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DEVELOPMENT AND APPLICATION OF A DECISION MODEL FOR THE INTEGRATED PRODUCTION AND MATERIAL PLANNING OF COLOR FILTER MANUFACTURING INDUSTRY: AN EMPIRICAL STUDY

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Color Filters (CF) is a critical module of TFT-LCD industry whose products are widely applied to the customer electronics products. Since the color filters manufacturing stays in the 1-tier enterprise of the supply network of the TFT-LCD industry, its logistics planning is quite complex. This paper develops a LP-based planning method to support the logistics of a color filter manufacturing company. This developed planning model focuses on the mid-term planning, considering the issues in terms of production and material requirement planning in an integrated way. For application, this developed method is implemented by the optimization software LINGO and then integrated to the database system as decision support. To test the quality of this method, 52 weeks of real factory data are studied, and the validation result shows a variation less than 10%.

Significance: This research demonstrates the methodology and experience of one Color Filter factory, and with the LINGO system to analyze all conditions and to compare with real data. This model and analysis can offer some reference to relevant industry and commercial software industry to carry on conducting in advanced planning and scheduling system (APS).

Keywords: Color Filter, Logistics Management, Collaboration, Advanced Planning Systems (APS).

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1. INTRODUCTION

TFT-LCD (Thin Film Transistor-Liquid Crystal Display) is a technology intensive as well as capital intensive industry. Its products can be widely applied to the customer electronic products, such as computers, LCD TV, mobile phone, car display, etc. Color Filter (CF) is a critical module of TFT-LCD industry and takes about 15-20% of the total cost of TFT-LCD manufacturing. For a CF manufacturing company, normally the material cost takes about 60% of the total cost and the materials must be sourced from many different suppliers with technology capability. In addition, since the CF manufacturing is the upstream of TFT-LCD manufacturing, its production plan must synchronize with the demand of the TFT-LCD manufacturing so that an efficient logistics planning is necessary. This paper develops a LP-based planning method based on the concept of Advanced Planning Systems (APS) to support the production and material planning of a color filter manufacturing company. This developed planning model focuses on the mid-term planning, considering the issues in terms of production and material requirement planning in an integrated way. This planning method is implemented by the optimization software LINGO and then integrated to the database system as decision support. This paper will be so organized: the section 2 gives an overview about the supply network of the TFT-LCD industry. A LP-based decision model for the integrated logistics planning will be developed in the section 3. The section 4 will validate this approach by a case study.

2. BUSINESS LOGISTICS OF THE COLOR FILTERS MANUFACTURING

2.1 Supply network of the color filters manufacturing

The supply network of TFT-LCD industry could be considered to be the tier of material supply, manufacturing of color filters, manufacturing of panels, TFT-LCD assembly as well as the consumer electronics company. In it, the tier of material supply includes the supply of glass panels, color resistors, target materials, general chemical materials, etc. which provide the required materials to the color filters manufacturing. The color filters and the modules produced by the panels

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manufacturing will be integrated by the TFT-LCD manufacturing, by the process of array, cell and assembly. Finally the TFT-LCD panels will be sent to the consumer electronics company. Figure 1 describes the supply network.

