The Analysis of Different Production Planning Decision Models in the Supply Chain Network

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***Abstract*—In many industries, production stages are assigned to different plants and distribution centers that have been established in geographically dispersed locations. After the sales department received the future monthly forecast demands, the forecast demands of the different customers are aggregated according to the various products. Then the personnel in the production planning department will allocate the forecast demands to the multiple plants by the respective months. This paper proposed an allocation programming models. Besides, three different planning decision models are compared and related sensitivity analysis are also discussed.**

***Index Terms*—Network, Production Planning, TFT-LCD, Supply Chain.**

I. Introduction

Recent years, many enterprises encounter difficulties in production planning because manufacturing environments have changed from traditional single-plant to current multi-plants. A manufacturing process which consists of several production steps can be defined as "multi-stage". Each production stage may involve more than one factory, constituting a multi-site manufacturing step. Therefore, "multi-stage" and "multi-site" establish the "supply chain network".

The systematic levels of supply chain concept comprise four levels: internal chain, dyadic relationship, external chain and network [3]. *Internal chain* model indicates that there is only one plant in the production network, which belongs to a single-site production environment. *External* model presents that there are different functions among plants in the multi-site production environment and these plants have sequential relationships in the manufacturing process. *Dyadic* model presents that there are some plants that have the same processes in the multi-site production environment. As the functions of plants are the same, the plants possess complementary or alternative property. The last model is the *network* model that is configured by external and dyadic model. The network model possesses both sequential and complementary features. Hence, it is more complicated than the other models.

For example, in the TFT-LCD (Thin Film Transistor–Liquid Crystal Display) manufacturing industry that is an essential technology in a wide range of electronic products, the "multi-stage" is composed of Array, Color filter, Cell and Module processes, and each production stage has several different generation plants located in varied places (e.g. in Taiwan or in China), called "multi-site" environment. Under the structure of the multi-site, multi-stage environment, the global planners will face production allocation problem to satisfy the demands of the customers. The decisions may include the manufacturing routings of demand products, and production quantities among multiple plants. For instance, a certain final demand of TFT-LCD products may be supplied from Array-Plant-1, Cell-Plant-2 to Module-Plant-1. And if the number of the final demand products is one hundred units, the planner may decide that seventy units are supplied from Module-Plant-1 and other thirty units are supplied from Module-Plant-2. These allocation planning operations are executed by the global (or headquarters) planners based on the monthly time-bucket.

In this paper, we proposed an allocation programming models. Besides, three different planning decision models are compared and related sensitivity analysis are also discussed.

II. Literature Review

The multi-site production planning problem in the supply chain network is similar to the multi-level capacitated lot-sizing problem (MLCLP). In MLCLP, the lot-sizes must be determined for multi-level production inventory systems with capacity constraints in the production facilities [7]. The similar problem is the capacitated lot sizing problem (CLSP) which consists of planning the lot sizes of multiple items over a planning horizon with the objective of minimizing setup and inventory holding costs [5]. Reference [2] thoroughly reviews the single item lot-sizing problems for uncapacitated and capacitated versions.

Reference [1] presented heuristic methods based on evolutionary algorithms to address the multi-stage CLSP problem, including setup costs and setup times. In [5] the CLSP is extended to include overtime decisions and capacity consuming setups. The objective function consists of minimizing inventory holding and overtime costs. The different approaches including the iterative relaxation approach, a Genetic Algorithm (GA) and a Simulated Annealing (SA) approach are proposed to compare among them.

As well as the above problems, studies recently have focused on the production planning in the supply chain network or production-distribution environment. Reference [6] investigated the value of coordinating production and

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distribution planning. An efficient heuristic based on Lagrangian Relaxation is proposed to deal with this model.

Reference [4] proposed an integrated process planning and scheduling (IPPS) model for the multi-plant supply chain (MSC). A genetic algorithm-based heuristic approach is developed to obtain good approximate solutions.

