The Medium-Term Capacity Planning Problem for TFT-LCD Industry: An Application of Fuzzy Bilevel Programming

Yin-Yann Chen

***Abstract*—In this paper, the strategic single-stage multi-plant capacity planning issues for TFT-LCD panel industry is discussed. The TFT-LCD panel manufacturing is divided into array, cell, and module process. As the array has long production lead time, huge capacity expansion costs, array process becomes a bottleneck in the TFT-LCD manufacturing process. Therefore, how to determine the time point of capacity expansion and capacity allocation decisions will be an important issue. This paper uses bilevel programming to split this capacity problem into two levels (inventory and production), and applies fuzzy approach to solve it. Finally, through practical examples to illustrate the feasibility of fuzzy bilevel programming, and compared with the fuzzy mathematical programming. The results show that when production environment have hierarchical characteristics, applying fuzzy bilevel programming, the performance index for capacity planning is better.**

***Index Terms*—TFT-LCD, capacity planning, bilevel programming, fuzzy approach.**

I. Introduction

The manufacturing process of TFT-LCD panel industry comprises three major stages, namely, the array, cell and module processes. In each stage, there exist more than one production factories with different technological generations to constitute a complicated multi-site manufacturing environment. The front-end array process, the critical bottleneck in the three processes, is similar to the semiconductor fabrication process, the only difference being that the thin-film transistors are placed on the glass substrate instead of the silicon wafer. The cell process joins the array substrate with a color filter substrate, inserts the liquid crystal between the two substrate layers, and cuts the combined substrate into the various sizes of LCD panels. The back-end module process involves taking the LCD panel and bonding the driver integrated circuits, and assembling backlights, metal frame and other components to form the finished TFT-LCD panels. Since the bottleneck process, array stage, is the capacity-oriented and capital-intensive environments that emphasize the high utilization of machines and reduce the loss of capacity, how to effectively procure, utilize, and align their production capacity across multiple sites is a crucial issue for the TFT-LCD industry. Consequently, this paper only focuses on the capacity allocation and expansion problem under single-stage and multi-site structures.

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

The purposes of this paper are described as follows.

- This paper discusses the medium-term capacity planning focusing on the array process in the TFT-LCD production chain, the optimal capacity configuration and the best capacity expansion methods are proposed when the demand is greater than the supply.
- Given that the demand in the future is fixed, this paper considers the features and constraints of array process, the fuzzy message transmission of different manufacturing plants and the hierarchy in the production environment, a mathematical model with bilevel programming is built and solved by fuzzy approach.
- Through the actual case in the TFT-LCD panel industry, the feasibility of capacity planning method proposed in this paper is verified, and the differences by comparing it with the fuzzy mathematical programming are also analyzed.

II. Research Method

This paper uses bilevel programming to formulate a mathematical model for the medium-term capacity planning problem ([1][2][3][4]), whose planning model is described as follows:

A. Indices

H High level- fuzzy mathematical programming
L Low level- fuzzy mathematical programming
B Bilevel Programming
F Fuzzy mathematical programming
S Single optimal model
i Index for production site $(i = 1,2,\ldots,I)$
p Index for product group $(p = 1,2,\ldots,P)$
t Index for planning time period $(t = 1,2,\ldots,T)$

B. Parameters

- *Demand-Related Parameters*

d_{pt} The demand forecast of product group *p* in period *t* (piece)
po_p The estimated phase-out time of product group *p*

- *Cost-related parameters*

bc_{ipt} The expansion cost for purchasing one auxiliary tool of product group p at site i in period t

hc_{ipt} The unit holding cost for the inventory for product group k at site i in period t (per piece)

pa_{ip} The unit penalty cost for surplus capacity of product group p at site i (per sheet)

pw_i The unit penalty cost for total surplus capacity of site i (per sheet)

tc_{ipt} The unit transportation costs for product group p at site i in period t (per piece)

sc_{pt} The unit shortage costs for product group p in period t (per piece)

vc_{ipt} The unit variable production cost for product group p at site i in period t (per sheet)

- *Manufacturing-related parameters*

cp_{ip} The capacity consumption rate of product group p at site i (per sheet)

cl_i The consumption capacity for change different product group's mask at site i (per sheet)

cr_{ip} The economic cutting ratio of product group p at site i (pieces/sheet)

ml_{ip} The minimum production lot for product group p at site i (sheet)

ye_{ipt} The yield rate of product group p at site i in period t (per sheet)

- *Production-related parameters*

ca_{ipt} The initial capacity of a product group p at site i in period t (sheet)

cw_{it} The total capacity of each site i in period t (sheet)

ea_{ip} The capacity expansion capability for product group p at site i. (If ea_{ip} =1, site i has a capability to expand capacity of product group p ; if ea_{ip} =0 , site i has no capability)

el_{ipt} The upper bound of expansion capacity for product group p at site i in period t (sheet)

elt_{ip} The expansion capacity lead time for product group p at site i

euc_{ip} The unit expansion capacity to purchase one auxiliary tool of product group p at site i (per auxiliary tool)

