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INTEGRATED PRODUCTION-DISTRIBUTION PLANNING WITH TIME DEPENDENT DEMAND IN MULTI-ECHELON SUPPLY CHAIN

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INTEGRATED PRODUCTION-DISTRIBUTION PLANNING WITH TIME DEPENDENT DEMAND IN MULTI-ECHELON SUPPLY CHAIN

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ABSTRACT

This paper discusses an integrated production-distribution planning for a 4-echelons supply chain system which consists of a manufacturer with a continuous production process, a distribution center, a number of distributors and a number of retailers. This situation can be found, for example, in a fertilizer production and distribution systems. Considering a time-dependent demand pattern which is approximated by a polynomial function at retailers that fluctuates by time and may not be identical for each retailer, and all entities of the entire echelon in the supply chain are allowed to hold inventory, the integrated production-distribution planning model is developed using the following approaches, i.e.: coordinated policy, echelon inventory concept and single cycle time policy. The periodic review inventory system is used as a basic model for developing the model. The model determines a production policy for the manufacturer and replenishment policies for all entities involved in the distribution system in order to minimize a total system cost. The total system cost consists of set-up/ordering costs, holding costs, backorder costs and transportation costs of all entities of the supply chain system. A heuristics solution procedure is developed to find the solution. Since the demand depends on the time, the level of maximum inventory is not equal for each period at the manufacturer, the distribution center, the distributors and the retailers.

KEY WORDS

Production-Distribution Planning, Echelon Inventory, Continuous Production, Time Dependent Demand

1. Introduction

Researches in the integrated production-distribution planning mainly address the discrete production process, such as [1], [2], [3], [4], [5] and [6]. In fact, some manufacturers use a continuous production process and a discrete distribution system, such as in the fertilizer and paper manufacturers. This paper proposes an integrated production-distribution model for the 4-echelons supply chain system. The system consists of a manufacturer with a continuous production process, a distribution center, a number of distributors and a number of retailers.

Most of the previous models assume that the pattern of the customer demand is deterministic, such as [1], [7] and [8] or probabilistic, such as [2], [3], [4], [5] and [6]. In fact, there are several kinds of product that have seasonal (time-dependent) demand pattern, for example in fertilizer industry. Research by [9] and [10] have considered the time-dependent demand but only determine an inventory policy for one echelon of a supply chain system. The time-dependent demand pattern has not been widely discussed in the previous integrated production-distribution planning.

The customer's demand that fluctuates with time occurs only at the retailers and may not be identical for each retailer. All entities in the entire echelon of the supply chain are allowed to hold inventory. Based on these conditions, the model is developed. The model determines a production cycle at the manufacturer and the replenishment cycles of distribution center, distributors and retailers in order to minimize the total system cost per year. The total system cost consists of the total costs per year at the manufacturer, distribution centers, distributors and retailers.

2. Framework

The framework of this research is depicted in Figure 1. Four entities are considered in, i.e.: a manufacturer with a continuous production process, a distribution center, a number of distributors and a number of retailers with a time-dependent demand. In this framework, a coordinated production and replenishment policies are decided by the manufacturer, the distribution center, the distributors and the retailers in order to minimize the total system cost.

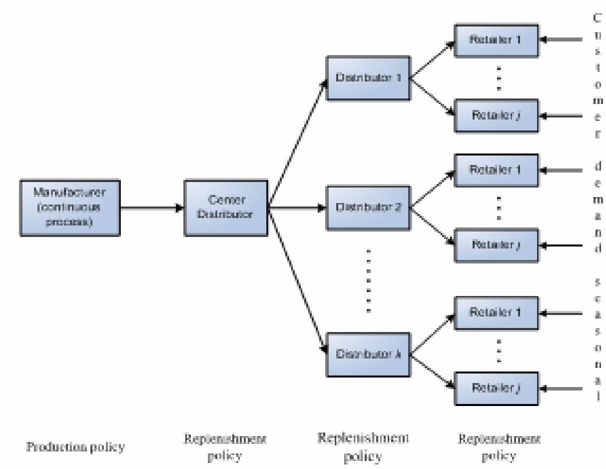

Figure 1: Framework of The Production-Distribution System

In developing the integrated production-distribution model, three approaches are used, i.e.: coordinated policy, echelon inventory concept, and single cycle time policy. The coordinated policy approach leads the manufacturer, the distribution center, the distributors and the retailers to perform coordination for determining the production and the replenishment policies. The production and the replenishment policies that have been decided must be obeyed by all entities in the supply chain systems.