Reference [7] proposed an approach for solving a multi-stage, multi-product lot-sizing problem in a multi-site environment. The goal is to determine an optimal plan for a multi-site structure, each site being a multi-machine work center. The transportation time between sites also has to be taken into account. The method alternates between solving a planning and scheduling problem in two separated planning and scheduling modules. A nice feature of the proposed methodology is its modularity.

While plenty of researches regarding the multi-site planning appeared recently, the specific problem features for the particular production environment or industries have only been considered insufficiently by previous studies so far. Reference [9] dealt with a capacitated master production planning and capacity allocation problem for a multi-plant manufacturing system with two serial stages in each plant. The author developed the iterative heuristic procedures based on the LP-relaxation approach.

The practical multi-site planning application is also found in [8] research taken from the chemical industry. They described a general mixed-integer linear programming (MILP) model based on a time-indexed formulation covering the relevant features. The model combines aspects related to production, distribution and marketing and involves production plants and sales points. Besides standard features of lot sizing problems, further aspects such as different time scales attached to production and distribution, the use of periods with different lengths, the modeling of batch are also considered.

In this paper, a TFT-LCD manufacturer case in Taiwan is taken as an illustration to explain these planning issues and provide some practical discussion.

III. Planning Models

Allocation decisions among multi-plant are made in terms of certain decision criterions (that is, the related costs). For example, the production costs, the inventory costs in each plant, the purchase costs of all kinds of key materials, and the transportation costs between factories and distribution centers. Besides, other decision considerations include some constraints have also been discussed.

There are so many production planning constraints in the TFT-LCD industry that here we just describe the major constraints as follows:

The capacity's constraint of each plant: Under the multi-site production framework, each plant has its own capacity limitation due to the finite and expensive machines.

The capacity's constraint for each product in a certain plant: Due to the different requirement in each product, such as panel's size, glass substrate thickness, specified materials, and limited flexibility of machines, the yield of each product is limited.

Key materials' constraint: In general, glass, color filter, polarizer, driver IC, PCB and back light are key materials in TFT-LCD manufacturing process. The lead-time for the procurement of these key materials is longer (over one month) and different with each other. Time to the acquisition of theses materials must be concerned when implementing the production plan. In addition, the allocation of key materials is also an important factor while different products compete with the common key materials.

The constraint of product's ranking: First, all products are classified in terms of size, and each product will be categorized again according to the divergence of glass's thickness in Array process. After Cell process, products are assorted as H-grade, M-grade and L-grade. L-grade products usually are scraped and M-grade products are put into production in Module process if customers are willing to accept them. In general, only H-grade products will be processed in Module process. Products will be classified again in Module process due to the specific materials requested by customers. Finally, every product will be tested in the inspection stage and ranked as A, B, C, D and E grades. Planners must determine the rate of the distribution of final five grades according to past experience.

Different customers may have different demands due to the materials and product's grades. For example, one customer needs XGA01-A-grade product and another needs XGA03-C-grade product. Planners must aggregate these diverse demands and calculate back by way of the known rate of the distribution of final five grades so as to obtain the production plan of putting into Array process initially.

The constraint of manufacturing process's paths: Manufacturing routing of each product is different due to the requested sizes, thickness, and features of products. Therefore, each product has its own manufacturing routing. For example, the products with 15 inches XGA-01 only can be produced in some specific plants but 17 inches XGA-01 ones are unrestricted.

The constraint of the specified materials by customers: This problem is mainly occurred in Module process, in which the customer will specify a certain supplier that provides the components such as drive ICs, PCBs and backlights.

Furthermore, in such multi-plant logistics supply chain networks, the production planning activities have to be well coordinated in order to avoid excessive inventories, inefficient capacity utilization and poor customer service. Traditionally, planning is carried out independently at the various locations. However, the concept of the multi-site planning is to integrate the entire supply chain planning, including multiple factories owned by the company, the supplying characteristics of key materials, and transportation operations, etc.

