International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:4, No:5, 2010

An Analytical Framework for Multi-Site Supply Chain Planning Problems

Yin-Yann Chen

***Abstract*—**As the gradual increase of the enterprise scale, the firms may possess many manufacturing plants located in different places geographically. This change will result in the multi-site production planning problems under the environment of multiple plants or production resources. Our research proposes the structural framework to analyze the multi-site planning problems. The analytical framework is composed of six elements: multi-site conceptual model, product structure (bill of manufacturing), production strategy, manufacturing capability and characteristics, production planning constraints, and key performance indicators. As well as the discussion of these six ingredients, we also review related literatures in this paper to match our analytical framework. Finally we take a real-world practical example of a TFT-LCD manufacturer in Taiwan to explain our proposed analytical framework for the multi-site production planning problems.

***Keywords*—**Multi-Site, Production Planning, Supply Chain, TFT-LCD.

I. Introduction

In the past years the multi-site production planning problems have attracted many researchers' attention, but most of the researches put emphasis on the methodology to solve the multi-site planning and scheduling problem. Few of those researches are to analyze the essence and definition of the multi-site production planning problem. The analytical framework of the multi-site production planning problem is proposed in this paper. This structural framework is composed of six elements: multi-site conceptual model, product structure (bill of manufacturing), production strategy, manufacturing capability and characteristics, production planning constraints, and key performance indicators. Through this analytical framework, we can describe the multi-site production problem more thoroughly. In addition, we take a real-world practical example of a TFT-LCD (Thin Film Transistor- Liquid Crystal Display) manufacturer in Taiwan to illustrate our proposed analytical framework for the multi-site production planning problem.

II. An Analytical Framework

This section will analyze the multi-site production planning problem. First, we describe the definition of the multi-site planning problem appeared in the past literatures. And then, a structural framework is proposed and six ingredients of the analytical framework are explained sequentially in detail.

A. Multi-site planning problems

In the literatures, many researchers had different definitions for the term: "multi-site" or "multi-plant". The multi-site production planning problem is mainly the production allocation decisions among multiple plants. Thierry et al. [1] thought that the manufacturing process of products may require the usage of many resources located in different production units. Furthermore, some alternative manufacturing routings may exist. Some production units of a company may have equivalent or complementary profiles for a given manufacturing process. In most cases each production site has its own production planning mode. The coordination of the different production units is critically important. Thus the multi-site production planning problem is to determine how many quantities are produced in different production units and are transported between plants on different time periods.

Guinet [2] also discussed that the aim of a multi-site production planning is to give answers to the two related questions: "who must produce?" and "when products and manufactured parts must be processed?"

Although the multi-site production planning problems have attracted many researchers' attention in the past, most of the researches emphasize the methodology to solve the multi-site planning and scheduling problems. Few of those researches are to analyze the essence of the multi-site production planning problem.

Thus we propose the structural framework for the multi-site production planning problems as shown in Fig. 1. The six ingredients of this analytical framework are as follows: multi-site conceptual model, product structure (bill of manufacturing), production strategy, manufacturing capability and characteristics, production planning constraints, and key performance indicators. The multi-site production planning problem in a variety of practical industries can be identified clearly by these six ingredients. The detailed interpretations of six ingredients are discussed in the following section.

B. Multi-site conceptual model

We develop the conceptual model of production structure based on the related literatures to describe the structure of multi-site production environments. As well as the structure of

Yin-Yann Chen is with the Industrial Management Department, National Formosa University, Yunlin 632, Taiwan, R.O.C. (phone: +886-5-6315716; fax: +886-5-6311548; e-mail: yyc@nfu.edu.tw).

This work was supported in part by the National Science Council, Taiwan, R.O.C., under contract No. NSC 97-2221-E-150-080-MY2.

multi-site production, the conceptual model includes warehouse positions, plant locations and transportation links between plants. Thus the conceptual model can clearly describe the practical multi-site production environment.

