Parameter-based Preemptive Objective Optimization for Solar Cell Manufacturing

Li-Chih Wang, Yu-Jie Wong and Cheng-Mei Li
Department of Industrial Engineering and Enterprise information
Tunghai University
Taichung, Taiwan, ROC

Li-Chih Wang and Shuo-Tsung Chen
Tunghai Green Energy development and management Institute (TGEI)
Tunghai University
Taichung, Taiwan, ROC

Tzu-Li Chen
Department of Information Management
Fu Jen Catholic University
New Taipei City, Taiwan, ROC

Abstract

This paper studies a preemptive objective linear programming (POLP) problem of solar cell manufacturing. Under the issues of environmental protection and depletion of the natural resources, developing renewable and green power gains a lot of attention in solar cell industry. Accordingly, the needs and production complexity of solar cell are rising up. To make a best production decision based on different considerations including minimum cost, fulfillment of customer demand, and minimum inventory, it is necessary to develop a POLP model for solar cell manufacturing. Based on a parametric processing, we solve the preemptive optimization problem of the model numerically. Finally, a solar cell industry case is illustrated to verify the applicability and feasibility of the proposed production planning model and parameter-based algorithm for the preemptive objective optimization.

Keywords
Preemptive, solar cell, parametric, optimization

1. Introduction
Production planning plays a vital role in operations management for many manufacturing environment. Florian and Klein (1971) studied a deterministic production planning problem with concave costs and present a simple dynamic programming algorithm for the problem. Jagannathan and Rao (1973) extended Florian and Klein's results to a more general function which is neither convex nor concave. Swoveland (1975) considered a single product production planning problem over a finite planning horizon. The demands in each period are known and the holding cost and backorder cost are considered. Gfrerer and Zapfel (1995) considered two-level hierarchical production planning model under demand uncertainty. Smith and Zhang (1998) considered a production planning problem over the infinite horizon in a system with time-varying convex production and inventory holding costs and the demand is deterministic at each period. Feng and Gao (2006) proposed a type of multiple product and multiple period production planning model based on two-stage fuzzy optimization method to solve a production planning problem which includes fuzzy variable coefficients. Chritou *et al*. (2007) studied a hierarchical production planning for multi-product lines in the beverage industry. Wu and Chien (2008) developed a decision framework in which preference over vendors at strategic level and order allocations at operational level can be integrated.

Under the issues of environmental protection and depletion of the natural resources, developing renewable and green power gains a lot of attention in solar cell industry. Accordingly, the needs and production complexity of solar cell are rising up. Wang *et al*. (2013) studies a solar cell industry scheduling problem. To dynamically adjust the number of machines, they developed a hybrid flowshop scheduling model considering dedicated machines and lot-splitting for the solar cell industry. In this study, we firstly realize characteristics of production in solar cell manufacturing. To make a best production decision for solar cell manufacturing, it is necessary to develop a POLP model based on different considerations including minimum cost, fulfillment of customer demand, and minimum inventory. By using a parametric processing, we solve the preemptive optimization problem of the model numerically. Finally, a solar cell industry case is illustrated to verify the applicability and feasibility of the proposed production planning model and parameter-based algorithm for the preemptive objective optimization. The realistic data of the industry are used as the known information in the model. Moreover, some analysis and discussion are made to verify the optimal results.

The remainder of this paper is organized as follows. Section II introduces the characteristics of solar cell manufacturing and the proposed preemptive objectives model of solar cell manufacturing. Section III optimizes the preemptive objectives of the model. Experiments are conducted to test the performance of our proposed method in Section IV. Finally, conclusions are summarized in Section V.

2. Preemptive Objectives Model for Solar Cell Manufacturing.

2.1 The characteristics of solar cell manufacturing

The solar cell manufacturing process involves six production stages. They are respectively texturing, diffusion, PSG etching, PECVD, printing, and testing/sorting. Accordingly, there exists a wafer production problem for solar industry when customers deliver purchase orders. Usually, a customer has following requirements in purchasing:

- Product color.
- Conversion efficiency distribution and average conversion efficiency.
- Percentage of good products and defective products.