- *Interest rate-related parameters*

r Interest rate per period

C. Decision Variables

- *Objective-related variables*

Z_{TIRC} Total present value of related cost for inventory

Z_{TPRC} Total present value of related cost for production

Z_{OC} Total present value of operational cost

- *Demand-related variables*

TP_{ipt} The transportation quantity of product group p at site i in period t (unit: piece)

SV_{pt} The stockout quantity of product group p in period t (unit: piece)

- *Capacity expansion-related variables*

EP_{ipt} The purchasing amount for the new auxiliary tool for expanding the capacity of product group p at site i in period t

- *Capacity configuration-related variables*

Y_{ipt} The product-mix decision for product group p at site i in period t (If Y_{ipt} =1, site i produces the product group p; if Y_{ipt} =0, site i does not produce the product group p)

XI_{ipt} The production input quantity for product group p at site i in period t (unit: sheet)

SA_{ipt} The surplus capacity for product group p at site i in period t (unit: sheet)

SW_{it} The total surplus capacity for site i (unit: sheet)

HP_{ipt} The inventory quantity of product group p at site i in period t (unit: piece)

D. The Objective Function of Fuzzy Bilevel Programming

The objective function can be divided into high level and low level based on the features of bilevel programming. The objective function of each level is described as follows:

- *Objective function for high level fuzzy mathematical programming*

$$\underset{TP_{ipt},HP_{ipt},SV_{pt}}{Min} \quad Z_{TIRC} = \sum_t \left[\left[\sum_i \sum_p \left(hc_{ipt} \times HP_{ipt} \right) + \sum_i \sum_p \left(tc_{ip} \times TP_{ipt} \right) + \sum_p \left(sc_{pt} \times SV_{pt} \right) \right] \times \frac{1}{(1+r)^t} \right] \quad (1)$$

In this research, the objective function for high level fuzzy mathematical programming in the bilevel programming model refers to the minimum total present value of related cost for inventory during the planning horizon. The related cost for inventory in each period includes the inventory holding cost, the transportation cost and shortage cost. The related cost for inventory is multiplied by P/F factor in this period, it equals to the present value of the related cost for inventory for the period.

- *Objective function of low level fuzzy mathematical programming*

$$\underset{\substack{XI_{ipt},SW_{it},\\ SA_{ipt},EP_{ipt}}}{Min} \quad Z_{TPRC} = \sum_t \left[\left[\sum_i \sum_p \left(vc_{ipt} \times XI_{ipt} \right) + \sum_i \left(pw_i \times SW_{it} \right) + \sum_i \sum_p \left(pa_{ip} \times SA_{ipt} \right) \right. \right. \quad (2)$$

$$+\sum_i \sum_p \left[\frac{bc_{ipt} \times EP_{ipt}}{po_p - t + 1} \times \left[\min(po_p, T) - t + 1 \right] \right] \Bigg] \times \frac{1}{(1+r)^t} \Bigg]$$

The objective function of low level fuzzy mathematical programming in the bilevel programming model refers to the minimum total present value of related cost for production during the planning horizon. The related cost for production in each period includes variable production cost, penalty cost of surplus capacity, penalty cost of surplus capacity for product group, and cost of expanding capacity. The related cost for production is multiplied by P/F factor in this period, it equals to the present value of the related cost for production for the period.

- *Objective function of bilevel programming*

$$Min \quad Z_{OC} = Z_{TIRC} + Z_{TPRC} \qquad (3)$$

The objective function of the bilevel programming model in this paper refers to the minimum total present value for the operational costs in the planning horizon. The total present value of operational costs includes total present value of related cost for inventory in high level and that for production in the low level.

A. The Objective Function of Single Optimal Model and Fuzzy Mathematical Programming

$$Min \quad Z_{OC} = \sum_t \Bigg[\Bigg[\sum_i \sum_p \left[\frac{bc_{ipt} \times EP_{ipt}}{po_p - t + 1} \times \left[\min(po_p, T) - t + 1 \right] \right] + \sum_i \sum_p \left(hc_{ipt} \times HP_{ipt} \right)$$
$$+ \sum_i \sum_p \left(tc_{ip} \times TP_{ipt} \right) + \sum_p \left(sc_{pt} \times SV_{pt} \right) + \sum_i \sum_p \left(vc_{ipt} \times XI_{ipt} \right)$$
$$+ \sum_i \left(pw_i \times SW_{it} \right) + \sum_i \sum_p \left(pa_{ip} \times SA_{ipt} \right) \Bigg] \times \frac{1}{(1+r)^t} \Bigg] \qquad (4)$$