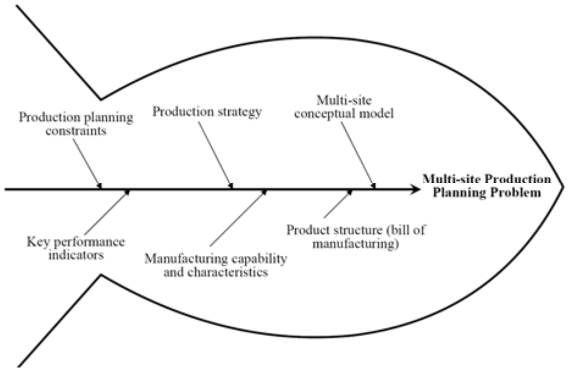

Fig. 1 An analytical framework of multi-site production planning

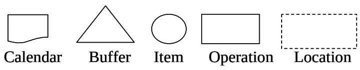

Fig. 2 Symbols of conception model

In order to present the conceptual model, we develop some symbols based on supply chain key model definitions of i2 software as shown in Fig. 2. The “calendar” symbol represents the usage limitation of finite resource buffers, and the “buffer” symbol stands for the resource buffers or temporal buffers in manufacturing processes. The “item” symbol describes materials, semi-finished goods or finished goods, and the SKU (stock keeping unit) is a mixture of combining the buffer and item. The “operation” symbol indicates an activity, for example, manufacturing or assembly. Finally, the “location” symbol describes the geographical positions.

The multi-site conceptual model can be distinguished three classes: external (serial chain), dyadic (parallel chain) and network. Because there are so many multi-site models in the real world that this paper just interprets and analyzes the major multi-site conceptual structure, including the seven multi-site conceptual models called respectively from Type A to Type G.

The examples of the external conceptual model are Type A and Type B. Type A is shown in Fig. 3. The plants in Type A are located in the same place. When the materials are delivered to the warehouse of upstream plants, the plant will start to produce the products. After finishing the semi-finished goods, the plants will deliver the semi-finished goods to the downstream plants. Because all of the plants in Type A are in the same place, the transportation between plants is not required. The transportation operation in our research represents the products or materials transported between different places geographically rather than the same location.

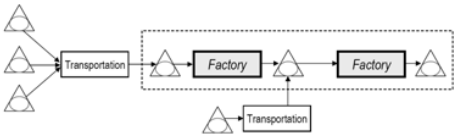

Fig. 3 Multi site conceptual model of Type A

The multi-site conceptual model of type B is as showed in Fig. 4. The mainly different point between Type A and Type B is that the upstream and downstream plants are located in different places geographically.

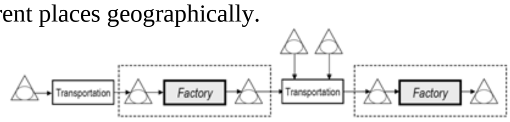

Fig. 4 Multi site conceptual model of Type B

Type B requires the transportation operation to transfer the semi-finished goods from upstream to downstream plants. Thus the multi-site planning in Type B needs to consider the transportation planning between sites. The transportation planning may consider some constraints, for example, whether the transportation planning will be influenced by the planning output time of upstream plants, and how to select transportation modes subject to the transportation calendar etc.

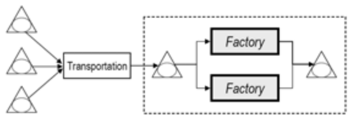

Fig. 5 Multi site conceptual model of Type C

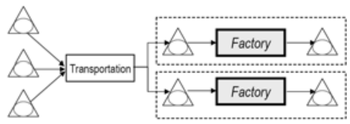

Fig. 6 Multi site conceptual model of Type D

The major types of the dyadic (parallel) model are showed in the Fig. 5 and Fig. 6, called Type C and Type D. The multiple plants are located in the same place in Type C. Thus there are not transportation operations in Type C. When the related materials are delivered to the warehouses of plants, the plants can start to produce the finished goods rather than the semi-finished goods. In Type C, the order allocation problem needs to be considered. That is, how to allocate the production quantities of customer orders to the appropriate plants for fulfilling the due dates of orders is the critical planning decision.