2.2 Optimization problem of solar cell manufacturing

We discuss a linear programming model for the wafer production problem with the requirements in section A. First of all, some assumptions for the model are given as follows:

- Planning horizon is finite and is divided into a number of discrete periods.
- Bill of material (BOM) is not considered.
- The demand of customers may not be satisfied.
- The capacities of production facilities are limited.

The indices, known parameters, decision variables, and objectives for the linear programming model are as follows:

Indices

z: customer, $z=1,2,\dots,Z$.

c: color, $c=1,2,\dots,C$.

e: conversion efficiency, $e=1,2,\dots,E$.

g: product level, $g=1,2,\dots,G$.

j: product type, $j=1,2,...,J$.

i: wafer type, $i=1,2,...,I$.

t: time period, $t=1,2,...,T$.

Known parameters

de_{jzt} : total demand of type-j product for customer z in time period t.

ca_t : capacity of wafer production in time period t.

ae_{jzt} : average conversion efficiency of type-j product specified by customer z in time period t.

β_{ijg} : ratio of product with level g, conversion efficiency e, and color c.

γ_{ijgec} : ratio of product with level g,

fv_{jgec} : inventory of product with level g, conversion efficiency e, and color c before production.

ck_e : value of conversion efficiency e.

cp_{it} : unit cost of wafer i in time period t.

cm_t : unit cost of production in time period t.

cw_{it} : unit inventory cost of wafer i in time period t.

cs_{jzt} : unit penalty of type-j product to customer z in time period t.

cf_{jgec} : unit inventory cost of type-*j* product with level *g*, conversion efficiency *e*, and color *c*.

sp_{jzt} : price of type-*j* product to customer *z* in time period *t*.

$pg_{jgzt} = \begin{cases} 1, \text{ if customer } z \text{ orders type-} j \text{ product with level } g. \\ 0, \quad \text{otherwise.} \end{cases}$ $pc_{jczt} = \begin{cases} 1, \text{ if customer } z \text{ orders type-} j \text{ product with color } c. \\ 0, \quad \text{otherwise.} \end{cases}$

$pe_{jezt} = \begin{cases} 1, \text{ if customer } z \text{ orders type-} j \text{ product with conversion efficiency } e. \\ 0, \quad \text{otherwise.} \end{cases}$

Decision Variables

QP_t : purchasing quantity of wafer *i* in time period *t*.

QW_{ijt} : quantity of wafer *i* for producing type-*j* product.

QA_{ijgt} : quantity of product with wafer *i* and level *g* for producing type-*j* product.

QG_{ijgect} : quantity of type-*j* product with wafer *i* and level g for producing product with conversion efficiency *e* and color *c*.

QH_{it} : inventory quantity of wafer *i* after production.

QI_{jgect} : inventory quantity of type-*j* product with level *g*, conversion efficiency *e*, and color *c* after production.

QC_{jgeczt} : the quantity of product with level *g*, conversion efficiency *e*, and color *c* for customer *z*.

QS_{jzt} : shortage quantity of type-*j* product for customer *z*.

Mathematical Model

The purpose of the proposed model aims to minimize product inventory firstly and maximize profit secondly under several logistic constraints. Hence, the model is divided into two sub-models:

Sub-Model 1.

$$Minimize \;\; F_1 \equiv \sum_j \sum_g \sum_e \sum_c QI_{jgec}$$

Subject to

$$(1) QH_{i(t-1)} + QP_{it} - \sum_j QW_{ijt} = QH_{it} \quad \forall i,\ t = 2,...,T$$

$$(2) \sum_g QA_{ijgt} = QW_{ijt} \quad \forall i,\ j,\ t \quad (3) QA_{ijgt} = \beta_{ijg} \times QW_{ijt} \quad \forall i,\ j,\ g,\ t$$

