Production Scheduling of Supply Chain System

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Abstract

This study aims to construct a supply chain system by using two models.The first model is the main frame of supply chain,and purchase,production, inventory,distribution,product shortage and demands are considered to solve the optimization.In addition,based on the optimal production quantity,the second model (production layout-PL) is applied to reveal the suggested layout of the production system.The syntax of Lingo 9.0 and Visual Basic 6.0 is applied to achieve the optimum solutions of the proposed models respectively.This study provides a referenced tool to an enterprise on multi-interval planning and production system layout design for a supply chain system.

keywords: supply chain, production scheduling, Lingo 9.0, visual basic, production layout-PL

I. Introduction

Traditional management theories propose that all enterprises and firms are motivated to seek production at a minimum cost and for a maximum profit. However, in this highly competitive society, they should not simply pursue maximization of their own profits. Whether the joint profit of the entire supply chain system can be maximized is also an important factor that they need to take into account.

Weng (1997) mentioned that under short product life cycles, uncertainties of demands, and price impacts, manufacturers and distributors should seek a maximum joint profit through coordination. Coordination refers to the way that firms share information and jointly decide a product's price, its production/order quantity to obtain a maximum profit for all. As mentioned by Simchi-Levi (2001), a supply chain is also called a logistics network, which consists of suppliers, manufacturers, warehouses, distributors, and retailers. Raw materials, work-in-process inventories, and finished goods will flow between facilities in this network. According to Parnell (1999), supply chain management (SCM) has five major benefits:

1. Reduced inventories: Finished goods inventory can be reduced by 20~50%, and work-in-process inventory can be reduced by 20~40%.
2. Improved customer service: On-time delivery rate can be increased by 20~70%, and the sales revenue can be increased by 10~20%.
3. Shortened supply chain cycle: The production lead time can be shortened by 20~50%, while the planning cycle time can be slashed by 50~80%.
4. Obsolete inventory can be reduced by 20~50%.
5. Asset utilization can be increased by 5~10%.

Rodrigues, et al. (2008) focused on an uncertainty model for the supply chain to

Establish a transport operation. Wu and Blackhurst(2005) using a modeling methodology to discuss about supply chain system, model , analysis disruptions by linking hierarchical level methods. Kim and Rogers (2005) aims to using an object-oriented approach building a flexible supply chain business model including Unified Modeling Language(UML) and provides some information to modeling a supply chain. Berman and Kim(2004) using_Poisson process and the facility provides service which takes exponential amounts of time, and discuss about an optimal inventory control in a supply chain. Berman and Kim(2001) considered the single class of customers, company and suppliers in internet-base supply chain to discussed about a problem of dynamic replenishment. Dai et al(2008) consider a two-echelon supply chain with one supplier and two retailers, in which the supplier carries all inventory to supply the retailers, and focus on nonstationary inventory and pricing problem.

As discussed above, SCM can be viewed as a way to manage and create a network of activities without borders between organizations. Through this network, all members can form a close relationship of cooperation, increase mutual and value, and jointly create a management model that maximizes the profit of the entire supply chain. In short, SCM is management of all the cooperative relationships in a supply chain.

The purpose of production scheduling management is to make the best use of productive machines and processes on the condition that finished products can be delivered on the customer-demanded (or negotiated) date. Production scheduling management can help manufacturers minimize the production lead-time, enhance machine production efficiency, and control the entire production progress to maintain their reputation for delivery.

Muth and Thompson (1963) provided their views of industrial scheduling and proposed the basic concept of scheduling. Charnsirisakskul et al. (2004, 2006) constructed a profit-maximizing model with constraints of productivity, holding cost, and penalty cost to discuss production scheduling based on flexible order choice and lead-time. Chen and Lan (2001) argued that through proper selection of productive machines, manufacturers can effectively achieve expected production goals while minimizing the total production cost. With an objective to minimize the cost of holding completed goods and the backorder cost, Markland et al. (1990) used customer orders as a basis to propose a multi-objective production scheduling program, in an attempt to obtain an optimal production scheduling decision. Brucker et al (2007) survey the complexity of shop -scheduling problems with fixed number of jobs. Haouari et al. (2007) using an exact branch-and-bound algorithm to solve an optimal scheduling of a two-stage hybrid flow shop problem that considered multiple identical machines in each stage. Chatfield et al. (2009) develop a Supply Chain Modeling Language platform that enables supply chain problem instance reuse and sharing, provides a common format for analytical software interoperability, and can improve the quality of the supply chain description. Chen and Xiao (2009) focus on Demand disruption and coordination of the supply chain with a dominant retailer that consider two coordination schedules, linear quantity discount schedule and Groves wholesale price schedule. Jawahar and Balaji (2009) using genetic algorithm (GA) to evolutionary search heuristics is proposed and illustrated and considers a two-stage distribution problem of a supply chain that is associated with a fixed charge. Kreipl and Dickersbach (2008) discussed about production planning , scheduling in supply chain planning software. Hall and Potts (2003) using the using several classtcal scheduling objectives to achieve minimize the overall scheduling and delivery.scheduling and discussed about batching, and delivery problems in supply chain that makes delivery to manufactures and customers. Kim and Jeong (2009) using benchmarked genetic algorithm method to integrated a production and scheduling model in supply chain system. Amaro and Barbosa-Póvoa (2008) development of a master representation model for optimal scheduling of industrial supply chains.