In the echelon inventory concepts [11], total inventory at an entity in one echelon is the sum of on-hand and in-transit inventories and all inventories at its downstream echelons. This concept is very different with the normal calculation of holding cost that uses average inventory at each entity.

Using the single cycle time policy [12] means that all entities start to produce or order product in the same time. As a result, the production cycle (T_o) would be an integer multiplied by the replenishment cycle of distribution center (T_g), i.e., $T_o=N_gT_g$, where N_g is an integer. By the same token, the replenishment cycle of distribution center (T_g) is an integer multiplied by the replenishment cycle of distributor k (Td_k) and the replenishment cycle of distributor k (Td_k) is also an integer multiplied by the replenishment cycle of retailer j; $j \in k$ (Tr_{kj}). Generally, the single cycle time policy can be formulated as follow:

$$T_o = N_g T_g = N_g N_{d_k} T_{d_k} = N_g N_{d_k} N_{r_{kj}} T_{r_{kj}} \qquad (1)$$

In addition to the three approaches explained above, an integrated production-distribution model is developed with periodic review based on models that are developed by [5] and [6].

3. Model Development

3.1. Mathematical Notation

The mathematical notations used in the model are defined as follows:

Indexes

- k distributor index
- j retailer index

Variables

- To production cycle
- Tg replenishment cycle of distribution center
- Td_k replenishment cycle of distributor k
- Tr_{kj} replenishment cycle of retailer j supplied by distributor k
- Ng an integer of a multiplication of the replenishment cycle of the distribution center in a production cycle
- Nd_k an integer of a multiplication of the replenishment cycle of distributor k in a replenishment cycle of the distribution center
- Nr_{kj} an integer of a multiplication of the replenishment cycle of retailer j in a replenishment cycle of distributor $k; j \in k$
- R_o level of maximum inventory at the manufacturer
- R_g level of maximum inventory at the distribution center
- Rd_k level of maximum inventory at distributor k
- Rr_{kj} level of maximum inventory at retailer $j; j \in k$
- Zr_{kj} demand function at retailer j; $j \in k$ (a polynomial function of time)
- Zd_k demand function at distributor k (a polynomial function of time)
- Z_g demand function at the distribution center (a polynomial function of time)
- Z_o demand function at the manufacturer (a polynomial function of time)
- C total system cost per year

Parameters

- Ar_{kj} cost of each product replenishment at retailer j that is supplied by distributor k

Hr_{kj} product holding cost per ton per year at retailer j that is supplied by distributor k

Ad_k cost of each product replenishment at distributor k

Hd_k product holding cost per ton per year at distributor k

A_g cost of each product replenishment at the distribution center

H_g product holding cost per ton per year at the distribution center

A_p cost of production facility maintenance

A_o production facility start-up cost

H_o product holding cost per ton per year at the manufacturer

ψ production rate

w_t technical production facility age

C_g^o transportation cost of product from manufacturer to distribution center

$C_{d_k}^g$ transportation cost of product from distribution center to distributor k

$C_{r_j}^{d_k}$ transportation cost of product from distributor k to retailer j; $\forall j \in k$

3.2. Model Formulation

The production cycle, the integer of a multiplication of the replenishment cycle of the distribution center in a production cycle, the integer of a multiplication of the replenishment cycle of distributor k in a replenishment cycle of the distribution center integer of a multiplication of the replenishment cycle of retailer j in a replenishment cycle of distributor k; $j \in k$ will be determined so that the total system cost per year is minimum. The total system cost per year (C) consists of total cost per year at manufacturer (C_o), distribution centers (C_g), distributors (C_d) and retailers (C_r).

The assumptions used in developing the model are:

1. The customer's demand at all retailers depend on time and are deterministic
2. No stock-outs are permitted at all echelons
3. The entire replenishment lot size is added to inventory at the same time (for distribution center, all distributors and all retailers)
4. Products at a distributor can be transferred to other distributors; similarly at a retailer.
5. Production capacity is large enough to supply all customer demands.
6. Production cost per unit; ordering cost at distribution centers, distributors and retailers; and transportation cost per unit are constant

