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A Development of a Simulation Tool for Production Planning with Capacity-Booking at Specialty Store Retailer of Private Label Apparel Firms

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***Abstract*—**In this paper, we suggest a simulation tool to make a decision of monthly production planning for maximizing a profit of Specialty store retailer of Private label Apparel (SPA) firms. Most of SPA firms are fabless and make outsourcing deals for productions with factories of their subcontractors. Every month, SPA firms make a booking for production lines and manpower in the factories. The booking is conducted a few months in advance based on a demand prediction and a monthly production planning at that time. However, the demand prediction is updated month by month, and the monthly production planning would change to meet the latest demand prediction. Then, SPA firms have to change the capacities initially booked within a certain range to suit to the monthly production planning. The booking system is called "capacity-booking". These days, though it is an issue for SPA firms to make precise monthly production planning, many firms are still conducting the production planning by empirical rules. In addition, it is also a challenge for SPA firms to match their products and factories with considering their demand predictabilities and regulation abilities. In this paper, we suggest a model for considering these two issues. An objective is to maximize a total profit of certain periods, which is sales minus costs of production, inventory, and capacity-booking penalty. To make a better monthly production planning at SPA firms, these points should be considered: demand predictabilities by random trends, previous and next month's production planning of the target month, and regulation abilities of the capacity-booking. To decide matching products and factories for outsourcing, it is important to consider seasonality, volume, and predictability of each product, production possibility, size, and regulation ability of each factory. SPA firms have to consider these constructions and decide orders with several factories per one product. We modeled these issues as a linear programming. To validate the model, an example of several computational experiments with a SPA firm is presented. We suppose four typical product groups: basic, seasonal (Spring / Summer), seasonal (Fall / Winter), and spot product. As a result of the experiments, a monthly production planning was provided. In the planning, demand predictabilities from random trend are reduced by producing products which are different product types. Moreover, priorities to produce are given to high-margin products. In conclusion, we developed a simulation tool to make a decision of monthly production planning which is useful when the production planning is set every month. We considered the features of capacity-booking, and matching of products and factories which have different features and conditions.

***Keywords*—**Capacity-booking, SPA, monthly production planning, linear programming.

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I. Introduction

THESE days, Specialty store retailer of Private label Apparel firms, which have an integrated system from manufactures to sales by themselves becomes more common. In apparel market, the products' life cycle is short because of its seasonality. And also it is difficult to predict its demand, because spot demand is happened by advertisements and so on. To accept these characteristics of demand, most of all SPA firms take the form of fabless manufacturing. Under this fabless system, SPA firms own no factories by themselves, and they have subcontracting factories to outsource their products (Fig. 1).

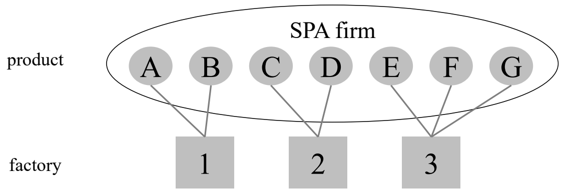

Fig. 1 Fabless system in SPA firms

SPA firms make a monthly production planning and "capacity-booking" for each factory every month. This capacity–booking is important to absorb sharp changes of the monthly production planning and to reduce production cost.

Capacity-booking is a booking for production lines and manpower in the factories, which can be changed afterward in a certain range. Fig. 2 shows a flow of manufacturing from capacity-booking to production. For each month, capacity-booking is conducted a few months in advance based on a demand prediction and a monthly production planning at that time. The demand prediction is updated month by month, and the monthly production planning may be changed to meet the latest demand prediction. Then, SPA firms can change the capacities initially booked within a certain range to suit to the monthly production planning.

There are some difficulties of capacity-booking. When SPA firms make a monthly production planning, they should consider demand predictability of each product, production planning for previous and next month's, and the flexibility of capacity-booking. SPA firms' apparel products have different seasonality, volume, and demand predictability. Subcontract factories also have different production possibility, factory size, and regulation ability for capacity-booking change. These conditions should be considered when a SPA firm determines capacity-bookings for each factory, but in fact, many firms are still conducting the production planning by empirical rules. In addition, there are problems of product-factory mismatches. Because products have different seasonality, volume, and demand predictability, on the other hand, subcontract factories also have different production possibility, factory size, and regulation ability for changing capacity-booking, these should be considered to decide the factory for manufacturing each product, to avoid their mismatches. It is also a challenge to manufacture one production at several factories. These are not considered in previous study of supply-chain problems [1]-[3]. In this paper, we suggest a simulation tool to make a decision of capacity-booking and monthly production planning for maximizing a profit of SPA firms. In addition, we consider a matching of products and subcontract factories which have different characteristics and conditions.