From the above studies, we can infer that a good production schedule can significantly enhance the productivity, efficiency, and reduce work-in-process inventory with limited availability of resources.

Therefore, we attempt to establish a supply chain system with considerations of multiple intervals, products, raw materials, suppliers, manufacturers, distributors, and deliverers. Through this system, we can find out the optimal quantity of each raw material that each manufacturer should order from its supplier, the optimal production quantity of each product, the optimal quantity of products delivered to each distributor, and the optimal quantity of each raw material and each product that should be held in inventory during each interval. Besides, for each distributor, we can also estimate the optimal quantity of each product to be held in inventory, the optimal quantity of each product to be delivered to customers, and the optimal quantity of each product that can be backordered. Later, based on the production quantity of each product, a production schedule can be planned for its manufacturer to enhance its production efficiency. Finally, we will use Lingo 9.0 extended version and Visual Basic 6.0 to solve the problem and provide a platform for enterprises to make a comprehensive and real-time analysis of multi-interval planning for a supply chain system.

The major contribution of this research is to present a practical modeling system, which integrates the upstream and downstream firms on a supply chain and their bases of production scheduling. This system serves as an important decision-making platform that managers can use for supply chain management.

II. Assumptions and Notations

All the assumptions and Notations used in this paper are explained as follows respectively:

(1) Assumptions

The assumptions in this paper are listed as follows:

1. Based on a four-layer supply chain (supplier, factory, distributor, and customer), we aim to construct a supply chain model with an objective of profit maximization.
2. In this model, we assume that factories and distributors are owned by the same business group, and customers are retailers;
3. Suppliers should deliver all orders to customers at the deadline of each order.
4. The duration of each production interval is known;
5. Product demand is a known figure estimated on the basis of historic sales data.

(2) Notations

1. Notations in the model

t : the code of the time interval, t=1,2,…, T

d: the code of the supplier, d=1,2,…, D

f: the code of the factory, f=1,2,..., F

w: the code of the distributor, w=1,2,..., W

c: the code of the customer, c=1,2,..., C

g: the code of the product, g=1,2,..., G

r: the code of the raw material, r＝1,2,..., R

2. Input parameters

P_{cg} : the price for customer c to purchase product g.

L_{tcg} : the quantity of product g that the demand of customer c at time interval t.

RC_{tdr} : at interval t, the cost of purchasing raw material r from supplier d.

IC_{tfr} : the cost for factory f to hold raw material r in inventory at time interval t.

TC_{tdfr} : the cost for supplier d to transport raw material r to factory f at time interval t.

PB_{tdr} : the maximum quantity of raw material r that supplier d can provide at time interval t.

RA_{gr} : the ratio of raw material r to the materials needed for product g.

MC_{tfg} : at interval t, the cost of manufacturing one unit of product g at factory f.

MT_{tfg} : the time that factory f needs to produce one unit of product g at time interval t.

IC_{tfg} : the cost for factory f to hold one unit of product g in inventory at time interval t.

S_r : the inventory space needed to hold one unit of raw material r.

S_g : the inventory space needed to hold one unit of product g.

TC_{tfwg} : the cost of transporting one unit of product g from factory f to distributor w at time interval t.

IC_{twg} : the cost for distributor w to hold one unit of product g in inventory at time interval t.

TC_{twcg} : the cost for distributor w to transport one unit of product g to customer c at time interval t.

UP_{tf} : the maximum working hours in factory f at time interval t.

US_{tf} : the inventory space that factory f can provide at time interval t.

US_{tw} : the inventory space that distributor w can provide at time interval t.

GC_{twcg} : at interval *t*, the lost sales penalty that distributor *w* needs to bear for one unit of product *g* backordered by customer *c*.

n: the number of production stages for a given product.

MS: the set of all available machines types.

ij: $0 \le i < j \le$ n, the code of workstation functioning from production stage *i*+1 to *j* in sequence. *ij* is said to be a feasible workstation if there is a machine $M_{ij} \in \mathrm{MS}$; where M_{ij} is a machine type of performing a sequence of production stages(from *i*+1 to *j*).