$$(4) \sum_e \sum_c QG_{ijgect} = QA_{ijgt} \quad \forall i,\ j,\ g,\ t \quad (5) QG_{ijgect} = \gamma_{ijgec} \times QA_{ijgt} \quad \forall i,\ j,\ g,\ e,\ c,\ t$$

$$(6) \sum_g \sum_e \sum_c ck_e \times QC_{geczt} \geq ae_{jzt} \times \sum_{g'} \sum_{e'} \sum_{c'} QC_{g'e'c'zt} \quad \forall j,\ z,\ t \quad (7) \sum_g \sum_e \sum_c QC_{geczt} + QS_{zt} = de_{zt} \quad \forall j,\ z,\ t$$

$$(8) QC_{geczt} \leq pg_{jgzt} \times pc_{jczt} \times pe_{jezt} \times M \quad \forall j,\ g,\ e,\ c,\ z,\ t$$

$$(9) fv_{jgect} + \sum_i QG_{ijgect} - \sum_z QC_{jgeczt} = QI_{jgect} \quad \forall j,\ g,\ e,\ c,\ t$$

$$(10) QI_{jgect} + \sum_i QG_{ijgect} - \sum_z QC_{jgeczt} = QI_{jgect} \quad \forall j,\ g,\ e,\ c,\ t \quad (11) wq_i + QP_{it} - \sum_j QW_{ijt} = QH_{it} \quad \forall i,\ t = 1$$

$$(12) \sum_i QW_i \leq ca$$

$$(13) QP_{it}, QW_{ijt}, QH_{it}, QA_{ijg}, QG_{ijgec}, QI_{igec}, QS_{jz} \geq 0$$

Sub-Model 2.

$$Minimize \ \ F_2 \equiv \sum_z \sum_i \sum_j \sum_g \sum_e \sum_c \left(sp_{jz} \times QC_{ijgecz} \right) - \sum_j \sum_g \sum_e \sum_c \left(cf_{jgec} \times QI_{jgec} \right) - \sum_i \left(cw_i \times QH_i \right) - \sum_i \sum_j \left(cm \times QW_{ij} \right) - \sum_i \left(cp_i \times QP_i \right) - \sum_z \sum_j \left(cs_{jz} \times QS_{jz} \right)$$

Subject to

(1)-(13), and

(14) $0 \le z^* - \varepsilon \le F_1 \le z^* + \varepsilon$,

where $z^* = \min\{F_1\}$ and ε is a positive number.

3. Preemptive Objectives Optimization

In this section, we propose a parameter-based algorithm for the preemptive objective optimization of the mathematical model in section 2. The algorithm detail is as follows.

Step 1. Establish sub-model 1and sub-model 2.

Step 2. Find the optimal solution z^* of the objective F_1 in sub-model 1.

Step 3. Add a positive parameter ε into sub-model 2.

Step 4. Add inequality $0 \le z^* - \varepsilon \le F_1 \le z^* + \varepsilon$ into the constraints in sub-model 2.

Step 5. Find optimal solution of the objective F_2 in sub-model 2. If the optimal solution is obtained, finish. Otherwise, go to step 4.

The detail procedure is shown in Fig. 2.

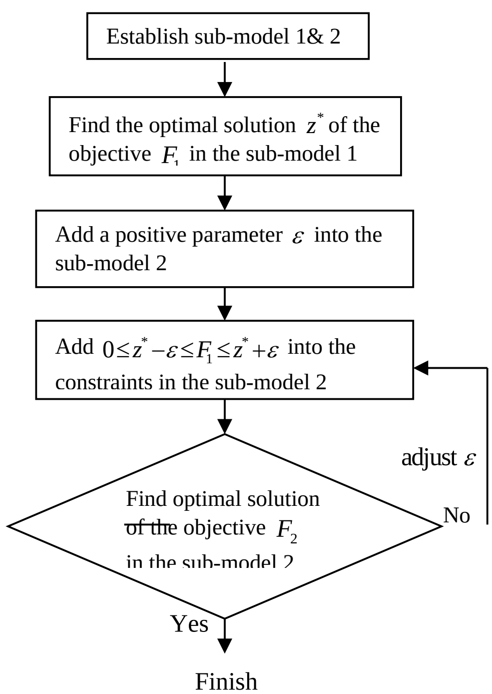

Fig. 2. The procedure of the proposed parameter-based algorithm.