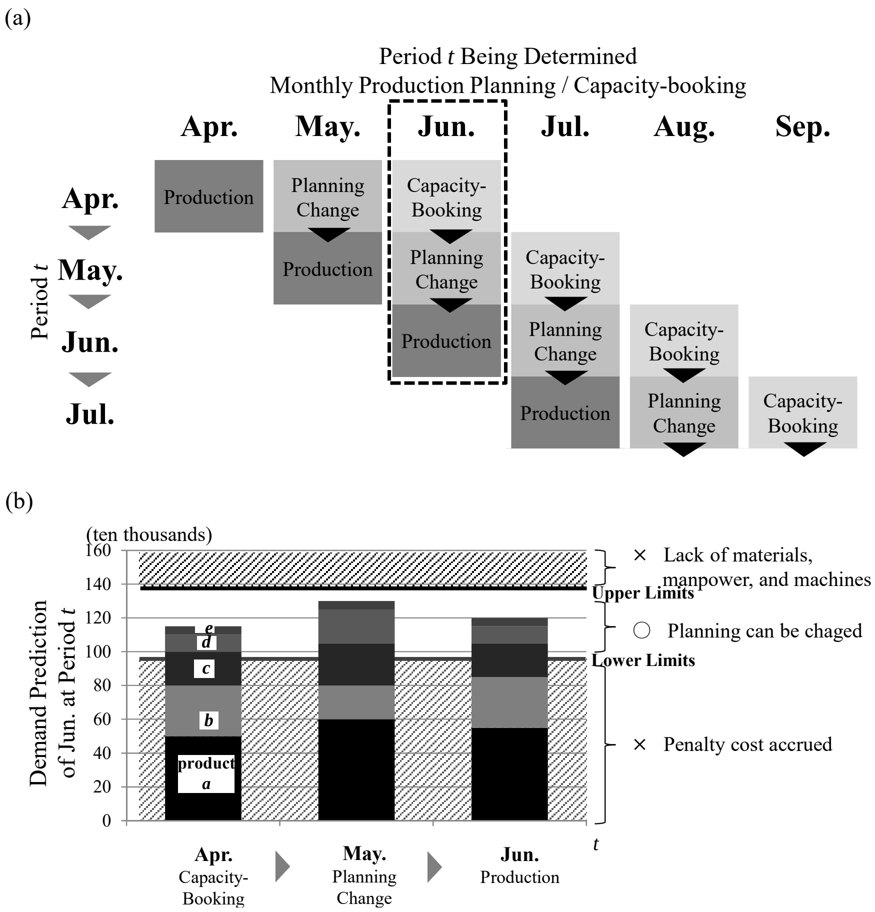

Fig. 2 Flow from Capacity-booking to production (e.g. June)

II. RESEARCH MODEL

A. Lot-Sizing Problems

Multi-item and dynamic lot sizing problem is to determine volume of manufacturing of several products in multi-period [4], [5]. The objective is to minimize the total cost which is of manufacturing cost and inventory cost. In this research, we suggest a new model which is a basic model added constraints for capacity-booking, and which objective is to maximize total profit.

B. Model Assumptions

The model we propose in this paper assumes the followings:

1) This is a simulation tool to maximize a total profit at total period T (T: 12periods, one period t: one month).
2) Demand prediction of each product is produced by normal random number, average of which is given by basic demand volume of each season, standard variation of which is demand predictability of each product.
3) Each product has different seasonality, volume, and demand predictability.
4) Each factory has different production possibility, factory size, and regulation ability for capacity-booking change.
5) To calculate monthly production planning and capacity-booking, we use coefficient of production which depends on man-hour.
6) Each product can be manufactured in several factories.
7) Capacity-booking for period t is determined in period t-2.
8) After the capacity-booking of period t is determined, monthly production planning for the period can be changed only in the booked range. If the amount of production is less than the lower limit, penalty cost will accrue.