The multi-site conceptual model of Type D is as showed in Fig. 6. The multiple manufacturing plants are located in different places geographically. Thus in Type D, the transportation operation planning needs to be considered. In other words, the materials are directly delivered to the local warehouses of different plants. The planners must to decide the allocation problem of related materials among multiple warehouses.

The network models are showed in Fig. 7, Fig. 8 and Fig. 9, called Type E, Type F and Type G respectively. The network model is a mixture of the external (serial) and dyadic (parallel) model. In the network model there also have the order allocation problems similar to the dyadic model, because there are the same functions of plants in the network model. All of the plants in Type E are located in the same place, thus Type E don't have the transportation operation planning problem.

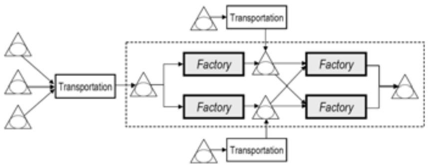

Fig. 7 Multi site conceptual model of Type E

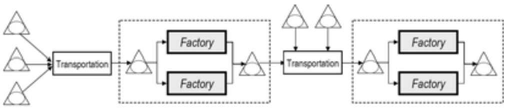

Fig. 8 Multi site conceptual model of Type F

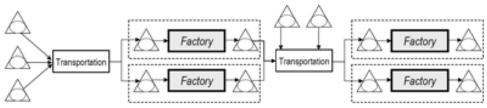

Fig. 9 Multi site conceptual model of Type G

The multi-site conceptual model of Type F is as showed in Fig. 8. The upstream and downstream plants are located in the different places geographically. Therefore, it needs to employ the transportation operations to transfer the semi-finished goods from upstream to downstream plants.

The multi-site conceptual model of type G is as showed in Fig. 9. All of the plants in Type G are located in the different places, thus there have the transportation planning among plants. And the materials are directly delivered to the local warehouses of different plants which is similar to Type D. The production planners must to decide the allocation problem of materials among warehouses.

C. Product structure (bill of manufacturing)

In multi-site production planning problems, the product structure will influence the manufacturing routings of products among plants. In instance, if the product structure is simpler, then this product can be finished by a single plant. Otherwise, the product will be finished through multiple plants. Hence it will result in the multi-site planning problem. This problem needs to decide the multi-site production plan in terms of time, quantity in each plant and order (production) allocation decisions among multiple plants. Therefore the planners must understand the product structures before engaging in the multi-site planning problem. The various product structures will bring about a variety of multi-site planning problems.

D. Production strategy

Due to the environmental evolution, the production strategy has been changed from mass production- oriented to customer-oriented. The production-oriented strategy pursues the mass production in order to reduce the unit production cost. But the customer-oriented strategy changed the direction to achieve the target of fulfilling the customer demands. Therefore the production strategy has gradually changed from "make-to-stock" to "make-to-order". The customer-oriented strategy adopts the customization approach to fulfill the customer demands. The customization strategy will influence the stock points in the supply chain and business production management.

The degree of customization is decided by the decoupling point (DP). The DP will divide two categories of production strategy, one is forecast-driven, and the other is order-driven production strategy. The production operations in the upstream plants of the DP are according to the forecast demands. But in the downstream plants of the DP, the production operations are driven by customer orders.

Simchi *et al*. [3] describe the decoupling point as the concept of the "push-pull boundary". They employ the concept of the push-pull boundary to divide the production structure into "push supply chain" and "pull supply chain".