Fig.1 illustrates the schematic diagram of multi-plant in supply chain network which consists of four main stages: Array, Cell, Color Filter and Module processes. The way to match the critical parts with the demand will determine the customer fulfillment rate and satisfaction level, which are the important performance for the TFT-LCD industry.

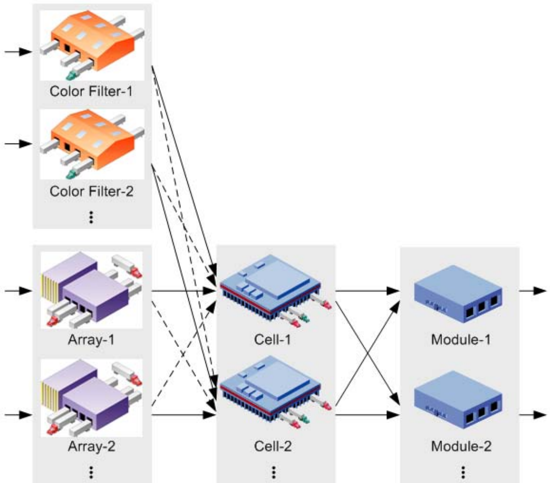

Fig.1 The diagram of multi-plant production planning problem in supply chain network

A. *Programming Models*

In this section, we described mathematical programming models considering different relevant constraints and characteristics.

Index:

- t = period index of monthly time-bucket (t=1,2,…,T)
- p = product index (p=1,2,…,P)
- i, j = production plant index (i, j=1,2,…,N. Here, N stands for the total numbers of plants)
- k = raw material index (k=1,2,…,K)
- A = set of plants in the first production stage
- Z = set of plants in the final production stage
- F(i),F(j) = set of plants in the previous production stage of plant i and j, respectively
- L(i),L(j) = set of plants in the next production stage of plant i and j, respectively

Decision variables:

- Q_{ipt} = production amounts of product p at plant i in period t
- B_{ikt} = purchase amounts of material k at plant i in period t
- I_{ipt} = amounts of end of period inventory of product p at plant i in period t
- U_{ipt} = backorder amounts of product p at plant i in period t
- M_{ikt} = amounts of end of period inventory of material k at plant i in period t
- T_{ijpt} = amounts of product p transported between plant i and j in period t
- QF_{ipt} = intermediate variables standing for the output in period t from the release production in period t-1
- QP_{ipt} = intermediate variables standing for the output in period t from the release production in period t

Parameters:

- d_{ipt} = demand of product p at plant i in period t
- bom_{ipk} = number of units of material k used to make a unit of product p at plant i
- yd_{it} = the yield rate at plant i in period t
- cp_{ipt} = unit cost of production for product p at plant i in period t
- ch_{ipt} = unit cost of inventory for product p at plant i in period t
- cs_{ipt} = unit cost of shortage for product p at plant i in period t
- cb_{kt} = unit cost of purchase for raw material k in period t
- cm_{kt} = unit cost of inventory for raw material k in period t
- ct_{ijt} = unit cost of transportation between plant i and j in period t
- cap_{it} = available capacity limit for production at plant i in period t
- $unit_{ip}$ = converted production unit for product p at plant i
- LT_i = the production lead time for making one unit at plant i
- BT_k = the purchase lead time for raw material k
- DT_t = number of days included in period t

Objective function:

$$\begin{aligned} Min\quad & \sum_i\sum_p\sum_t\left(cp_{ipt}Q_{ipt}+ch_{ipt}I_{ipt}\right)+\sum_{i\in Z}\sum_p\sum_t\left(cs_{ipt}U_{ipt}\right) \\ & +\sum_i\sum_k\sum_t\left(cb_{kt}B_{ikt}+cm_{kt}M_{ikt}\right) \\ & +\sum_{i,i\notin Z}\sum_{j,j\notin A}\sum_p\sum_t\left(ct_{ijt}T_{ijpt}\right) \end{aligned} \quad (1)$$

The total costs considered include as follows: the production cost of each plant, the storage cost of products, the shortage cost of unfulfilled demands, the purchase cost and storage cost of raw materials, and the delivery cost of transporting semi-products between plants. Then, the objective is to minimize the above-mentioned total costs.