C. Objective Function

The objective function of this model is to maximize total profit in period *T*.

$$\max \sum_{t\in T}\sum_{k\in K}\sum_{j\in J}\{p_k^t\cdot v_{kj}^t-(c_{kj}\cdot x_{kj}^t+h_{kj}\cdot I_{kj}^t)\}$$

$$-\sum_{t\in T}\{\sum_{j\in J}(m_j^t-\sum_{k\in K}a_{kj}\cdot x_{kj}^t)\cdot b_j\}-\sum_{t\in T}\sum_{k\in K}\sum_{j\in J}f_j^t\cdot y_{kj}^t \quad (1)$$

$$s.t. \sum_T\sum_J y_{kj}^t\geq 1, \forall t \quad (2)$$

$$\sum_K a_{kj}\cdot x_{kj}^t\leq M_j^t, \forall t, j \quad (3)$$

$$v_{kj}^t\leq z_{kj}^t+x_{kj}^t, \forall t,k,j \quad (4)$$

$$\sum_J v_{kj}^t\leq d_k^t, \forall t,k \quad (5)$$

$$\sum_J(m_j^t-\sum_K a_{kj}\cdot x_{kj}^t)\cdot b_j\geq 0, \forall t \quad (6)$$

$$y_{kj}^t=\{0,1\}, \forall t,k,j \quad (7)$$

$$v_{kj}^t\geq 0, \forall t,k,j \quad (8)$$

$$x_{kj}^t\geq 0, \forall t,k,j \quad (9)$$

$$I_{kj}^t\geq 0, \forall t,k,j \quad (10)$$

T : set of period t; K : set of product k; J : set of factory j; d_k^t : demand for product k in period t; p_k^t : price of product k in period t; v_{kj}^t : supplied amount of product k from factory j in period t; c_{kj} : production cost of product k at factory j; x_{kj}^t : production volume of product k at factory j in period t
a_{kj} : coefficient of production of product k at factory j; h_{kj} : inventory cost of product k at factory j; z_{kj}^t : initial stock of product k at factory j in period t; I_{kj}^t : volume of inventory of product k at factory j in period t; m_j^t : lower limit of capacity-booking at factory j in period t; M_j^t : upper limit of capacity-booking at factory j in period t; b_j : penalty cost for per product coefficient at factory j; y_{kj}^t : 0-1 variable number to manufacture product k; at factory j in period t; f_j^t : fixed cost to open factory j in period t

Equation (1) is an objective function to calculate total profit, which subtracts total production cost, total inventory cost, and total penalty cost from total sales. Constraints are as follows:

1. Each product is manufactured by more than one factory.
2. Total coefficient of production is less than the upper limit at each factory.
3. Supplied amount is less than the total amount of initial stock and production volume of each product, in each period.
4. Supplied amount is less than demand of each product, in each period.
5. Penalty cost is non-negative.
6. For each product, 0-1 is given to determine its manufacturing factories.
7. Supplied mount is non-negative.
8. Production amount is non-negative.
9. Volume of inventory is non-negative.

III. Solution and Analysis Methodology

A. Outline of Simulation Tool and Solution

A purpose of development of this simulation tool is to suggest a valuable quantitative data for decision-making of follows: (1) To make a capacity-booking and monthly production planning for each subcontract factory, (2)To determine subcontract factories to manufacture each product. This research model is to solve small-scale problems (e.g. number of product: 10, factory: 5), and linear programming is used.

B. Determining Capacity-Booking and Monthly Production Planning

In this simulation tool, in period *t*, demand prediction during period t to t+11 is generated. Then, monthly production planning for each month and capacity-booking in period *t+2* is determined. This algorithm is repeated while period *T*. At the end, total profit is calculated. The details are as follows:

Step1: Initialization / Input Data Generation: Demand for each product in period *t* = 1~12, upper / lower limits by capacity-booking in period *t* = 13, 14 are given as an input information. Initial parameter of period is *t* = 13.

Step2: Simulation in Period *t:* At the beginning of simulation of period *t*, the upper/lower limits by capacity-booking are determined.

Step2-i: Demand Prediction: For each product, demand prediction for period from *t* to *t+11* is generated used by normal random number.

Step2-ii: Determine Monthly Production Planning: For each factory, determine monthly production planning for period from *t* to *t+11*.

Step2-iii: Repeated Judgement

(n=n+1, if n≤N, return to Step2-1)

For one period, simulate and output the monthly production planning for N times.

Step2-iv: Determine Capacity-booking of Period *t+2:* Upper / lower limits are determined by max / min number of production planning for period *t+2* in N times' repeat.

Step2-v: Calculate Sales of Period *t:* Average sale is as sale in period *t*.

Step3: Repeated Judgement

(t=t+1, if t≤T+11, return to Step2)

Step4: Calculate Total Profit in Period *T:* Total profit in period *T* is total sales of period *t~t+11* minus total production cost, total inventory cost, and total penalty cost.

C. Review for Matching of Products and Factories

In this paper, we also review for matching of products and factories which have different characteristics and conditions, if each product can be manufactured by several factories.