4. Experimental Results

This section illustrates a solar cell industry case to verify the applicability and feasibility of the proposed production planning model and parameter-based algorithm for the preemptive objective optimization.

4.1 Known information of the proposed model

A model with two product types, two product levels, two colors, and six customers is utilized. Fig. 3 shows this model. The realistic data of the industry listed in Tables 1-3 are used as the known information in the model. The optimal results for the two objectives and the decision variables are listed in Fig. 4 by red color.

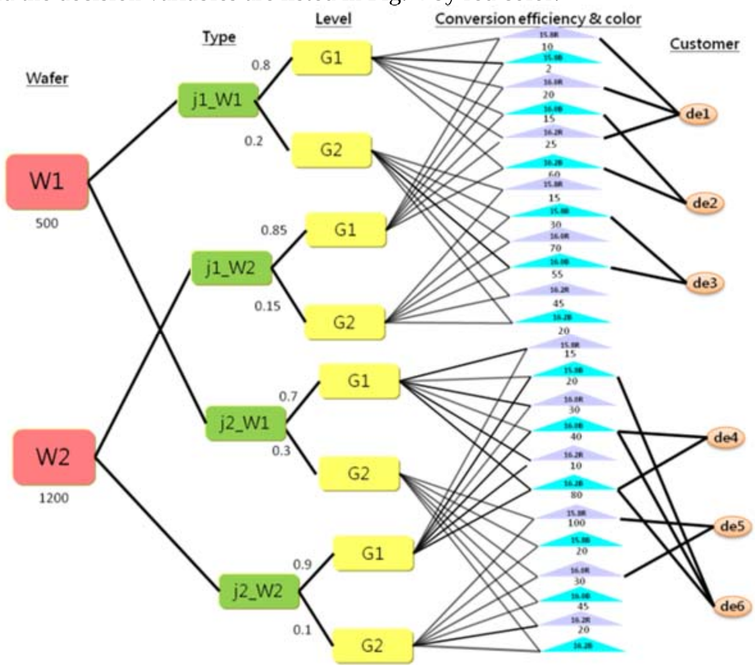

Fig. 3. The proposed model with two product types, two product levels, two colors, and six customers.

Table 1: Information of customers.

time	customer	product type	product level	conversion efficiency	average conversion efficiency	color	demand
t=1	de1	j1	G1	15.8~16.2	16	R	400
	de2	j1	G1	16.0~16.2	16	B	600
	de3	j1	G2	15.8~16.0	15.8	B	1000
	de4	j2	G1	16.0~16.2	16	B	800
	de5	j2	G2	15.8~16.0	15.8	R	500
	de6	j2	G1	15.8~16.2	16	B	1200
t=2	de1	j1	G1	15.8~16.0	15.8	B	350
	de2	j1	G1	16.0~16.2	16.0	R	800
	de3	j1	G2	16.0~16.2	16.0	B	1200
	de4	j2	G1	15.8~16.2	15.8	R	900
	de5	j2	G2	15.8~16.0	15.8	R	650
	de6	j2	G2	15.8~16.2	16.0	B	1500
…	…	…	…	…	…	…	…

t=T	…	…	…	…	…	…	…

Table 2: Information of inventory.

product type	product level	conversion efficiency	color	inventory at t=1
j1	G1	15.8	R	547
		15.8	B	283
		16	R	96
		16	B	0
		16.2	R	0
		16.2	B	0
	G2	15.8	R	109
		15.8	B	0
		16	R	116
		16	B	0
		16.2	R	82
		16.2	B	75
j2	G1	15.8	R	1271
		15.8	B	0
		16	R	449
		16	B	0
		16.2	R	638
		16.2	B	0
	G2	15.8	R	348
		15.8	B	380
		16	R	0
		16	B	403
		16.2	R	199
		16.2	B	189