Constraints:

$$QF_{ipt}=\left(\frac{LT_i}{DT_{t-1}}\right)\times Q_{ip,t-1}\times yd_{i,t-1}\times unit_{ip}\qquad \forall i,p,t \quad (2)$$

$$QP_{ipt}=\left(\frac{DT_t-LT_i}{DT_t}\right)\times Q_{ipt}\times yd_{it}\times unit_{ip}\qquad \forall i,p,t \quad (3)$$

Constraint Eqs.(2)-(3) indicate the production features in the TFT-LCD manufacturing process. Since the production lead time is long, e.g., 7~10 days in the Array process, the release production quantities in the present time-bucket will output partially into the current time-bucket and subsequent time-bucket respectively.

In addition, the term "unit" means the production unit. The production unit in the Array process is a *cassette* (or *lot*) including about twenty glass substrates. When entering into the Cell process, a glass substrate will be split into 6, or 8 pieces through the partition operation, according to *economic cutting size* (that is, minimizing the percentage of discarding a useless part of one glass substrate) affected by the different sizes of substrates and various products. In the Cell process, the release production is a *sheet*, and the output unit in this process is called a *piece*. Finally, the production unit in the Module process is a *piece*, i.e. the size of the 17 inches or 19 inches products, etc.

$$I_{ipt}=I_{ip,t-1}+\left(QF_{ipt}+QP_{ipt}\right)-\sum_{j\in L(i)}T_{ijpt}\qquad \forall i(i\notin Z),p,t \quad (4)$$

$$I_{ipt}=I_{ip,t-1}+\left(QF_{ipt}+QP_{ipt}\right)+U_{ipt}-U_{ip,t-1}-d_{ipt}\qquad \forall i(i\in Z),p,t \quad (5)$$

$$M_{ikt}=M_{ik,t-1}+B_{ik,t-bt_k}-\sum_p\left(bom_{ipk}\times Q_{ipt}\right)\qquad \forall i,k,t \quad (6)$$

Constraint Eq.(4) is the balance equations for the inventory of products in every production stage except for the last stage. Constraint Eq.(5) is also the balance equations for the inventory of products but it's for the last production stage, considering demands of products for customers and backorder status. Constraint Eq.(6) is the balance equations for the inventory of raw materials.

$$Q_{jpt} = \sum_{i \in F(j)} T_{ijpt} \qquad \forall j (j \notin A), p, t \tag{7}$$

$$\sum_{p} Q_{ipt} \le cap_{it} \qquad \forall i, t \tag{8}$$

$$Q_{ipt}, I_{ipt}, U_{ipt} \ge 0 \qquad \forall i, p, t \tag{9}$$

$$B_{ikt}, M_{ikt} \ge 0 \qquad \forall i, k, t \tag{10}$$

$$T_{ijpt} \ge 0 \qquad \forall i, j, p, t \tag{11}$$

Constraint Eq.(7) is the balance equations for the transportation between factories. The number of products that release production in the next manufacturing stage must be equal to the number of products that leave from the last manufacturing stage. Constraint Eq.(8) is the available capacity constraints. Every plant has its own capacity limitation due to the finite and expensive machines. Constraint Eqs.(9)-(11) are the non-negativity restriction on the decision variables.

B. Results

The input parameter data of the proposed programming model are gotten from a certain TFT-LCD manufacturer in Taiwan, such as forecast demands, production capacity in each plant, related costs, and so on.