For example, as shown in Fig. 10, the production environment in front of the DP is the "push multi-site" environment, and after the DP the production environment is the "pull multi-site". The transportation operations are in the "pull multi-site" production environment. In this production structure, the semi-finished goods will be finished by "push multi-site", and then those will be stored in the warehouses owned by those plants. The production operations in "pull multi-site" are driven by customer orders. The "pull multi-site" planning will consider the multiple constraints, e.g., capacity constraints, material supplying constraints, and transportation constraints, etc. When receiving the customer orders, the "pull multi-site" acquires the semi-finished goods through transportation operations from the upstream warehouses of plants and starts to produce demand products.

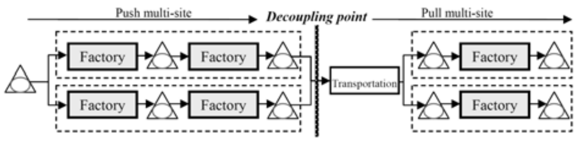

Fig. 10 The first example of the decoupling point

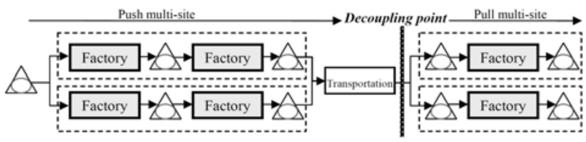

Fig. 11 The second example of the decoupling point

Fig. 11 shows the other example, the production environment in front of the DP is the "push multi-site" environment, and after the DP the production environment is the "pull multi-site". The transportation operations are in the "push multi-site". Thus after the production in the "push multi-site", the semi-finished goods directly deliver to the local warehouses of the downstream plants ("pull multi-site"). The "pull multi-site" doesn't have order or material allocation problems.

We review the related literatures:

- *External (serial) multi-site, considering transportation planning*

Huang [4] addressed the external (serial) multi-site structure model and considered the transportation planning operations among plants. The multi-site environment focuses on the Array and Cell processes in the TFT-LCD industry.

- *External (serial) multi-site, not considering transportation planning*

Gnoni et al. [5] studied the external (serial) multi-site model in the automobile industry. This paper planed that how many quantity will be produced in every production period of each plant in the multi-site environment. The goal is to achieve the balance between supply and demand.

- *Dyadic (parallel) multi-site, considering transportation planning*

Timpe and Kallrath [6] discussed the dyadic (parallel) multi-site model in the chemical industry. The multi-site model considered the transportation planning. The plants have the same manufacturing processes so that they can produce the same products. And these plants have the complementary relationship. All plants can independently produce the products from raw materials to finished goods. These plants are located in Europe, the Unite States and Asia. The planners must decide which products or what quantities will be delivered to other sales regions to sell.

- *Dyadic (parallel) multi-site, not considering transportation planning*

Moon et al. [7] proposed the dyadic (parallel) multi-site model and this category don't consider the transportation planning among plants. The transportation activity planning considered in this paper is the transmission of products between machines within a certain plant or plants for a quite short time.

- *Network multi-site, considering transportation planning*

Jang et al. [8] depicted the network multi-site model and the model incorporates transportation planning. The authors define the elements of the multi-site structure are plant (P), warehouse (W), distribution (D) and customer (C). They divided the network multi-site model into P-P-P model, P-P-W model and W-D-C model for discussion. For example, the P-P-W model decided the production quantity in each plant, stock quantity in each warehouse and transportation quantities between sites.

- *Network multi-site, not considering transportation planning*

Leachman et al. [9] addressed the network multi-site model in the semiconductor industry. This network multi-site structure includes five manufacturing processes: wafer fabrication, wafer probe, assembly, initial test and finial test. These five segments are located in different plants. And they have the sequential relationship. The authors employ the IMPReSS (Integrated Manufacturing Production Requirement Scheduling System) to plan the semiconductor multi-site planning problem. The IMPReSS divided five modules: test requirements planner, die requirements planner, front-end requirements planner (capacitated loading and allocation to back ends), back end capacitated loading, and availability calendar.