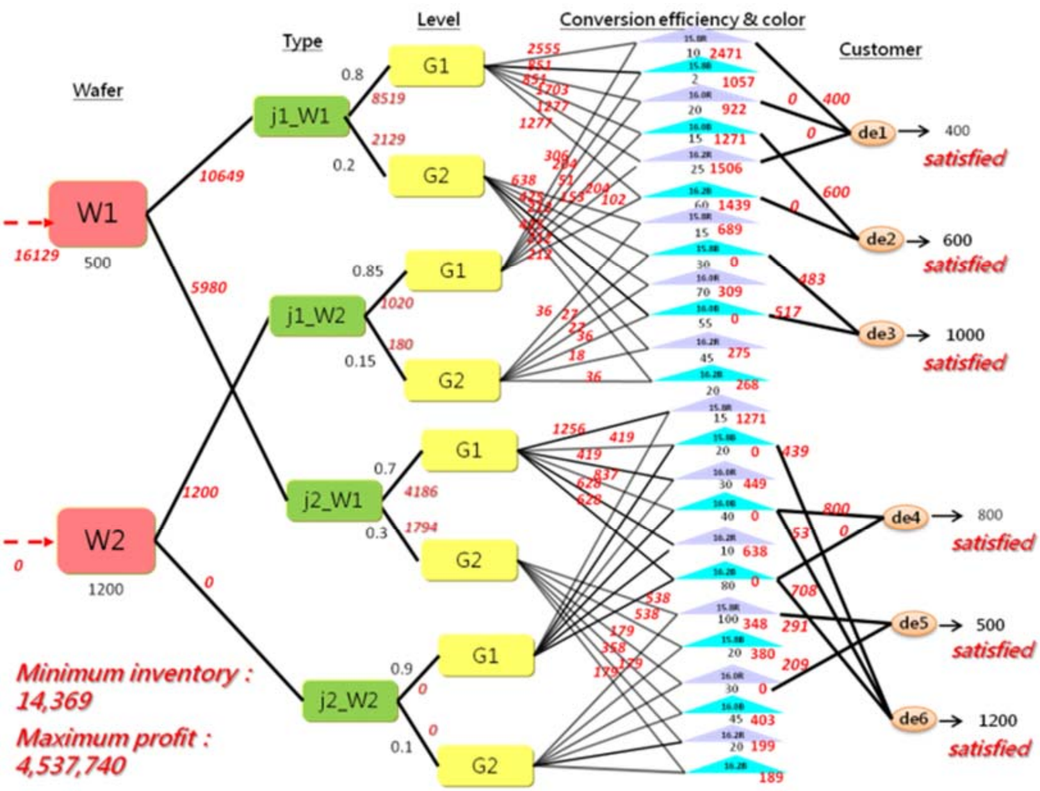

Fig. 4: Experimental results by using red color.

Table 3: Information of known parameter.

Wafer	Product type	Product level	Production ratio	Conversion efficiency	color	Production ratio
W1	j1_W1	G1	0.8	15.8	R	0.3
				15.8	B	0.1
				16	R	0.1
				16	B	0.2
				16.2	R	0.15
				16.2	B	0.15
		G2	0.2	15.8	R	0.3
				15.8	B	0.2
				16	R	0.1
				16	B	0.2
				16.2	R	0.1
				16.2	B	0.1
	j2_W1	G1	0.85	15.8	R	0.3
				15.8	B	0.1
				16	R	0.1
				16	B	0.2
				16.2	R	0.15
				16.2	B	0.15
		G2	0.15	15.8	R	0.3
				15.8	B	0.2
				16	R	0.1
				16	B	0.2