Every manufacturing stage (that is, Array, Cell, color filter and Module processes) possesses two complementary factories. For the reason that these plants are located in the dispersed areas, e.g. Module-Plant#1 is in Taiwan and Module-Plant#2 is in China, the transportation between these two plants has to be involved. In addition, we consider the two sizes of TFT-LCD products, that is, 15 inches and 17 inches. The planning horizon covers six months.

Through the calculation of optimization software, the final decision information such as the production quantities of every product in each plant can be obtained (see Table.1), e.g. the numbers of releasing production for 15 inches XGA-01 and 17 inches XGA-01 products in Array-Plant#1 are 94 and 448 units (lots) respectively in the first month (January). Besides, the purchase quantities of every raw material are displayed (see Table.1) in order to provide these forecast data for the upstream suppliers and preventing shortage of materials in the future, e.g., the purchase quantities of the backlight in Module-Plant#1 is 25,000 units in January. The total related cost in this planning stage is $2,640,484.

Table.1 The optimal output data

The Release Production Qty.	15"XGA-01						15"XGA-02					
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
Array-Plant#1	94	278	81	49	0	0	566	142	339	371	420	420
Array-Plant#2	604	448	388	700	306	0	596	52	412	0	194	500
CF-Plant#1	78	239	83	96	0	0	472	181	317	324	420	420
CF-Plant#2	526	466	374	660	348	2	574	34	476	0	152	498
Cell-Plant#1	1332	4115	2107	1819	311	0	7068	3685	5693	5981	7489	7800
Cell-Plant#2	8960	9200	7289	12267	7561	935	5540	5000	4711	4733	1639	8265
Module-Plant#1	16065	23671	17206	15631	13103	5438	25935	15329	21794	23369	25897	33562
Module-Plant#2	19282	18103	18187	18181	35152	0	28718	27897	27813	27819	10848	46000
The Release Production Qty.	17"XGA-01						17"XGA-02					
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
Array-Plant#1	448	230	340	285	420	122	452	370	260	315	180	478
Array-Plant#2	461	236	314	289	356	210	439	464	386	411	344	490
CF-Plant#1	354	285	300	296	381	184	346	365	350	354	269	466
CF-Plant#2	402	264	294	288	340	223	398	436	406	412	360	477
Cell-Plant#1	5805	5751	5764	5761	7123	4206	4195	4049	4036	4039	2677	5594
Cell-Plant#2	6874	5475	5619	5606	6463	4630	4726	5525	5381	5394	4537	6370
Module-Plant#1	26887	25136	25261	25252	32723	17248	23113	23864	23739	23748	16277	31752
Module-Plant#2	32234	30165	30313	30302	32506	27943	25766	24835	24687	24698	22494	27057

The Purchase Qty. of Materials		Jan.	Feb.	Mar.	Apr.	May.	Jun.
Array-Plant#1	Glass Substrate				540	1020	
Array-Plant#2	Glass Substrate			1050	1200	1200	
CF-Plant#1	Glass Substrate				410	1070	
CF-Plant#2	Glass Substrate			860	1200	1200	
Cell-Plant#1	Color Filter	30500	35200	35200	35200	35200	
	Polarizer		45600	56000	40400	40400	
Cell-Plant#2	Color Filter	1338278	1428446	1436339	1434039	1503314	
	Polarizer	25000	88000	88000	88000	88000	
Module-Plant#1	Drive IC		876711	1638488	1549231	1734114	
	Back Light				100000	101000	
Module-Plant#2	Drive IC				540	1020	
	Back Light			1050	1200	1200	

C. *Comparison of three planning models*

We compared with three planning decision models as follows (also see Table.2):

(a) Concurrent optimization planning model

In this model, the planning operation is to *concurrently* integrate multiple plants owned by the enterprise. The result of programming model is really global optimization. The total cost is $2,640,484, and related costs are as follows: the percentage of production cost is 42.98%, the percentage of inventory cost is 1.21%, the percentage of purchase cost for key materials is 29.43%, the percentage of storage cost for key materials is 4.13%, and the percentage of transportation cost between plants is 22.25%.