B. Common Constraints

- *Capacity expansion and capability constraint*

$$EP_{ipt} \le M \times ea_{ip} \qquad \forall i, p, t \qquad (5)$$

- *Lead time constraint*

$$EP_{ipt} = 0 \qquad \forall i, p, t \le elt_{ip} \qquad (6)$$

- *The upper bound constraint for capacity expansion*

$$\sum_{t'=1+elt_{ip}}^{t} EP_{ipt'} \times euc_{ip} \le el_{ipt} \quad \forall i, p, t > elt_{ip} \qquad (7)$$

- *Production capability constraint*

$$XI_{ipt} \le M \times Y_{ipt} \qquad \forall i, p, t \qquad (8)$$

- *Production batch size constraint*

$$XI_{ipt} \ge ml_{ip} \times Y_{ipt} \qquad \forall i, p, t \qquad (9)$$

- *Total capacity constraint of each site*

$$\sum_p \left(cp_{ip} \times XI_{ipt} \right) + SW_{it} = cw_{it} - \left[\left(\sum_p Y_{ipt} \right) - 1 \right] \times cl_i \qquad \forall i, t \qquad (10)$$

- *Capacity constraint of each product group at each site*

$$XI_{ipt} + SA_{ipt} = ca_{ipt} + EA_{ipt} \qquad \forall i, p, t \qquad (11)$$

- *The actual output constraint of each product group at each site*

$$XO_{ipt} = XI_{ipt} \times cr_{ip} \times ye_{ipt} \qquad \forall i, p, t \qquad (12)$$

- *Demand satisfaction constraint*

$$\sum \sum (XI_{ipt} \times cr_{ip} \times ye_{ipt}) = \sum d_{pt} \qquad \forall p \qquad (13)$$

- *Inventory balance constraints*

$$HP_{ipt} = XI_{ipt} \times cr_{ip} \times ye_{ipt} - TP_{ipt} \quad \forall i, p, t = 1 \qquad (14)$$

$$HP_{ipt} = HP_{ip(t-1)} + XI_{ipt} \times cr_{ip} \times ye_{ipt} - TP_{ipt} \ \forall i, p, t > 1 \qquad (15)$$

- *Transportation balance constraints*

$$\sum_i TP_{ipt} + SV_{pt} = d_{pt} \quad \forall p, t = 1 \qquad (16)$$

$$\sum_i TP_{ipt} - SV_{p(t-1)} + SV_{pt} = d_{pt} \quad \forall p, t > 1 \qquad (17)$$

- *Shortage constraint*

$$SV_{pt} = 0 \qquad \forall p, t = T \qquad (18)$$

- *Domain constraints*

$EP_{ipt} \ge 0 \quad \forall i, p, t$, are integer (19)

$Y_{ipt} \ge 0 \quad \forall i, p, t$, are binary (20)

$$XI_{ipt}, HP_{ipt}, SA_{ipt}, TP_{ipt}, SW_{it}, SV_{pt} \ge 0 \ \forall i, p, t \qquad (21)$$

III. RESULTS AND CONCLUSION

In this paper, the fuzzy approach for bilevel integer programming problem, modified from [1], is applied to solve the proposed medium-term capacity planning problem for TFT-LCD industry. Three models, the single optimal model, fuzzy mathematical programming, and fuzzy bilevel programming, are compared by the real data of a certain case company in Taiwan.

From Table 1, we can find that when the problem scale is enlarged, the fuzzy message transmission among the manufacturing plants becomes invisible and complicated due to the increase of manufacturing plants and product groups. Therefore, the total present value for operational costs in fuzzy mathematical programming is about 37.07% greater than that of single optimal model. However, the fuzzy bilevel programming takes the hierarchical characteristics of the manufacturing plants into account, then its total present value for operational cost is about 47.91% greater than that of single optimal model.

TABLE I: TOTAL PRESENT VALUE OF OPERATION COSTS IN EACH MODEL

Model / Performance index	The single optimal model	Fuzzy mathematical programming	Fuzzy Bilevel Programming
Total present value of operational cost	463,835,185	635,806,930	686,068,776
Degree of differences	0%	37.07%	47.91%

Unit: US dollars

REFERENCES

[1] O. E. Emam, "A fuzzy approach for bi-level integer non-linear programming problem," *Appl. Math. Comput*. 2006, vol. 172, pp. 62-71.

[2] D. Cao and M. Y. Chen, "Capacitated plant selection in a decentralized manufacturing environment: A bilevel optimization approach," *Eur. J. Oper. Res.* 2006, vol. 169, pp. 97-110.

[3] R. J. Kuo and C. C. Huang, "Application of particle swarm optimization algorithm for solving bi-level linear programming problem," *Comput. Math. Appl.* 2009, vol. 58, pp. 678-685.

[4] H. Shih, Y. Lai, and E. S. Lee, "Fuzzy Approach for Multi-Level Programming Problems," *Comput. Oper. Res.* 1996, vol. 23, no. 1, pp. 73-91.