E. Manufacturing capability and characteristics

Every plant based on different products and production strategies has the different manufacturing facilities and production characteristics. The manufacturing process generally can be divided three types: flow shop manufacturing, job shop manufacturing and fixed site manufacturing. The multi-site production planning will be influenced by the above-mentioned manufacturing process and production strategy.

Each product has the different production characteristics and manufacturing lead time. There will also have distinct qualities of the same products due to different machines whose functions are the same. Even though the plants have the same manufacturing process or machines, the qualities of products will be different. For example, two plants have the same production processes but they are located in different places geographically. They will produce the different qualities of products. Therefore, the planners need to understand the manufacturing capability and characteristics of each plant before engaging in the multi-site production planning problem.

F. Production constraints

The production constraint is one of the major factors to influence the multi-site planning. The production constraints can be classified as the hard constraints and soft constraints. The hard constraint is defined it can not be violated, for example, the arrival time of materials, capacity usage constraints etc. And the soft constraint is defined it can be released or violated flexibly if necessary, e.g., the due date of products. Thus the production planning constraints in the different industries are distinct. Every industry has own specific constraints.

G. Performance indicators

Performance indicators are the target of multi-site production planning problem. The performance indicators selected depend on the various industries and production environments. In the past literatures, the performance indicators can be divided four categories: Due Date, Flow Time, Work Center Utilization and Cost.

The target pursued of the multi-site planning problem in the literatures is almost to minimize the total costs. The costs include the production cost, the set-up cost, the inventory holding cost, and the transportation cost etc. The researches whose targets are to maximize profits or to minimize the tardiness time are few. If the target is to minimize the total costs, most of the planning methods in the past researches are the mathematic programming or operations research.

III. Case: A TFT-LCD Manufacturer

In this section, we take a practical example of a TFT-LCD (Thin Film Transistor-Liquid Crystal Display) manufacturer in Taiwan to illustrate our proposed analytical framework of the

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:4, No:5, 2010

multi-site planning problem. First, we give the background description. And then, we explain sequentially the six elements of the framework by means of the TFT-LCD industry.

A. The background description

A TFT-LCD manufacturing process consists of three main sub-processes: Array, Cell and Module processes. Each process may have more than one factory, constituting a multi-site manufacturing environment. And the planning system of each process has different planning goals.

B. The analysis of the multi-site planning problem in the TFT-LCD industry

In this subsection, we explain sequentially the six ingredients of the analytical framework by means of the TFT-LCD industry.

- Multi-site conceptual model

The multi-site conceptual model in TFT-LCD industry is the "network" multi-site model. The former plants of the TFT-LCD manufacturer illustrated here, Array and Cell manufacturing processes, are located in Taiwan, and these different generation plants are in the different places geographically. The latter plants, the Module process, is in China, therefore the transportation planning operations between Cell and Module plants is an important problem.

- Product structure (bill of manufacturing)

The Array process is very similar to semiconductor wafer fabrication except the material components. The raw material of Array process is the glass substrate which must be processed 5-7 times through cleaning, coating, exposure, developing, etching, and strip, etc.

The Cell process is the special step in TFT-LCD manufacturing, in which two components, Color Filter and TFT will be processed through cleaning, alignment, layer printing and rubbing. Then Color Filters will be added on the seal and be appended to TFT. After assembling, the liquid crystal will be injected into the panel. The former structure in Cell process is the parallel production lines, TFT and Color Filter processes respectively, and the production structure becomes the special-purpose lines after the partition operations.

The Module process is the last stage of TFT-LCD manufacturing process where the TFT-LCD panels are assembled with all the necessary parts such as black lights, ICs, and PCBs, to complete the final TFT-LCD products. Thus basically, the Module process is the assembly production lines.

- Production strategy

The production strategy in the TFT-LCD industry should adopt the assembly-to-order (ATO) strategy after the discussion with the managers in this company because of the factors of product structures, manufacturing characteristics and a variety of customer demands. The Array and Cell manufacturing processes should be the make-to-stock (MTS) strategy and the Module manufacturing process should be the make-to-order (MTO) strategy.