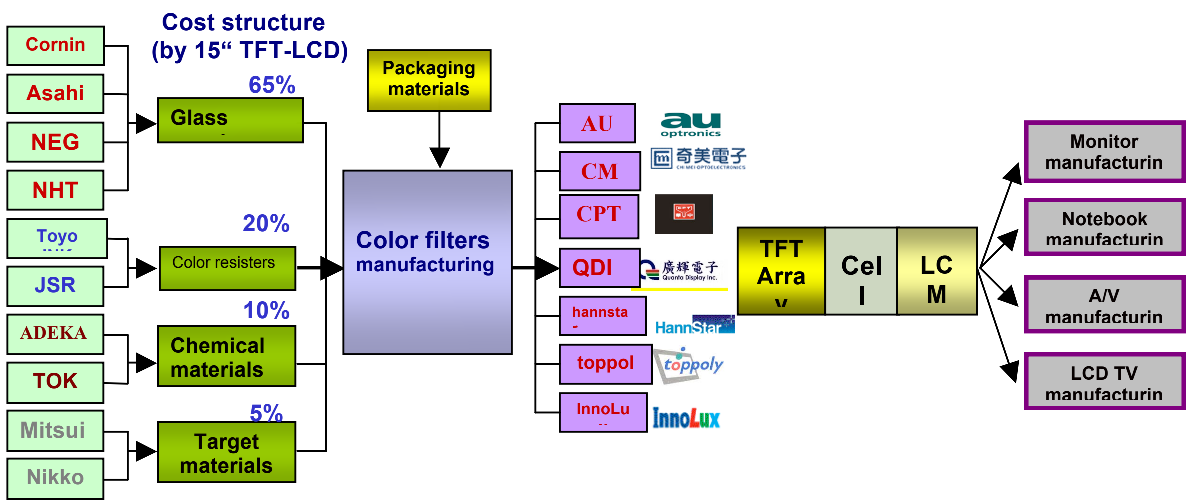

Figure 1. Supply Network of the TFT-LCD industry

Normally the color filters manufacturing takes about 25% of the total cost of TFT-LCD manufacturing, more than the cost of control IC (18%), and that of the panels (16%). Moreover, the product generation of TFT-LCD depends on the technology of color filters manufacturing. To the color filters manufacturing, the material takes about 60% of the total cost, wherein the materials have different characteristics in management. The glass panel takes 65% of its cost and has a long supply lead-time and the supply is not stable in the market. The color resisters are critical materials which are supplied by some companies from Japan. Its supply lead-time is stable, while it must be storage in low temperature condition and the expiration date must be considered. The supply of the target materials and the general chemical materials are stable, but some chemical materials must consider the expiration date.

From above, it can be seen that the materials planning plays an important role for the operations of a color filters manufacturing company. In the industrial practice, since the issues of short demand fulfillment date, different sourcing condition, supply lead-time, expiration, etc. are quite complex, many color filters manufacturing companies have problems in the coordination of production and materials planning which leads to the result of high inventory level, poor on-time demand fulfillment, poor capacity utilization, etc. so that an integrated planning solution as support is necessary.

2.2 Literature review

Bongju Jeong et al.(2002) studies the backend module assembly and its in-bound logistics of the TFTLCD industry. In this study, an ATP (Available To Promise) model is developed, yet the materials acquisition is not included into the planning model. Nagendra et al. (2001) gives a PCA model for the materials acquisition in which the materials planning is hierarchical executed based on the BOM (Bill Of Materials) and the given production plan. However, such an approach will lead to high inventory, when the production type is a job-shop one, or the production cycle-time is long. Holmström et al. (2002) and Tage Skjoett-Larsen et al. (2003) gives the concept of CPFR (Collaborative, Planning, Forecasting and Replenishment) which could be applied to the qualitative planning of the supply network planning. Hackman et al.(1989) studies the quantitative modeling of production factory, which can be extended to more complex scenarios. Bhatnagar et al. (1993) considers the supply network to be the phase of buyer-vendor coordination, production-distribution coordination as well as inventory-distribution coordination. Min, H. and Zhou, G. (2002) indicated a supply chain is referred to as an integrated system which synchronizes a series of inter-related business processes. Simchi-Levi et al. (2003) considers the key issues spans a large spectrum of a firm's activities. Jang et al. (2002) gives a planning method for the multi-tier supply network by which given the demand plan, the production-distribution planning can be accomplished. However, in this model, the issue refers to the coordination of material and production planning is not considered so that this solution could be well applied to the color filters manufacturing enterprise.