F: *F*={*ij*|$0 \le i < j \le$ n and *ij* is a feasible workstation}, means the set of feasible workstations.

t_{ij} : the processing time per unit product performed by a single machine M_{ij} $\forall ij \in F$.

a_{ij} : the availability of machine M_{ij} , which is defined by $a_{ij} = \dfrac{\varepsilon_{ij}}{(\varepsilon_{ij} + \delta_{ij})}$;where

ε_{ij} and δ_{ij} are the mean time between failures and the mean time to fix a single machine M_{ij} respectively.

c_{ij}^{o} : the operation cost (dollar(s)per unit time) of a single machine M_{ij} .

c_{ij}^{m} : the maintenance cost (dollar(s)per unit time) of a single machine M_{ij} . Note that, $c_{ij}^{m}\delta_{ij}$ represents the mean maintenance fee of a single machine M_{ij} .

c_{ij}^{f} : the fixed cost (dollar(s)per unit time) of a single machine M_{ij} .

c_{ij}^{s} : the setup cost (dollar(s)per unit time) of a single machine M_{ij} .

L: $L = \{i_0 i_1, i_1 i_2, i_2 i_3 ....i_{r-1} i_r\}$ is a production lie which indicates a sequence of feasible workstations, $i_0 i_1, i_1 i_2, i_2 i_3 ....i_{r-1} i_r$, where $0 = i_0 < i_1 < i_2 < i_3 ... < i_r = n$.

T_L : the production time interval of the production line *L*.

R_L : the production rate of the production line *L*.

C_h : the holding cost of unit product per unit time (All the time points, factories, and products in Model 1 should be input into Model 2 to obtain a production layout, so we convert an IC_{tfg} in Model 1 into C_h in Model 2).

Q : the production quantity of product (All the time points, factories, and products in Model 1 should be input into Model 2 to obtain a production layout, so we convert an MA_{tfg} in Model 1 into Q in Model 2).

3. Decision variables:

RA_{tdr} : the quantity of raw material *r* to be purchased from supplier *d* at time interval *t*.

TA_{tdfr} : the quantity of raw material *r* that supplier *d* transports to factory *f* at time interval *t*.

IA_{tfr} : the quantity of raw material *r* stored by factory *f* at the end of time interval *t*.

MA_{tfg} : the quantity of product *g* produced by factory *f* at time interval *t*.

IA_{tfg} : the quantity of product *g* stored by factory *f* at the end of time interval *t*.

TA_{tfwg} : the quantity of product *g* transported from factory *f* to distributor *w* at time interval *t*.

IA_{twg} : the quantity of product *g* stored by distributor *w* at time interval *t*.

GA_{twcg} : the shortage quantity of product *g* for customer *c* from distributor *w* at time interval *t* .

TA_{twcg} : the quantity of product *g* that distributor *w* needs to deliver to customer *c* at time interval *t*.

$x_{ij}(L)$: the number of parallel machines for workstation ij in the production line L.

III. Model Construction

In this paper, a supply chain system is constructed. This system consists of two models. Model 1 is a supply chain model which focuses on purchase, production, inventory, distribution, and stockout. After the solution of output quantity is obtained, a production layout (PL) model can be established. This PL model is the second model of the system.