- Manufacturing capability and characteristics

The bottleneck processes almost occur in the Array and Cell plants for the TFT-LCD manufacturing. Because the gradual improvement of the TFT-LCD manufacturing technology, it will result in the production constraints in the different generation factories, for example, the products with 15 inches only can be produced in some specific plants but 17 inches ones are unrestricted. Therefore, when engaging in the multi-site production planning, the planners must consider the manufacturing capability in each plant and what products which plants are able to produce.

- Production planning constraints

There are so many production planning constraints in the TFT-LCD industry, including the capacity's constraint of each plant, the capacity's constraint for each product in a certain plant, key materials' constraint, etc. [10]

- Performance indicators

In general, the performance indicators in the TFT-LCD industry are to minimize the total related costs, average tardiness time of forecast orders, average tardiness time of customer orders, and average setup time of orders, etc.

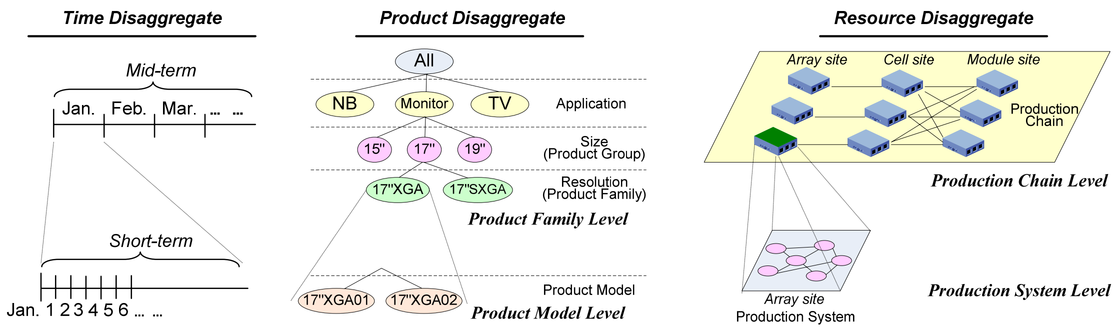

Fig. 12 Disaggregation mechanism of hierarchical planning for TFT-LCD industry

C. Hierarchical Planning for TFT-LCD industry

The planning model for TFT-LCD industry is the hierarchical framework. As Fig. 12 shows, the disaggregation mechanism in this hierarchical framework can be described as time disaggregation, product disaggregation and resource disaggregation.

D. The mathematical model

Generally, the sales department receives the future monthly forecast demands (e.g., six months). The forecast demands of the different customers are aggregated according to the various TFT-LCD products. Then, the personnel in the production planning department allocate the forecast demands to the multiple plants by the respective months.

Allocation decisions among multi-plant are made in terms of established decision criteria (i.e., the related costs), for example, production costs, products inventory costs, key materials purchase costs, and transportation costs between factories and distribution centers. Other decision considerations include the capacity constraints in each plant, key materials' supplying constraints and the constraints of manufacturing process's paths.

The multi-site planning model can be formulated by the mathematical programming considering multiple practical planning characteristics and constraints. Here, the linear programming (LP) model is illustrated, as follows:

- *Indices*：

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.

- *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 for production at plant i in period t.
$unit_{ip}$= the 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.

- *Decision variables*：

Q_{ipt}= production amounts of product p at plant i in period t.
B_{ikt}= purchase amounts of raw 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.

- *Objective function*：

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 (1) is to minimize the above-mentioned total costs.

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

- *Constraints*：

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

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

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

$$I_{ipt} = I_{ip,t-1} + \left(QF_{ipt} + QP_{ipt}\right) + U_{ipt} - U_{ip,t-1} - d_{ipt} \tag{5}$$

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

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

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

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

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

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

Constraints (2)–(3) indicate the production features in the TFT-LCD manufacturing process. Due to the lengthy manufacturing lead time, e.g., 5-7 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. Note that the term "unit" means the production unit. The production unit in the Array process is a "cassette (or lot)" that includes about 20 glass substrates. After entering the Cell process, a glass substrate is split into six or eight pieces through partition operation. They are split 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 a process is called “a piece”. Finally, the production unit in the Module process is “a piece”, i.e. the size of the 17” or 19” products.