3. DEVELOPMENT OF AN INTEGRATED LOGISTICS PLANNING MODEL

In this section, an integrated planning solution for the coordination of material and production of color filters manufacturing will be developed. The planning framework is described by the figure 2.

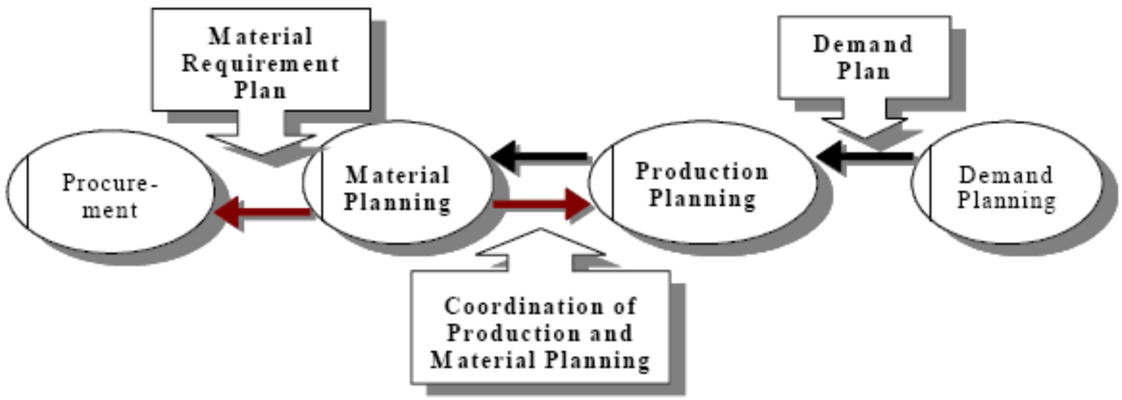

Figure 2. Solution framework of the integrated material and production planning

Based on the solution framework, the decision model is given by the following:

Index and parameters

b index of product, b =1,2,…,B

t index of planning horizon, t = 1,2,…,T

k index of color filters manufacturing fab, k = 1,2,…,K

j index of TFT-LCD manufacturing company, j= 1,2,3,…,J

u type of glass panel, u= 62×75, 68×88

m index of glass panel supplier, m =1,2,…,M

x index of color resisters, x=1,2,…,X

s index of color resisters supplier, s = 1,2,…,S

l^m supply lead time from the glass panel m to the material warehouse

g^s supply lead time from the color resisters suppliers s to the material warehouse

GA_u^m maximal supply quantity of glass panel type u from the supplier m, u ∈ {62×75, 68×88}

RA_x^s maximal supply quantity of color resisters supplier *s* for the color resisters type *x, u*∈{R,G,B}

α_u^b 1, if manufacturing of the product *b* requires the glass panel type *u*, *u*∈{62×75, 68×88}；0, else

$\beta_{k,x}^b$ material requirement of color resisters type x for the manufacturing of one unit of product type b in the manufacturing fab k, b∈B, k∈K, x∈{R, G, B}

δ_u^k 1, the manufacturing fab *k* has the manufacturing technology in terms of the glass panel *u*, *u*∈{62×75, 68×88}；0, else

CZ_k maximal manufacturing capacity of fab *k*, *k*∈K

W_k^b capacity requirement for the manufacturing of one unit of product type *b* in the fab *k*

CT_k^b production cycle time of product type *b* in the fab *k*

L^x maximal storage capacity of color resisters *x* in the material warehouse, *x*∈{R, G, B}

LT^x maximal storage period of color resister *x* in the material warehouse

LG^u maximal storage period of glass panel type *u* in the material warehouse, *u*∈{62×75, 68×88}

PG_u^m unit price of glass panel type *u* from the supplier *m, u*∈{62×75, 68×88}

PR_x^s unit price of color resisters type *x* from the supplier *s*, *x*∈{R, G, B}