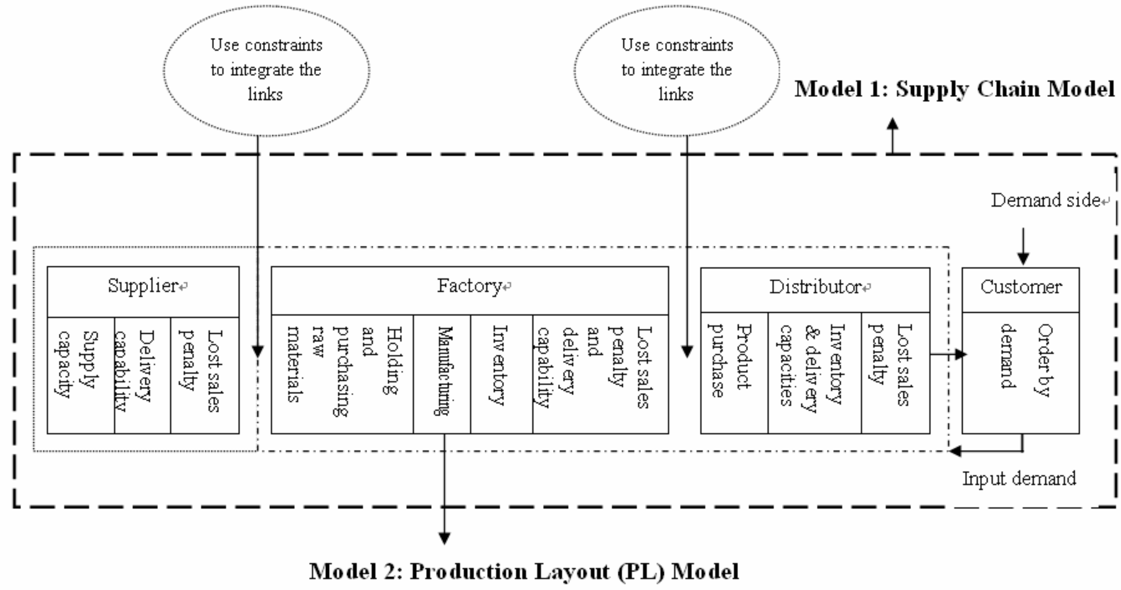

Figure 1 Production Scheduling of Supply Chain System

Model 1:

Model 1 is a supply chain model with an objective of profit maximization.

$$Max\sum_{g}\sum_{c}\left[P_{cg}\times\left(\sum_{t}L_{tcg}-\sum_{t}\sum_{w}GA_{twcg}\right)\right]$$

$$-\{\sum_{t}\sum_{d}\sum_{r}[RC_{tdr}\times RA_{tdr}]$$

$$+\sum_{t}\sum_{d}\sum_{f}\sum_{r}\left(TC_{tdfr}\times TA_{tdfr}\right)$$

$$+\sum_t\sum_f\sum_r\left(IC_{tfr}\times IA_{tfr}\right)$$

$$+\sum_t\sum_f\sum_g \ \{\left\lfloor MC_{tfg}\times MA_{tfg}\right\rfloor+\left(IC_{tfg}\times IA_{tfg}\right)\}$$

$$+\sum_t\sum_f\sum_w\sum_g \ \left(TC_{tfwg}\times TA_{tfwg}\right)$$

$$+\sum_t\sum_w\sum_c\sum_g\left(TC_{twcg}\times TA_{twcg}\right)$$

$$+\sum_t\sum_w\sum_g\left[\left(IC_{twg}\times IA_{twg}\right)+\left(GC_{twcg}\times GA_{twcg}\right)\right]\} \tag{1}$$

s.t.

$$\sum_f\sum_g\left(MA_{tfg}\times RA_{gr}\right)\le\sum_d RA_{tdr}\le\sum_d PB_{tdr} \qquad \forall t,r \tag{2}$$

$$\sum_g\left(MA_{tfg}\times MT_{tfg}\right)\le UP_{tf} \qquad \forall t,f \tag{3}$$

$$\sum_g IA_{tfg}\times S_g+\sum_r IA_{tfr}\times S_r\le US_{tf} \qquad \forall t,f \tag{4}$$

$$\sum_g IA_{twg}\times S_g\le US_{tw} \qquad \forall t,w \tag{5}$$

$$\sum_f TA_{tdfr}=RA_{tdr} \qquad \forall t,d,r \tag{6}$$

$$IA_{(t-1)fr}+\sum_d TA_{tdfr}-\sum_g\left(MA_{tfg}\times RA_{gr}\right)=IA_{tfr} \qquad \forall t,f,r \tag{7}$$

$$IA_{(t-1)fg}+MA_{tfg}-\sum_w TA_{tfwg}=IA_{tfg} \qquad \forall t,f,g \tag{8}$$

$$IA_{(t-1)wg}+\sum_f TA_{tfwg}-\sum_c TA_{twcg}=IA_{twg} \qquad \forall t,w,g \tag{9}$$

$$\sum_c\left(L_{tcg}-\sum_w TA_{twcg}\right)=\sum_w\sum_c GA_{twcg} \qquad \forall t,g \tag{10}$$

$$RA_{tdr},TA_{tdfr},IA_{tfr},MA_{tfg},IA_{tfg},TA_{tfwg},GA_{twcg},IA_{twg},TA_{twcg}\ge 0 \ \text{ and integer.} \tag{11}$$

Formula (1) is the objective function of the model that to maximize profit, and the total cost including cost of raw materials, transportation cost for suppliers, factories, and distributors, raw material and product inventory cost, inventory cost for distributors, production cost for factories, and stockout cost for distributors).

Formula (2) to (11) are the constraints of this research model. Formula (2) is the constraint of supply. The quantity of raw material *r* needed by all the factories cannot be greater than the quantity of raw material *r* supplied by all suppliers; the quantity of raw materials *r* supplied by all suppliers cannot be greater than the maximum quantity of raw material *r* that all suppliers can supply. Formula (3) is the constraint of factory production capacity at each time interval. It defines that the hours that factory *f* needs to produce all products is not greater than its maximum working hours of factory *f* at each time interval. Formula (4) is the constraint of factory inventory space at each time interval. The inventory space that factory *f* uses to store all products and raw materials at each time interval is not greater than the maximum inventory space of factory *f*. Formula (5) is the constraint of inventory space of distributor at interval *t*. It defines that the inventory space that distributor *w* uses to store all products cannot be greater than its maximum inventory space at each time interval. Formula (6) defines that the quantity of raw material *r* transported by supplier *d* to all factories is equal to the quantity of raw material *r* that all factories purchase from supplier *d* at each time interval.