(b) Sequential planning model

The *sequential* planning model prevalently exists in most companies. Generally speaking, in a company, the forecast demands are firstly received by sales personnel. And then, the planners in the last production stage, that is, module process, will allocate optimal quantities among plants which belong to this manufacturing stage. After the planning tasks in the last stage, the allocation operation will transfer to the previous production stage based on the *locally optimal* decision results in the current stage.

The total cost by *sequential planning* is $2,909,924 which is more 10.20% than concurrent optimization planning model, and all relevant costs are stated as follows: the percentage of production cost is 39.02%, the percentage of inventory cost is 1.13%, the percentage of purchase cost for key materials is 26.69%, the percentage of storage cost for key materials is 3.75%, and the percentage of transportation cost between plants is 29.42%.

(c) Planning model by experiential rules

As a result of the lack of the optimization tools in many companies, some planners almost engage in production planning tasks by their experiential rules. As an example of the case in this paper, the planners allocate quantities by the first priority of the consideration for transportation cost.

The total cost by experiential rules is $3,079,845 which is more 16.64% than concurrent optimization planning model, and related costs are described as follows: the percentage of production cost is 36.86%, the percentage of inventory cost is 1.04%, the percentage of purchase cost for key materials is 25.22%, the percentage of storage cost for key materials is 3.54%, and the percentage of transportation cost between plants is 33.33%.

Table.2 Comparison of three planning models

Planning Model	Total Cost	Comparison (%)
Concurrent optimization planning model	$2,640,484	—
Sequential planning model	$2,909,924	+10.20%
Planning model by *experiential rules*	$3,079,845	+16.64%

Table.3 Comparison of related costs under different multipliers for unit production cost

multipliers	0.5	0.8	1.0	1.5	2.0
Production cost	-49.80%	-19.99%	*	50.00%	99.94%
inventory cost	1.18%	-1.6%	*	1.4%	-1.55%
transportation cost	-2.3%	1.5%	*	—	1.6%
Total cost	-21.52%	-8.60%	*	21.49%	42.98%

* base case；— stands for no evident difference

Table.4 Comparison of related costs under different multipliers for unit inventory cost

multipliers	0.5	1.0	1.5	2.0	2.5
Production cost	—	*	0.1%	0.3%	0.4%
inventory cost	-46.04%	*	49.77%	55.53%	40.77%
transportation cost	-0.30%	*	—	2.11%	4.68%
Total cost	-0.63%	*	0.61%	1.15%	1.55%

* base case；— stands for no evident difference

Table.5 Comparison of related costs under different multipliers for unit transportation cost

multipliers	0.5	0.8	1.0	1.5	2.0
Production cost	—	—	*	0.1%	1.3%
inventory cost	-25.87%	—	*	3.70%	6.90%
transportation cost	-48.72%	-20.00%	*	49.71%	99.28%
Total cost	-11.15%	-4.45%	*	11.10%	22.19%

* base case；— stands for no evident difference

IV. Sensitivity Analysis

The comparisons of related costs under the different multipliers for the unit production cost, unit inventory cost, and unit transportation cost, respectively, are shown in Table.3－Table.5.

From the comparison analysis illustrated above, we found the unit product cost and unit transportation cost are the key factors for effect on the total costs when engaging in allocation operation. As shown in Table.3 and Table.5, in case the unit production and transportation cost increase, the total cost in the final decision will markedly rise. On the other hand, in Table.4, the increase of the unit inventory cost has little impact.

V. Future Research

In this paper, we proposed an allocation programming models considering multiple practical characteristics and constraints. Linear programming is employed. Through optimization procedures, the information and decisions on production or procurement in the multi-plant network can be derived. Besides, three different planning decision models are compared and related sensitivity analysis are also discussed. From the analysis for the case illustrated in this paper, we found the product cost and transportation cost are the key factors for effect on the total costs when engaging in allocation operation.

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