IA^t maximal storage capacity of finished product

Y_k^b manufacturing yield of product type *b* in the fab *k*

$d_{b,j}^t$ order quantity with due-date t for the product type b of the down-stream TFT-LCD manufacturing company j

PP_b^t price of product type *b* in the period *t*

Decision variables

$Q_{b,k}^t$ manufacturing quantity of product type *b* in the fab *k* of the planning period *t*

I_b^t inventory of product type b of the planning period t

$E_{m,u}^t$ ordered quantity of the glass panel type u from the supplier m in the period t, u∈{62×75, 68×88}

$H_{s,x}^t$ ordered quantity of color resisters x from the supplier s in the period t, x∈{R, G, B}

IG_u^t storage quantity of glass panel type u in the material warehouse, in the end of planning period t, u∈{62×75, 68×88}

IR_x^t storage quantity of color resister x in the material warehouse, in the end of planning period t, x∈{R, G, B}

Objective function

The life cycle of TFT-LCD products is short and thus the color filters manufacturing should consider the issues of price-down as well as storage cost of the finished products inventory. The material inventory of glass panels and the color resisters should consider the storage cost, furthermore, the expiration date of the material color resisters should be well considered. Based on these considerations, a planning objective function to minimize the average inventory is formulated as the following:

$$Minimize \frac{\left[\left(\sum_{j}\sum_{u} PG_{u}^{m} \times IG_{u}^{t}\right) + \left(\sum_{t}\sum_{x} PR_{x}^{s} \times IR_{x}^{t}\right) + \left(\sum_{b}\sum_{t} PP_{b}^{t} \times I_{b}^{t}\right)\right]}{T} \quad \ldots \quad (1)$$

Constraint functions ... (2)

$$\sum_{b} Q_{b,k}^{t} * W_{k}^{b} \leq CZ_{k} , \forall b,k,t$$

$$I_{b}^{t-1} + \sum_{k} Q_{b,k}^{(t-CT_{k}^{b})} * Y_{k}^{b} \geq \sum_{j} d_{b,j}^{t} , \forall b,t \quad \ldots \quad (3)$$

$$I_{b}^{t} = \left[\sum_{k} Q_{b,k}^{(t-CT_{k}^{b})} * Y_{k}^{b}\right] - \left[\sum_{j} d_{b,j}^{t}\right] + I_{b}^{t-1} , \forall b,t \quad \ldots \quad (4)$$

$$\sum_{b} I_{b}^{t} \leq IA^{t} , \forall t \quad \ldots \quad (5)$$

$$\sum_{m} E_{m,u}^{t-l^{m}} + IG_{u}^{t-1} \geq \sum_{k} \sum_{b} Q_{b,k}^{t} * \alpha_{u}^{b} , \forall u,t \quad \ldots \quad (6)$$

$$\sum_{m} E_{m,u}^{t-l^{m}} + IG_{u}^{t-1} = \sum_{k} \sum_{b} Q_{b,k}^{t} * \alpha_{u}^{b} + IG_{t}^{u} , \forall u,t \quad \ldots \quad (7)$$

$$E_{m,u}^{t} \leq GA_{u}^{m} , \forall u,m,t \quad \ldots \quad (8)$$

$$IG_{u}^{t} \leq LG^{u} , \forall t,u \quad \ldots \quad (9)$$

$$\sum_{s} H_{s,x}^{t-g^{s}} + IR_{x}^{t-1} \geq \sum_{k} \sum_{b} Q_{b,k}^{t} * \beta_{k,x}^{b} , x \in \{\mathbf{R},\mathbf{G},\mathbf{B}\} \quad \ldots \quad (10)$$

$$\sum_{s} H_{s,x}^{t-g^{s}} + IR_{x}^{t-1} = \sum_{k} \sum_{b} Q_{b,k}^{t} * \beta_{k,x}^{b} + IR_{t}^{x} , x \in \{\mathbf{R},\mathbf{G},\mathbf{B}\} \quad \ldots \quad (11)$$