Constraint (4) is the balanced equation for the inventory of products in every production stage, except for the last stage. Constraint (5) is also the balanced equation for the inventory of products; however, it is for the last production stage, considering demands of products for customers and backorder status. Constraint (6) is the balanced equation for the inventory of raw materials.

Constraint (7) is the balanced equation 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 (8) is the available capacity constraints. Every plant has its own capacity limitation because of the finite and expensive machines. Constraints (9)–(10) are the non-negativity restrictions on the decision variables.

IV. Conclusion

In this paper, we propose the structural framework to analyze the multi-site production planning problems. The analytical framework is composed of six elements: multi-site conceptual model, product structure (bill of manufacturing), production strategy, manufacturing capability and characteristics, production planning constraints, and key performance indicators. Through this analytical framework, we can describe multi-site production problems more thoroughly. As well as the discussion of these six ingredients, our contribution also reviews related literatures to match our analytical framework. Finally we take a real-world practical example of a TFT-LCD manufacturer in Taiwan to illustrate our proposed analytical framework for the multi-site planning problems.

Acknowledgment

The author gratefully acknowledge the National Science Council, Taiwan, R.O.C., for support under contract No. NSC 97-2221-E-150-080-MY2.

References

[1] G. Thierry, P. Besnard, D. Ghattas, and G. Bel, “Multi-Site Planning:Non Flexible Production Units and Setup Time Treatment,” *ETFA '95 Proceedings*, 1995 INRIA/IEEE Symposium, vol. 3, 1995, pp. 10–13.

[2] A. Guinet, “Multi-site planning: a transshipment problem,” *International Journal of Production Economics*, vol. 74, 2001, pp. 21–32.

[3] L. D. Simchi, P. Kaminsky, and L. E. Simchi, *Design and managing the supply chain*, McGraw-Hill, 2003.

[4] C. C. Huang, *Multi-Site Planning and Scheduling for TFT-LCD Manufacturing Industry*, the Master thesis in Department of Industrial Engineering and Engineering Management at National Tsing-Hua University, Taiwan, 2003.

[5] M. G. Gnoni, R. Iavagnilio, G.. Mossa, G.. Mummolo, and A. D. Leva, “Production Planning of a Multi Site Manufacturing System by Hybrid Model: A Case Study from the Automotive Industry,” *International Journal of Production Economics*, vol. 85, 2003, pp. 251–262.

[6] C. H. Timpe, and J. Kallrath, “Optimal planning in large multi-site production networks,” *European Journal of Operational Research*, vol. 126, 2000, pp. 422–435.

[7] C. Moon, J. Kim, and S. Hur, “Integrated process planning and scheduling with minimal total tardiness in multi-plants supply chain,” *Computers & Industrial Engineering*, vol. 43, 2002, pp. 331–349.

[8] Y. J. Jang, S. Y. Jang, B. M. Chang, and J. Park, “A combined model of network design and production/ distribution planning for a supply network,” *Computers & Industrial Engineering*, vol. 43, 2002, pp. 263–281.

[9] R. C. Leachman, R. F. Benson, C. Liu, and D. J. Raar, “IMPReSS: An Automated Production-Planning and Delivery-Quotation System at Harris Corporation — Semiconductor Sector,” *Institute for Operation Research and the Management Sciences*, 1996.

[10] J. T. Lin, and Y. Y. Chen, “A Multi-site Supply Network Planning Problem Considering Variable Time Buckets- A TFT-LCD Industry Case,” *International Journal of Advanced Manufacturing Technology*, vol. 33, 2007, pp. 1031–1044.