IV. Computational Experiment

A. Objective of Experiment

In this research, we do computational experiments assumed a SPA firm of fast fashions. To simplify the problem, by using information about 10 products and 5 factories, we simulate monthly production planning.

B. Input Information about Product

Productions we consider in this experiment are grouped into four types: (a) basic product, (b) seasonal (Spring / Summer) product, (c) seasonal (Fall / Winter) product, and (d) spot product. Each product group has different characteristic of demand predictability, seasonality, and volume. Basic trends of these demands are shown in Fig. 3. Input information about products is in Table I.

C. Input Information about Factory

Input information about factories is in Table II.

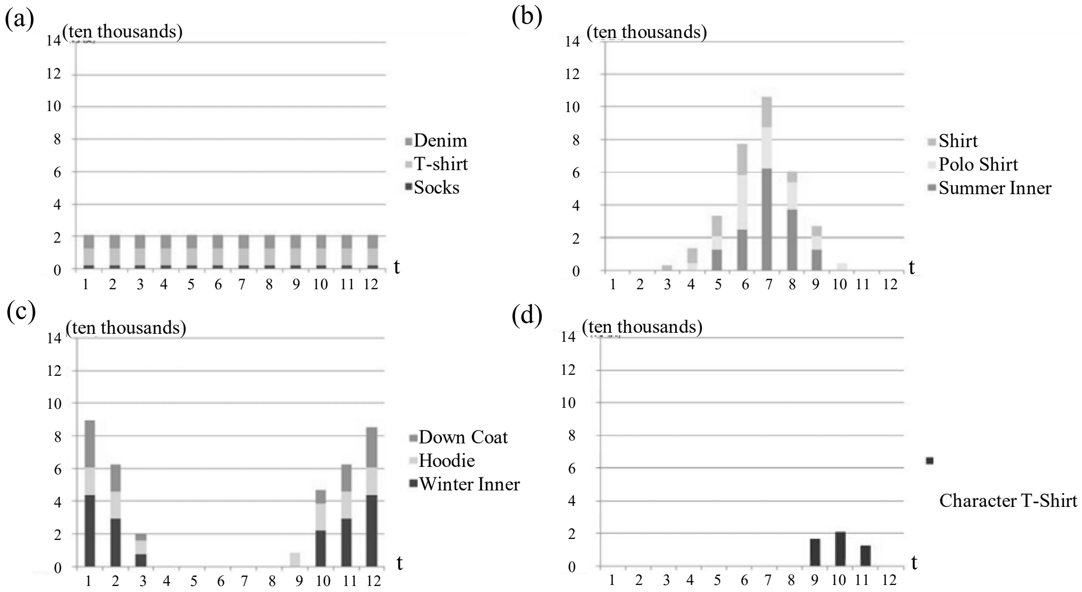

Fig. 3 product groups and trends

TABLE I
Input Information (Product)

Product Group	Product No.	Demand Predictability (%)		Coefficient of Production	Price (yen)	Production Cost (yen)	Inventory Cost (yen)	Profit Rate
	1	Low	5	1.0	330	231	33	0.2
(a)Basic	2	Low	5	1.2	1500	1050	150	0.2
	3	Mid	15	1.5	4000	2800	400	0.2
	4	High	30	1.2	1000	700	100	0.2
(b)S/S seasonal	5	Mid	15	1.3	2000	1400	200	0.2
	6	Low	5	1.3	2500	1750	250	0.2
	7	High	30	1.2	1300	910	130	0.2
(c)F/W seasonal	8	Mid	15	1.4	3000	2100	300	0.2
	9	Mid	15	1.5	7000	4900	700	0.2
(d)Spot	10	Very high	45	1.3	1500	1050	150	0.2

TABLE II
Input Information (Factory)

No.	Regulation Ability for Capacity-Booking Change	Lower / Upper Constraints (±%)
1	High	35
2	Mid	20
3	Mid	20
4	Low	10
5	Low	10

V. Results and Consideration

For each factory, capacity-booking and monthly production planning for period T is determined as Fig. 4. The total profit for period *T* which is an objective function of this model is calculated in Table III. As Fig. 4 shows, at factories which have higher regulation ability for capacity-booking change (e.g. Factory A), the range of capacity-booking was wider. Spot products and seasonality products, demand predictability of which is high tend to be produced at these factories. On the other hand, at factories which have lower regulation ability for capacity-booking change (e.g. Factory D, E), the range of capacity-booking was narrower. Basic products, demand predictability of which is low tend to be produced at these factories. As Table III shows, because of limited capacity of factories in each month, there were opportunity losses. But the variations between months were moderated effectively.