$$H_{s,x}^{t} \leq RA_{x}^{s} , \forall s,x \quad \ldots \quad (12)$$

$$IR_x^t \leq L^x \,,\, \forall t, x \qquad \cdots \qquad (13)$$

$$\alpha_u^b \geq \left(1-\delta_u^k\right) Q_{b,k}^t \,,\, \forall b, k, u, t \qquad \cdots \qquad (14)$$

$$IR_x^t \leq \sum_k \sum_b \sum_{r=t+1}^{r=t+yx} Q_{b,k}^t * \beta_{k,x}^b \,,\, x \in \{\mathbf{R},\mathbf{G},\mathbf{B}\} \qquad \cdots \qquad (15)$$

$$IG_u^t \geq 0 \,,\, \forall u, t \qquad \cdots \qquad (16)$$

$$IR_x^t \geq 0 \,,\, \forall x, t \qquad \cdots \qquad (17)$$

$$E_{m,u}^t \geq 0 \,,\, \forall u, m, t \qquad \cdots \qquad (18)$$

$$H_{s,x}^t \geq 0 \,,\, \forall x, s, t \qquad \cdots \qquad (19)$$

$$I_b^t \geq 0 \,,\, \forall b, t \qquad \cdots \qquad (20)$$

The equation (2) considers the production capacity of the manufacturing fab. The equation (3) guarantees the order fulfillment. The equation (4) describes the material flows refer to production quantity, inventory and ordered quantity of finished products. The equation (5) considers the storage capacity of warehouse for finished products. Equations (6) and (7) consider the material flow of glass panel in terms of material deployment and inventory. Equation (8) considers the supply capacity of glass panel. Equation (9) considers the storage capacity of glass panel in the material warehouse. The equations (10) and (11) consider the material flows refer to the color resisters deployment and inventory. Equation (12) considers the supply capacity of color resisters, and the storage capacity of color resisters in the material warehouse is considered by the equation (13). The technology of manufacturing fab is considered by (14). Expiration of materials is considered by the equation (15). Equations (16) to (20) make sure the decision variables are nonnegative.

4. CASE STUDY

4.1 The case

This section verifies the developed decision model by the data of a color filters manufacturing company in Taiwan. Supply network of the case company is presented by the figure 3, wherein the material supply and the down-stream TFT-LCD manufacturing are described. The case company has total 6 product types, wherein the production of each product type requires either the glass panel type 62×75 or 68×88. Two color filters manufacturing fabs of clean room class 10 are available. In it, the fab one can produce with the glass panel type 62×75, and the fab two is capable of the glass panel types 68×88 and 62×75. One warehouse with AR/RS and automated material handling system is available, which is composed of 3 parts, one is for the glass panels, and the second part is for the finished products, and the third part is a storage region with temperature 10℃ for the color resisters whose maximal expiration is 12 weeks. Three local suppliers of glass panels are available, whose supply lead time is 3 weeks, while the color resistors are imported from Japan with supply lead time 2 weeks. After the production, the finished color filters are transported to the warehouse by the third-party logistics in one week, and then are sold to six down-stream TFT-LCD manufacturing companies.