Formula (7) means that the inventory of material *r* in factory *f* at the end of time interval *t*-1 plus the quantity of material *r* that all suppliers transport to factory *f* at time interval *t* should be equal to the quantity of mater *r* consumed by factory *f* for production at time *t* plus the inventory of material *r* in factory *f* at the end of time interval *t*. Formula (8) means that the inventory of product *g* in factory *f* at the end of time interval *t*-1 plus the quantity of product *g* produced by factory *f* at time interval *t* minus the quantity of product *g* transported from factory *f* to all distributors at time interval *t* should be equal to the inventory of product g in factory *f* at the end of time interval *t*. Formula (9) means that the inventory of product *g* in distributor *w* at the end of time interval t-1 plus the quantity of product g transported from all factories to distributor w at time interval t minus the quantity of product g transported from warehouse w to all customers at time interval t should be equal to the inventory of product g in distributor w at the end of time interval t. Formula (10) means that the quantity of product g demanded by customer c minus the quantity of product g transported from all distributors to customer c should be equal to the short quantity of product g demanded by customer c from distributor w. Formula (11) defines that all decision variables are non-negative and integer constraints.

Model 2:

Model 2 is based on the production layout (PL) model built by Lan and Lan (2005).

$$\underset{R_L,T_L,x_{ij}(L)}{Min} \sum_{l} \left\{ \left[\frac{1}{2} C_h T_L - \sum_{ij \in L} t_{ij} \left(c_{ij}^{0} + c_{ij}^{m} \left(\frac{1}{a_{ij}} - 1\right) + c_{ij}^{f} \frac{1}{a_{ij}} \right) \right] R_L T_L - \sum_{ij \in L} c_{ij}^{s} x_{ij}(L) \right\} \tag{12}$$

s.t.

$$\sum_{L} R_L T_L = Q \tag{13}$$

$$x_{ij}(L) = \left[\frac{R_L t_{ij}}{a_{ij}} \right]^{+} \forall ij \in L \text{ and } x_{ij}(L) \text{ are integers} \tag{14}$$

Formula (12) represents the overall profit of a multi-production-line system for producing the given order quantity. Formula (13) limits that the total amount of products produced by the production lines in the system should be equal to the customer order quantity Q. Formula (14) represents that the number of machines for each workstation on the production line L should be an integer and equal to $\left[\frac{R_L t_{ij}}{a_{ij}} \right]^{+}$.

IV. Analysis of a Numerical Example

In the previous section, we established a supply chain model with a profit maximization objective and a production layout (PL) model. We also provided a complete explanation of these models. For the entire supply chain, all cost factors, including purchase, production, inventory, distribution, and stockout, are important for supply chain programming. For factories, production scheduling is a key to saving costs and enhancing capacity utilization. Therefore, in the programming of a supply chain, all the practical conditions should be considered so as to derive an optimal plan.

The setting of our experimental case is as follows: The duration of the program is divided into three intervals, with each interval lasting one month. A supply chain consists of 3 suppliers, 2 factories, 2 distributors, and 3 retailers. Each of these suppliers supplies 3 raw materials to the factories, and the factories use different proportions of these raw materials to produce 2 different kinds of products. The retail price of product 1 is \$600, and the retail price of product 2 is \$800. The quantity of each product demanded by each customer at each interval is presented in Table A.1. The data show that customer demands increase with the progress of time. Table A.2 shows the cost of supplying one unit of each raw material for each supplier. Table A.3 shows the cost of holding one unit of each raw material at each factory. Table A.4 shows the cost of transporting one unit of each raw material to each factory. Because the distances between suppliers and factories are different, the transportation cost will vary depending on the practical distance between them. Table A.5 shows each supplier's maximum supply of each raw material at each interval.

Table A.6 shows the proportion of each raw material needed to produce one unit of each product, i.e. the BOM (bill of materials) of each product. Table A7 shows the cost of producing one unit of each product for each factory at each interval. Table A.8

shows the time (in hour) needed to produce one unit of each product at each factory. Table A.9 shows the cost of holding per unit of each product at each factory at each interval. In this example, we assume that the space needed to hold per unit of each raw material is 1 cubic unit. Hence, holding one unit of product 1 requires 9 cubic units of space, and holding one unit of product 2 requires only 6 cubic units of space.