Due to the pattern of the customer demand occurred at retailer is deterministic time-dependent, inventory at the end of cycle is zero and safety stock is not necessary. Therefore the level of maximum inventory per period is equal to total demand per period. The time-dependent demand cause the level of maximum inventory is not equal for each period. In this model, a polynomial function is used as an approximation for the time-dependent pattern of the customer demand. According to the above analysis, total cost of retailer per year that consisted of replenishment cost and holding cost per year at all retailer j, $j \in k$ is given as follows:

$$C_r = \sum_{\forall k} \sum_{\forall j \in k} \left\{ \frac{A_{r_{kj}}}{T_{r_{kj}}} + \frac{H_{r_{kj}} T_{r_{kj}}}{2} \int_0^1 z_{r_{kj}}(t)\,dt \right\} \tag{2}$$

The total cost of distributor per year can be obtained from replenishment cost, holding cost and transportation cost per year at all distributor k. As result of using echelon inventory concept, total inventory at distributor k is the total inventory at distributor k itself and total inventory at all retailer j that are supplied by distributor k. By using this method, total cost of distributor per year can be formulated as follows:

$$= \sum_{k=1}^{K} \left\{ \frac{A_{d_k}}{T_{d_k}} + \frac{H_{d_k} T_{d_k}}{2} \left(\int_0^1 z_{d_k}(t)\,dt + \sum_{\forall j \in k} \int_0^{\frac{Nr_{kj} Tr_{kj}}{Td_k}} z_{r_{kj}}(t)\,dt \right) + \sum_{\forall j \in k} C_{r_j}^{d_k} \int_0^1 z_{r_{kj}}(t)\,dt \right\} \tag{3}$$

Total inventory at the distribution center is total inventory at distribution center itself, all distributors and all retailers. By the same token, the total cost of distribution center per year is formulated as shown:

$$C_g = \frac{A_g}{T_g} + \frac{H_g T_g}{2} \left(\int_0^1 z_g(t)\,dt + \sum_{\forall k} \int_0^{\frac{Nd_k T_{d_k}}{T_g}} z_{d_k}(t)\,dt + \sum_{\forall k} \sum_{\forall j \in k} \int_0^{\frac{Nd_k Nr_{kj} Tr_{kj}}{T_g}} z_{r_{kj}}(t)\,dt \right) + \sum_{\forall k} C_{d_k}^g \int_0^1 z_{d_k}(t)\,dt \tag{4}$$

With a production rate (ψ), the average of operational inventory per cycle at the manufacturer can be obtained using this equation:

$$= \frac{1}{2} \int_0^{T_o} z_o(t)\,dt \left(1 - \frac{1}{\psi} \int_0^1 z_o(t)\,dt \right) \tag{5}$$

According to the echelon inventory approach used, the formulation of total cost of the manufacturer per year is:

$$C_o = \frac{A_o + A_p}{T_o} + \frac{H_o T_o}{2}\left(\int_0^1 z_o(t)\,dt \left(1 - \frac{1}{\psi}\int_0^1 z_o(t)\,dt\right) + \int_0^{\frac{N_g\,T_g}{T_o}} z_g(t)\,d + \right.$$

$$\left. \sum_{\forall k} \int_0^{\frac{Ng\,Nd_k T_{d_k}}{T_o}} z_{d_k}(t)\,dt + \sum_{\forall k}\sum_{\forall j \in k} \int_0^{\frac{Ng\,Nd_k Nr_{kj} Tr_{kj}}{T_o}} z_{r_{kj}}(t)\,dt \right) +$$

$$C_g^o \int_0^1 z_g(t)\,dt \tag{6}$$

Finally, we can derive the objective function. The objective function is total system cost per year that comprises of the set-up or replenishment cost, holding cost and transportation cost at manufacturer, distribution center, distributors and retailers, as in the following formula:

Minimize the total system cost

$$C = \frac{A_o + A_p}{T_o} + \frac{H_o T_o}{2}\left(\int_0^1 z_o(t)\,dt \left(1 - \frac{1}{\psi}\int_0^1 z_o(t)\,dt\right) + \int_0^{\frac{N_g\,T_g}{T_o}} z_g(t)\,dt + \right.$$

$$\left. \sum_{\forall k} \int_0^{\frac{Ng\,Nd_k T_{d_k}}{T_o}} z_{d_k}(t)\,dt + \sum_{\forall k}\sum_{\forall j \in k} \int_0^{\frac{Ng\,Nd_k Nr_{kj} Tr_{kj}}{T_o}} z_{r_{kj}}(t)\,dt \right) + C_g^o \int_0^1 z_g(t)\,dt +$$

