				200				200
Expected purchase quantity											200				200	

chain is independent and replenishes its own product inventory in accordance with TOC-SCRS replenishment mechanism, there still exists a close relation between the inventory and process. Throughout the TFT-LCD supply chain, the end products are various types of panel products, and it is the module process that receives the actual orders while the order requirements of the array and cell processes are to satisfy and meet the development of module process. Therefore, the key issue is that how to effectively link the orders of customers demand in the module process to the array and cell process in order to produce the quantity required by the module process. To a single process, its inventory can be divided into two types, one of which is finished goods, while the other is the materials, components or semi-finished goods required for the manufacturing process. There is a close connection between process and inventory which will be explained next, as well as the illustration of how to apply the TOC-SCRS replenishment mechanism. The inventory of finished goods in the module process, for example, accommodates a wide variety of panel types of finished goods such as liquid crystal displays, notebook computers, LCD TVs and other types of panel finished goods. This inventory will meet customers demand with currently available stocks, and calculate out the maximum inventory buffer for each product in accordance with the sold quantity of products and the TOC-SCRS replenishment mechanism. Furthermore, it will consider the module capacity, the assessment of products replenishment frequency, the expected replenishment lead time to calculate the replenishment volume for each product. Undertaking the replenishment requirement from the module finished good inventory, the module plant will develop plans based on different scheduled systems. If the arrangement of processing sequence in production planning is developed based on the drum-buffer-rope (DBR), it will use the bottleneck as a production planning standard to establish the production rhythm for the bottleneck machines and calculate out the rope. As all products can base on the rope to feed, therefore, the component inventory and module raw material inventory can precede replenishment in accordance with the rope to meet the requirement of components and raw material in the processing for all products in module process. After meeting the feed requirement of module plant, the raw material inventory module, driver IC inventory, backlight module inventory, printed circuit boards will be in accordance with TOC-SCRS stock replenishment mechanism to calculate their own maximum stock buffer for each product in the inventory, and assess the replenishment frequency, expected replenishment lead time. After the calculation of replenishment volume for each product, the raw material inventory of module will propose the replenishment requirement to its upstream cell process, as well as to other component supplier. The finished good inventory in the cell includes all dimensions of the semi-finished panels. The finished good of cell inventory and raw material of module inventory are the same semi-finished goods of all dimension of cut panel. The only difference is the locations of inventory which needs the transportation to deliver the stocks. Therefore, after the cell finished goods inventory meeting the requirement of module raw material inventory in accordance with cell's existing available stocks through the transportation delivery, it will then calculate the maximum inventory buffer for all dimension panels, as well as assess the replenishment frequency and expected replenishment lead time to obtain the replenishment volume for each product, and then propose the replenishment request to cell plant. The cell material stocks inventory is different from the cell finished good inventory. The stocks in cell raw material inventory are semi-processed glass substrates which have not be processed and cut by cell plant. Whereas the yield pieces of different dimensions of glass substrates cut by different generation of plant might not be exactly the same. For example, a 3.5-generation plant might cut 6 pieces of 15' glass substrate and 4 piece of 17' glass substrate, but the five-generation plant can cut 15 pieces of 15' glass substrate and 9piece of 17' glass substrate. Therefore, while in feeding, the cell plan will, in accordance with the variety of panel dimension demand proposed by the cell finished good inventory and the consideration of the best cutting piece which the generation plant can achieve, plan out the need of glass substrate for each dimension, and develop the Rope with the different scheduling. The afore-mentioned module plant is assumed to design out the Rope through the DBR method.

After meeting the material feeding for the cell plants, the glass semi-finished products , color filters will, in accordance with TOC-SCRS stock replenishment mechanism, calculate the maximum inventory buffer for all of dimension of glass substrate, and assess the replenishment frequency, the expected replenishment lead time, to find out the replenishment volume for all dimension glass substrates. Next on, the cell raw material inventory will propose its replenishment request to the upstream array finished good inventory, as well as the replenishment

Table 13. Result of inventory change.

Period (day)	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16
Demand (unit)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Order quantity				200				200				200				200
Expected purchase quantity											200				200	
Expected ending inventory (600)	550	500	450	400	350	300	250	200	150	100	250	200	150	100	250	200

requirement of color filters to its suppliers. The unit of raw material in array raw materials inventory is larger unprocessed glass substrates which mainly provide to cell plants. The array plant will develop all production plans in accordance with different scheduling systems and calculate the rope. Therefore, the array raw materials inventory , after being its requirement being met by the array plant based on the array rope, will in accordance with the TOC-SCRS replenishment mechanism to calculate its maximum inventory buffer for of all dimensions of glass substrate and the assess the replenishment frequency as well as the expected replenishment lead-time. And after finding out the replenishment volume for all dimensions of glass substrate, it will then propose replenishment request to its upstream suppliers of glass substrate.

According to the demand of each cycle, replenishment quantity and the pre-ending inventory, the current ending inventory can be obtained through, minus the current demand volume and then add the current purchase quantity, as shown in the equation (14):

$$S_{i,p,j} = S_{i,p,j-1} - D_{i,p,j} + R_{i,p,j} \quad , j = 1, 2, ..., J \qquad (14)$$

From the data of Table 4 after the calculation of equation (1), if the maximum inventory buffer of the 15” cartridge is 600, then the daily expected inventory change in the next 16 days, with the 4 days of replenishment frequency and 7 days of replenishment lead time, are shown in Table 13.

Conclusion

This research focuses on the study of TFT-LCD plant. Firstly, by analyzing the data predicted by current panel plants, this study developed production planning mode followed with the proposal of the constraint theory of supply chain system. Next, with the input of the data of replenishment frequency, replenishment lead time as well as maximum inventory buffer, and obtaining output data of the replenishment volume, the purchase quantity and the inventory changes , this research provided the data to each process of TFT-LCD as a base for production planning. After understanding the connection between TFT-LCD manufacturing process and the inventory, we then input the replenishment frequency, replenishment lead time and maximum inventory buffer of each product in every inventory, and provided the output data of replenishment volume and the purchasing quantity to the upstream inventories or processes for their production planning without having to predict the demand. The experiments of this research proved that the constraint theory in supply chain system, either in the average inventory or order meeting of all dimensions of panel, is better than the prediction strategy especially when the forecast variation is more obvious.

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