Table A.10 shows the cost of transporting one unit of each product from factory to distributor at each interval. Table A.11 shows the unit inventory cost of each product for each distributor at each interval. Table A.12 shows the cost of transporting one unit of each product from distributor to customer at each interval. In this example, we set that the maximum working hour of each factory is 7,000 hours; each factory has an inventory space of 7,000 cubic units; and each supplier owns an inventory space of 4,500 cubic units. The lost sales penalty for suppliers is also considered in our model. Table A.13 shows the cost of lost sales penalty for one unit of each product at each interval.

This model involves a total of 225 variables (all are integer variables) and 184 constraints. This model can be classified as a pure integer linear programming (PILP) model. We used Global Solver built in Lingo 9.0 to obtain a global solution of the optimal profit: $8,644,500. The optimal programming result of the case is presented in Tables from 4.1 to 4.8.

Table 4.1 shows the quantity of each raw material purchased from its supplier at each interval. Table 4.2 shows the quantity of each raw material supplied to each factory at each interval. Table 4.3 shows the quantity of each raw material and product held by each factory at each interval.

Table 4.1 The quantities of raw materials purchased from suppliers (RA_{tdr})

	dr								
t	11	12	13	21	22	23	31	32	33
1	8,000	7,000	10,000	6,000	3,200	3,200	0	100	0

2	8,000	7,000	10,000	7,000	6,000	9,000	4,800	1,650	0
3	8,000	7,000	10,000	7,000	6,000	9,000	6,000	2,750	2,000

Table 4.2 The quantities of raw materials transported from suppliers to factories (TA_{tdfr})

td	*fr*					
	11	12	13	21	22	23
11	8,000	7,000	10,000	0	0	0
12	1,200	0	0	4,800	3,200	3,200
13	0	100	0	0	0	0
21	8,000	7,000	10,000	0	0	0
22	0	0	3,000	7,000	6,000	6,000
23	2,800	1,650	0	2,000	0	0
31	8,000	7,000	10,000	0	0	0
32	0	0	3,000	7,000	6,000	6,000
33	4.000	2,750	2,000	2,000	0	0

Table 4.3 The quantities of raw materials and products stored in factories (IA_{tfr} and IA_{tfg})

t	*fr/fg*					
	11	12	13	21	22	23
1	0/0	0/0	0/NA	0/0	0/0	0/NA
2	0/0	0/0	0/NA	0/0	0/0	0/NA
3	0/0	0/0	0/NA	0/0	0/0	0/NA

Table 4.4 shows the quantity of each product produced by each factory at each interval. Table 4.5 shows the quantity of each product transported to each distributor at each interval. Table 4.6 shows the quantity of each product held by each distributor at each interval. Table 4.7 shows the quantity of each product transported to each customer at each interval. Table 4.8 shows the quantity of each product backordered by each customer from each distributor at each interval.

Table 4.4 The quantities of products produced by the factories (MA_{tfg})

t	*fg*			
	11	12	21	22
1	2,900	2,100	0	1,600
2	4,350	2,150	0	3,000
3	5,250	2,250	0	3,000

Table 4.5 The quantity of products transported from factories to distributors (TA_{tfwg})

	fwg							
t	111	112	121	122	211	212	221	222
1	2,000	2,100	900	0	0	0	0	1,600
2	2,800	2,150	1,550	0	0	1,700	0	1,300
3	3,700	2,250	1,550	0	0	1,200	0	1,800

Table 4.6 The quantity of each product held by each distributor (IA_{twg})

	wg			
t	11	12	21	22
1	0	0	0	0
2	0	650	250	0
3	0	0	0	0

Table 4.7 The quantities of products transported from distributors to retailers (TA_{twcg})

	cg					
tw	11	12	21	22	31	32
11	800	500	1,200	1,600	0	0
21	1,200	1,400	1,600	1,800	0	0
31	1,600	1,800	2,100	2,300	0	0
12	0	500	0	0	900	1,100
22	0	0	0	0	1,300	1,300
32	0	0	0	0	1,800	1,800

Table 4.8 The short quantities of products demanded by retailers (GA_{twcg})

	cg					
tw	11	12	21	22	31	32
11	0	0	0	0	0	0
21	0	0	0	0	0	0
31	0	0	0	0	0	0
12	0	0	0	0	0	0
22	0	0	0	0	0	0
32	0	0	0	0	0	0

Through the proposed system, managers can make decisions based on optimal solutions and also obtain some important notes from them. For instance, in the above case, factory 1 can produce products at a lower cost. Managers can prioritize factory 1 for production and assign production tasks to factory 2 only when factory 1 has reached the allowed maximum working hour.