$$\frac{A_g}{T_g} + \frac{H_g T_g}{2}\left(\int_0^1 z_g(t)\,dt + \sum_{\forall k} \int_0^{\frac{Nd_k\,T_{d_k}}{T_g}} z_{d_k}(t)\,dt + \sum_{\forall k}\sum_{\forall j \in k} \int_0^{\frac{Nd_k Nr_{kj} Tr_{kj}}{T_g}} z_{r_{kj}}(t)\,dt \right) +$$

$$\sum_{\forall k} C_{d_k}^g \int_0^1 z_{d_k}(t)\,dt + \sum_{\forall k}\left\{ \frac{A_{d_k}}{T_{d_k}} + \frac{H_{d_k} T_{d_k}}{2}\left(\int_0^1 z_{d_k}(t)\,dt + \sum_{\forall j \in k} \int_0^{\frac{Nr_{kj} Tr_{kj}}{Td_k}} z_{r_{kj}}(t)\,dt \right) + \right.$$

$$\left. \sum_{\forall j \in k} C_{r_j}^{d_k} \int_0^1 z_{r_{kj}}(t)\,dt \right\} + \sum_{\forall k}\sum_{j \in k}\left\{ \frac{A_{r_{kj}}}{T_{r_{kj}}} + \frac{H_{r_{kj}} T_{r_{kj}}}{2} \int_0^1 z_{r_{kj}}(t)\,dt \right\} \tag{7}$$

Subject to the following constraints:

$$T_o = N_g T_g = N_g N_{d_k} T_{d_k} = N_g N_{d_k} N_{r_{kj}} T_{r_{kj}} \tag{8}$$

$$\int_0^1 z_o(t)\,dt = \int_0^1 z_g(t)\,dt = \sum_{\forall k}\int_0^1 z_{d_k}(t)\,dt = \sum_{\forall k}\sum_{\forall j \in k}\int_0^1 z_{r_{kj}}(t)\,dt \tag{9}$$

$$T_o \le w_t \tag{10}$$

Constraint (8) pertains to use the single cycle time policy approach explained in the framework. Constraint (9) ensure that the total annual demand at manufacturer is the same as the total annual demand at distribution center, and also is the same as the total annual demand at all distributors and is the same as the total annual demand at all retailers. The last constraint (10) ensures that there is enough time to maintain the production facility and the production cycle is less than the technical production facility age (w_t).

Constraints (8) and (9) are substituted to equation (7) and thus the objective function will become:

Minimize the total system cost

$$C = \frac{A_o + A_p}{T_o} + \frac{H_o T_o}{2}\int_0^1 z_o(t)\,dt \left(4 - \frac{1}{\psi}\int_0^1 z_o(t)\,dt\right) + \frac{A_g N_g}{T_o} +$$

$$\frac{3 H_g T_o \int_0^1 z_g(t)\,dt}{2 N_g} + \sum_{\forall k}\left(\frac{A_{d_k} N_g N_{d_k}}{T_o} + \frac{H_{d_k} T_o \int_0^1 z_{d_k}(t)\,dt}{N_g N_{d_k}} \right) +$$

$$\sum_{\forall k}\sum_{j \in k}\left\{ \frac{A_{r_{kj}} N_g N_{d_k} Nr_{kj}}{T_o} + \frac{H_{r_{kj}} T_o \int_0^1 z_{r_{kj}}(t)\,dt}{2 N_g N_{d_k} Nr_{kj}} \right\} +$$

$$\sum_{\forall k}\sum_{\forall j \in k}\int_0^1 z_{r_{kj}}(t)\,dt \left(C_{r_j}^{d_k} + C_{d_k}^{g} + C_g^o \right) \tag{11}$$

Subject to the following constraint:

$$T_o \le w_t \tag{12}$$

4. Solution Procedure

The optimal solution can not be obtained analytically. Therefore, the solution is found through the following heuristic procedure.