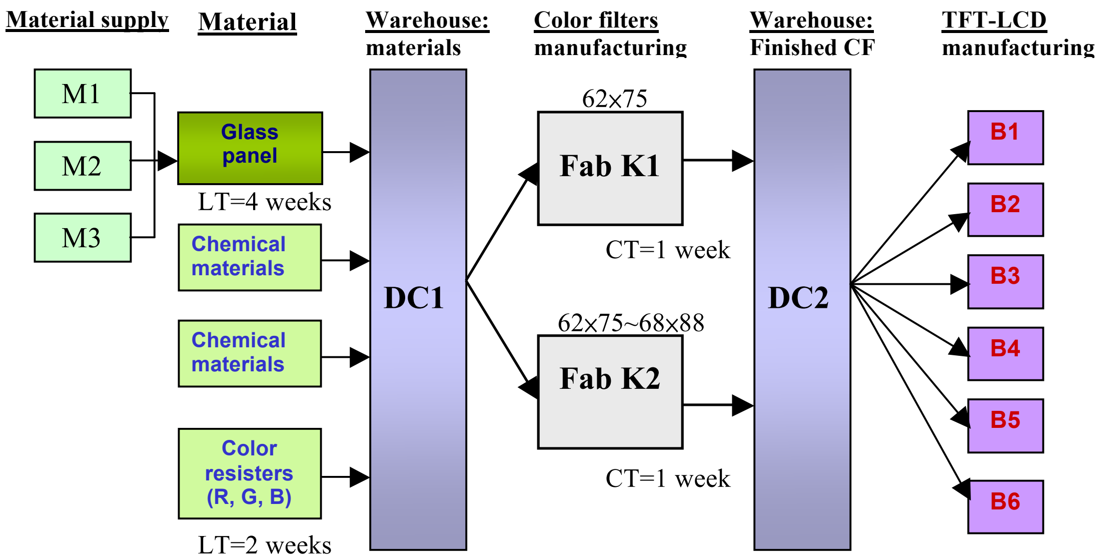

Figure 3. Supply network of the case company

4.2 Execution and analysis of results

48 weeks of planning is executed. Input data is the 48 weeks of demand planning data of the planning period 2005/06-2006/05 as well as the information refers to the supply network of the case company. The decision model developed by the section 3 is coded with the optimization software LINGO 8.0 and then integrated with the database of the case company.

After the execution, the planning results provided by the decision model are summarized and compared with the real data. Table 1 presents the comparison in terms of the object function, and the result shows a significant difference. The reason is that the case company has the safety inventory, while the decision model does not consider the issue.

Table 1. Comparison of planning result: average inventory

	Average inventory
Model	$7,827,666
Real	$140,080,592

The planning results provided by the decision model in terms of all decision variables are summarized and compared with real data. Figures 5-6 present the comparisons. In the figure 5, the production plan of fab 1 provided by the decision model and that of the real data are compared. In the comparison, one can see that for the most planning weeks the production quantity of real data is more than that provided by the decision model. The reason is that in the real case the fab 1 has the safety inventory policy of production. The manufacturing fab 2 does not have the safety inventory policy, so the production plan provided by the decision model is more stable (Figure 6). Another reason for the difference is that the planning result provided by the decision model is an integrated one, wherein the production capacity of the two available manufacturing fabs are allocated in an integrated manner considering the comparative advantages and the technology capability, however, in the real case the production planning of the fabs are considered independently.

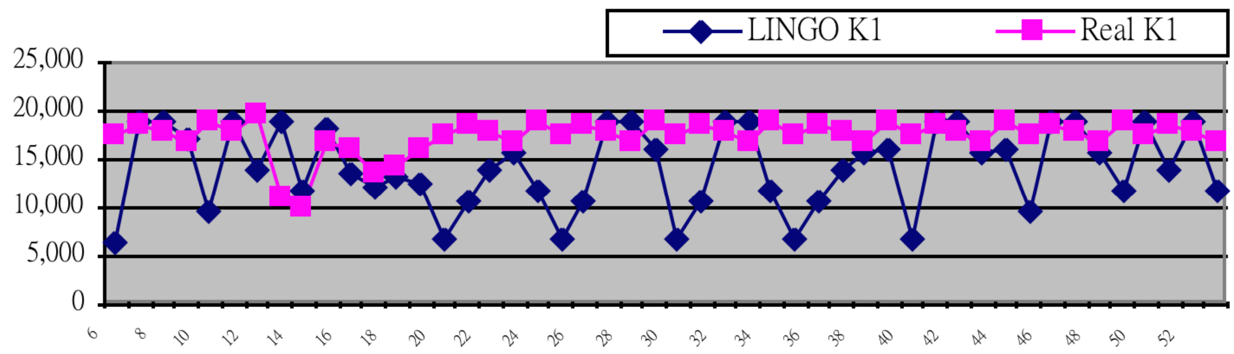

Figure 4. Comparison of production plans generated by the decision model and that of real factory data of fab 1