We obtained the quantity of products manufactured by each factory using Model 1 and used Model 2 to assist each factory in production scheduling. The quantity of product 1 manufactured by factory 1 at interval 1 (2900 units) and the operating costs of each factory (Appendix Table A.14) were used as the numerical example.

The optimal solution of the example is illustrated in Figure 2, The suggested multi-production-line system consists of three production lines.The first production line consists of workstations 01, 13, 36, and 67. The number of machines for workstation 01 is three(x_{01} =3), for workstation 13 is four(x_{13} =4), for workstation 36 is eight(x_{36} =8), and for workstation 67 is(one x_{67} =1).

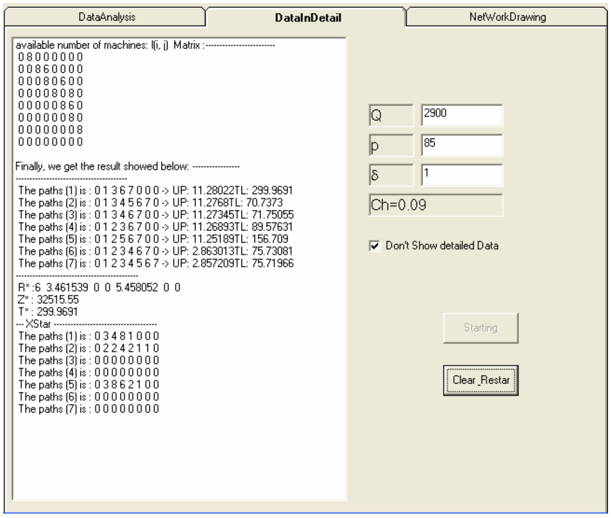

Figure 2　The suggested solution generated by the developed program

The production time interval of the first line is 299.9691 hours, and the production time interval of the second line is 156.709. The manufacturer who considered the holding cost of production will schedule all production lines to complete their production at the same time to reduce the product holding cost. Therefore, 143.2601 hours (299.9691-156.709=143.2601) after the first line starting production, the second line {01, 12, 25 ,56, 67} can then start its production with 5.458052 units per hour (production rate), and the number of machines for each workstation is x_{01}=3, x_{12}=8, x_{25}=6, x_{56}=2, x_{67}=1.

Based on the above-mentioned reason, 229.2318(299.9691-70.7373=229.2318) hours after the first line starting production, the third line(01, 13, 34, 45, 56,67) starts its production with 3.461539 units per hour, and the number of machines for each workstation is x_{01}=2, x_{13}=2, x_{34}=4, x_{45}=2, x_{56}=1, x_{67}=1 because its production time interval is 70.7373 hours.

V. Conclusions

Supply chain management (SCM) is to view all firms involved in a supply chain as a whole and seek cost optimization and profit maximization through information sharing and profit sharing. SCM has become one of important issues in modern management science. In this paper, we investigated the costs of purchase, production, transportation, and delivery in supply chain and further introduced the time factor into the supply chain model. Based on the structure of a supply chain, we then conducted a comprehensive discussion on various costs at each interval to provide an important reference on production scheduling.

The main contribution of this research is as follows: First of all, the solutions of the proposed supply chain system were obtained in two stages with various costs and time factor considered. Model 1 was a supply chain model with an objective of profit maximization. This model is a pure integer linear programming (PILP) model. We applied Lingo 9.0 extended version to implement this mathematic model. We then derived a global optimal solution using the built-in Global Solver and applied it to the production layout (PL) model (Model 2). Later, we performed production scheduling including planning and arrangement of production lines and time on Visual Basic 6.0, in hope of making the most effective use of resources and fulfilling the principle of JIT (just-in-time) production to save costs.

Given fixed external conditions, the data derived from the numerical example could be a reference for managers to make effective managerial and strategic plans. The goal of profit maximization in a supply chain system can be achieved only through systematic programming. Besides, we used Lingo 9.0 extended version and Visual Basic 6.0 to construct a computerized decision-making platform. This platform allows enterprises to plan and solve problems regarding production of multiple products at multiple intervals using multiple raw materials provided by multiple suppliers and transported to multiple distributors or retailers. The information obtained from this platform could be an important reference on overall planning of strategies and scheduling of production.

Besides, we applied software packages to find solutions in this paper, so the proposed model featured a high level of repeated characteristic. In other words, if all the parameters, including product price, order quantity, inventory cost, transportation cost, lost sales penalty, inventory space, and etc. are input into the model, a solution can be obtained. Thus, this model has it value for practical applications.