Table IV shows products which has high demand predictability should be outsourced to factories which can accept wide capacity-booking.

TABLE III
RESULT OF OBJECTIVE FUNCTION

t	Sale	Cost	Profit	Opportunity Loss
1	321,906,760	225,334,732	96,572,028	0
2	251,348,848	176,529,092	74,819,755	587
3	117,057,394	99,537,162	17,520,232	0
4	79,655,273	78,458,935	1,196,338	19,712
5	111,466,885	87,089,248	24,377,637	16,218
6	185,299,955	119,293,718	66,006,237	4,677
7	194,250,947	117,311,834	76,939,114	17,185
8	135,336,779	100,502,300	34,834,479	12,751
9	138,593,887	103,552,322	35,041,566	4,583
10	218,659,375	155,371,610	63,287,765	10,215
11	276,310,330	190,052,874	86,257,456	825
12	339,696,089	238,959,785	100,736,304	1,702
T	2,369,582,521	1,691,993,610	**677,588,911**	88,455

VI. CONCLUSION

In this paper, we developed a simulation tool to make a decision of monthly production planning and capacity-booking which is useful for SPA firms to determine monthly production planning every month. We suggest a multi-item and dynamic lot-sizing model to maximize total profit for a certain period, with considering upper/lower limits of production which are constraints from capacity-booking. In conclusion, we could develop a simulation tool which can determine effective monthly production planning and strategic capacity-booking. Moreover, we could review for matching of products and factories which have different features and conditions.

TABLE IV
MATCHING OF PRODUCTS AND FACTORIES

Product No.		Factory A	B	C	D	E
Product	1	0.1	0.1	0.1	0.4	0.4
	2	0.5	0.3	0.4	0.8	0.3
	3	0.3	0.3	0.2	0.5	0.5
	4	0.3	0.7	0.7	0.1	0.2
	5	0.5	0.3	0.2	0.4	0.3
	6	0.5	0.2	0.3	0.5	0.3
	7	0.5	0.5	0.6	0.5	0.2
	8	0.1	0.3	0.1	0.4	0.6
	9	0.6	0.4	0.4	0.1	0.1
	10	0.4	0.7	0.1	0.2	0.1

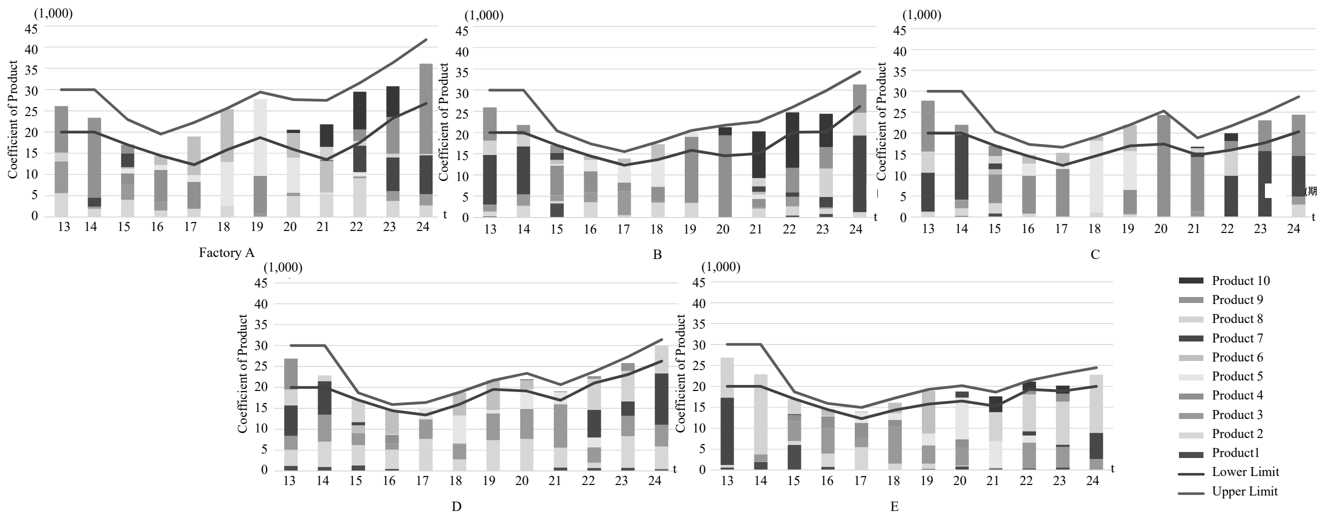

Fig. 4 Capacity-booking and Monthly Production Planning

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