				16.2	R	0.1
				16.2	B	0.1
W2	j1_W2	G1	0.7	15.8	R	0.3
				15.8	B	0.2
				16	R	0.05
				16	B	0.15
				16.2	R	0.2
				16.2	B	0.1
		G2	0.3	15.8	R	0.2
				15.8	B	0.15
				16	R	0.15
				16	B	0.2
				16.2	R	0.1
				16.2	B	0.2
	j2_W2	G1	0.9	15.8	R	0.3
				15.8	B	0.2
				16	R	0.05
				16	B	0.15
				16.2	R	0.2
				16.2	B	0.1
		G2	0.1	15.8	R	0.2
				15.8	B	0.15
				16	R	0.15
				16	B	0.2
				16.2	R	0.1
				16.2	B	0.2

5. Conclusion

This study proposed a preemptive objective linear programming (POLP) problem of solar cell manufacturing. We develop a POLP model for solar cell manufacturing and the proposed algorithm solve the model based on minimum inventory and maximum profit. Both the model and the algorithm help planner make a best production decision based on different considerations. Finally, a solar cell industry case is illustrated to verify the applicability and feasibility of the proposed production planning model and parameter-based algorithm for the preemptive objective optimization.

Acknowledgment

This research was supported by the program of Global Research & Education on Environment and Society (GREEnS) of Tunghai University.

Reference

Florian, M. and Klein, M., "Deterministic production planning with concave costs and capacity constraints," Management Science, Vol. 18, No. 1, pp. 12-20, 1971.

Jagannathan, R. and Rao, M.R., "A class of deterministic production planning problems," Management Science, Vol. 19, No. 11, pp. 1295-1300, 1973.

Swoveland, C., "A deterministic multi period production planning model with piecewise concave production and holding-backorder costs," Management Science, Vol. 21, No. 9, pp. 1007-1013, 1975.

Gfrerer, H. and Zapfel, G., "Hierarchical model for production planning in the case of uncertain demand," European Journal of Operational Research, Vol. 86, pp. 142-161, 1995.

Smith, R. L. and Zhang, R. Q., "Infinite horizon production planning in time-varying systems with convex production and inventory costs," Management Science, Vol. 44, No. 9, pp. 1313-1320, 1998.

Feng and Gao, "A two-stage production planning model in fuzzy decision systems," World Journal of Modelling and Simulation, Vol. 2, No. 5, pp.290-296, 2006.

I. T. Chritou, A. G. Lagodimos, and D. Lycopoulou, "Hierarchical production planning for multi-product lines in the beverage industry." Production Planning and Control, Vol. 18, No. 5, pp. 367-376, 2007.

J.-Z. Wu and C.-F. Chien, "Modeling strategic semiconductor assembly outsourcing decisions based on empirical settings." Springer-Verlag: OR Spectrum, Vol.2008, No. 30, pp. 401-430, 2008.

L.-C. Wang, Y.-Y. Chen, T.-L. Chen, C.-Y. Cheng, and C.-W. Chang, "A hybrid flowshop scheduling model considering dedicated machines and lot-splitting for the solar cell industry." International Journal of Systems Science, Vol.141 No.1, pp. 66-78, 2013.

Biography

Li-Chih Wang is currently the Dean of College of Engineering, Director of Tunghai Green Energy development and management Institute and a Professor of Department of Industrial Engineering and Enterprise Information at Tunghai University, Taiwan. He earned his BS degree in Industrial Engineering from Tunghai University, Taiwan and MS and PhD degrees in Industrial and Systems Engineering from The Ohio State University, USA. Dr. Wang's current research includes green supply chain management (GSCM), advanced planning and scheduling (APS) and corporate integrated information system. He has conducted extensive research leading to the current academic and industrial projects (e.g., semiconductor, memory module, electronic assembly, TFT-LCD). Dr. Wang has published three SCM/APS related books which are widely referenced in Taiwan and numerous scholarly papers and reports in these areas. His research has been supported by both government agencies (e.g., National Science Council, Ministry of Education, Ministry of Economy) and industry (e.g., Kingston, Macronix, EverTek, Farcent).