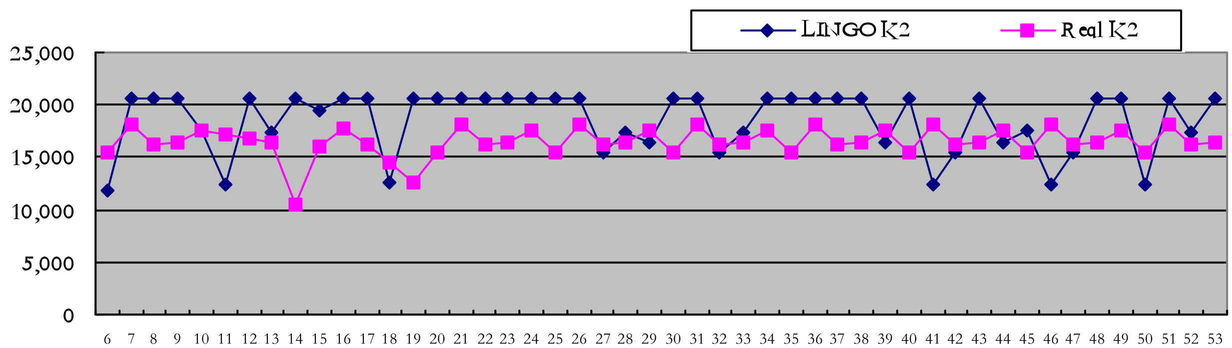

Figure 5. Comparison of production plans generated by the decision model and that of real factory data of fab 2

Table 2 gives the mean value and standard deviation of the production quantity provided by the decision model and the real data. In it, one can see that the planning results provided by decision model show a bigger variation. The reason is that the decision model is a static planning solution, which calculates the planning results under given data and objective function. However, in the real world, the planning must consider the dynamic environment, for example the factory maintenance, machine shot-down, orders change, dynamic requirement of material requirement, etc.

Table 2. Comparison of the standard deviation of planning results generated by decision and the real factory data: production quantity

	Mean	Standard deviation
Decision model(K1)	14,202	4,173
Real factory data (K1)	17,316	1,836
Decision model (K2)	18,442	2,934
Real factory data (K2)	16,451	1,400

5. CONCLUSIONS AND FURTHER RESEARCH

This paper develops a decision model for the supply network planning of the color filters manufacturing company. This decision model integrates the production planning, material planning as well as the demand fulfillment. In it, the issues of centralized planning, multi-sites production, product-mix, technology capability, centralized warehouse, supply of critical materials, expiration of materials, etc. are well considered. To test the quality of the developed model, 52 weeks of real data from a color filters manufacturing company are studied. The validation result shows a variation less than 10%.

This decision model is implemented by the standard optimization software LINGO 8.0 and is integrated with the database system of the case company. This solution is based on the concept Advanced Planning Systems (APS) given by Stadtler and Kilger (2002).

Further researches can be studied by the following: 1. Consideration of the dynamic planning issue based on the decision model. Such as the orders change of the down-stream TFT-LCD manufacturing, variation of materials supply, variation of the transportation of third-party logistics, etc. 2. Based on the decision model, the IT architecture of such an application can be well discussed. 3. Discussion of the information systems effectiveness based on the framework given by DeLone and McLean (1992). By it, the information effectiveness of such an APS implementation in the case study company could be discussed in the aspects of system quality, information 4. Based on the similar idea, a supply network planning model for the TFT-LCD manufacturing company can be developed.

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