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Appendix

Table A.1 The quantities of products demanded by customers (L_{tcg})

t	cg					
	11	12	21	22	31	32
1	800	1,000	1,200	1,600	900	1,100
2	1,200	1,400	1,600	1,800	1,300	1,300
3	1,600	1,800	2,100	2,300	1,800	1,800

Table A.2 The cost of supplying one unit of raw material (RC_{tdr} unit: dollar)

t	dr								
	11	12	13	21	22	23	31	32	33
1	11	14	17	11	14	17	11	14	17
2	11	14	17	11	14	17	11	14	17
3	11	14	17	11	14	17	11	14	17

Table A.3 The cost of holding one unit of raw materials at factory (IC_{tfr} , unit: dollar)

t	fr					
	11	12	13	21	22	23
1	15	20	18	15	20	18
2	15	20	18	15	20	18
3	15	20	18	15	20	18

Table A.4 The cost of transporting one unit of raw materials from supplier to factory (TC_{tdfr} , unit: dollar)

td	fr					
	11	12	13	21	22	23
11	30	60	20	40	70	60
12	40	70	30	30	60	50
13	45	65	35	35	65	55
21	30	60	20	40	70	60
22	40	70	30	30	60	50
23	45	65	35	35	65	55
31	30	60	20	40	70	60
32	40	70	30	30	60	50
33	45	65	35	35	65	55

Table A.5 The maximum quantities of raw materials that can be supplied (PB_{tdr})

t	dr								
	11	12	13	21	22	23	31	32	33
1	8,000	7,000	10,000	7,000	6,000	9,000	6,000	8,000	9,000
2	8,000	7,000	10,000	7,000	6,000	9,000	6,000	8,000	9,000
3	8,000	7,000	10,000	7,000	6,000	9,000	6,000	8,000	9,000

Table A.6 The ratio of raw material to all materials needed for one unit of product (RA_{gr})

	g	
r	1	2
1	1	1
2	2	3
3	2	2

Table A.7 The cost of manufacturing one unit of product at factory (MC_{tfg} , unit: dollar)

	fg			
t	11	12	21	22
1	30	50	30	50
2	30	50	30	50
3	30	50	30	50

Table A.8 The time needed to produce one unit of product (MT_{tfg} , unit: hour)

	fg			
t	11	12	21	22
1	1	2	1	2
2	1	2	1	2
3	1	2	1	2

Table A.9 The cost of holding one unit of product at factory (IC_{tfg} , unit: dollar)

	fg			
t	11	12	21	22
1	65	65	65	65
2	65	65	65	65
3	65	65	65	65

Table A.10 The cost of transporting one unit of product from factory to distributor (TC_{tfwg} , unit: dollar)

	wg			
tf	11	12	21	22
11	20	30	25	40
21	20	30	25	40
31	20	30	25	40
12	25	30	20	25
22	25	30	20	25
32	25	30	20	25

Table A.11 The cost of holding one unit of product by distributor (IC_{twg} , unit: dollar)

	wg			
t	11	12	21	22
1	20	50	20	50
2	20	50	20	50
3	20	50	20	50

Table A.12 The unit cost of transporting one unit of product from distributor to customer (TC_{twcg} , unit: dollar)

	cg					
tw	11	12	21	22	31	32
11	15	20	10	15	30	35
21	15	20	10	15	30	35
31	15	20	10	15	30	35
12	20	25	25	30	15	20
22	20	25	25	30	15	20
32	20	25	25	30	15	20

Table A.13 The lost sales penalty that each distributor needs to bear for one unit of product (GC_{twcg} , unit: dollar)

	cg					
tw	11	12	21	22	31	32
11	450	600	450	600	450	600
21	450	600	450	600	450	600
31	450	600	450	600	450	600
12	450	600	450	600	450	600
22	450	600	450	600	450	600
32	450	600	450	600	450	600

Table A.14 The various operating costs of each factory

Indices Ij	Machine Types M_{ij}	Processing Time t_{ij} (hrs)	Availability a_{ij}	Maximum available number of machines l_{ij}	Setup Cost c_{ij}^{s} ($)	Operation Cost c_{ij}^{0} ($/hr)	Maintenance Cost c_{ij}^{m} ($/hr)	Fixture Cost c_{ij}^{f} ($/hr)	Holding Cost c_h ($/hr)
01		0.44	0.9	8	60	20	8.5	2	
12		1.1	0.85	8	42	14.3	8	1.2	
13		0.52	0.9	6	75	30	11	2.2	
23		0.3	0.9	8	45	15	8	1.5	
25		1	0.95	6	75	26	10	2	
34		0.9	0.9	8	60	21.7	8.6	1.5	0.09
36		1.2	0.9	8	60	21	9.4	1.8	
45		0.5	0.9	8	55	20	8.5	2	
46		0.6	0.95	6	65	23.3	9.6	1.5	
56		0.18	0.95	8	55	18.3	8	1.5	
67		0.15	0.9	8	55	18.3	8	1.5	