Step 1. Find the optimal Ng^* that satisfies the following condition.

$$N_g^*\left(N_g^* - 1\right) \le \frac{\left(A_g + A_o + A_p\right)\left[2\sum_{\forall k} H_{d_k}\int_0^1 z_{d_k}(t)\,dt + 3H_g\int_0^1 z_g(t)\,d\right]}{\sum_{\forall k} 2A_{d_k} H_o \int_0^1 z_o(t)dt \left(4 - \frac{1}{\psi}\int_0^1 z_o(t)dt\right)} \le N_g^*\left(N_g^* + 1\right) \tag{13}$$

Step 2. Find out the optimal Nd_k^* for every k that satisfy the following condition

$$N_{d_k}^*\left(N_{d_k}^* - 1\right) \le \frac{\left(A_g + A_o + A_p\right) H_{d_k}\int_0^1 z_{d_k}(t)dt}{A_{d_k} N_g\left[3H_g\int_0^1 z_g(t)dt + H_o N_g\int_0^1 z_o(t)dt\left(4 - \frac{1}{\psi}\int_0^1 z_o(t)dt\right)\right]} \le N_{d_k}^*\left(N_{d_k}^* + 1\right) \tag{14}$$

Step 3. Find out the optimal Nr_{kj} for every (j, k) that satisfy the following condition.

$$N^*_{r_{kj}}\left(N^*_{r_{kj}}-1\right) \le val \le N^*_{r_{kj}}\left(N^*_{r_{kj}}+1\right) \tag{15}$$

where

$$val = \frac{\left(A_{d_k}+A_g+A_o+A_p\right)H_{r_{kj}}\int_0^1 z_{r_{kj}}(t)dt}{A_{r_{kj}}\left[2H_{d_k}\int_0^1 z_{d_k}(t)dt+3H_g N_{d_k}\int_0^1 z_g(t)dt+H_o N_g N_{d_k}\int_0^1 z_o(t)dt\left(4-\frac{1}{\psi}\int_0^1 z_o(t)dt\right)\right]}$$

Step 4. Find out the optimal To^*

$$T_o = \sqrt{\frac{\sum_{\forall k}\sum_{\forall j\in k} 2N_g N_{d_k} N_{r_{kj}}\left(A_{r_{kj}} N_g N_{d_k} N_{r_{kj}} + A_{d_k} N_g N_{d_k} + A_g N_g + A_o + A_p\right)}{nl}} \tag{16}$$

where

$nl=X+Y$

$$X = \sum_{\forall k}\sum_{\forall j\in k} H_{r_{kj}}\int_0^1 z_{r_{kj}}(t)dt + 2H_{d_k} N_{r_{kj}}\int_0^1 z_{d_k}(t)dt +$$

$$Y = \sum_{\forall k}\sum_{\forall j\in k} 3H_g N_{d_k} N_{r_{kj}}\int_0^1 z_g(t)dt + H_o N_g N_{d_k} N_{r_{kj}}\int_0^1 z_o(t)dt\left(4-\frac{1}{\psi}\int_0^1 z_o(t)dt\right)$$

Step 5. Determine the optimal level of the maximum inventory per period at the manufacturer (Ro_v^*), the distribution center (Rg_p^*), distributors (Rd_{kl}^*) and retailers (Rr_{kjs}^*).

At the manufacturer:

$$R_{o_v} = \int_{(v-1)T_o}^{vT_o} z_o(t)dt \qquad v = 1,\ldots, 1/T_o \tag{17}$$

At the distribution center:

$$R_{g_p} = \int_{\frac{(p-1)T_o}{N_g}}^{\frac{pT_o}{N_g}} z_g(t)dt \qquad p = 1,\ldots, N_g/T_o \tag{18}$$

At distributor k:

$$R_{d_{kl}} = \int_{\frac{(l-1)T_o}{N_g N_{d_k}}}^{\frac{lT_o}{N_g N_{d_k}}} z_{d_k}(t)dt \qquad l = 1,\ldots, N_g Nd_k/T_o;\ \forall k \tag{19}$$

At the retailer j:

$$R_{r_{kjs}} = \int_{\frac{(s-1)T_o}{N_g N_{d_k} N_{r_{kj}}}}^{\frac{sT_o}{N_g N_{d_k} N_{r_{kj}}}} z_{r_{kj}}(t)dt \qquad s=1,\ldots, N_g Nd_k\, Nr_{kj}/T_o;\ \forall j,k \tag{20}$$

Step 6. If $T_o \rangle w_t$ then $T_o=w_t$ and repeat step 5.

5. Numerical Example

The model is applied using the following numerical example. The supply chain system consists of a manufacturer with a continuous production process, a distribution center, two distributors and five retailers as shown in Figure 2. Retailer R_1 and R_2 are supplied by distributor D_1, while retailer R_3, R_4 and R_5 are supplied by distributor D_2.

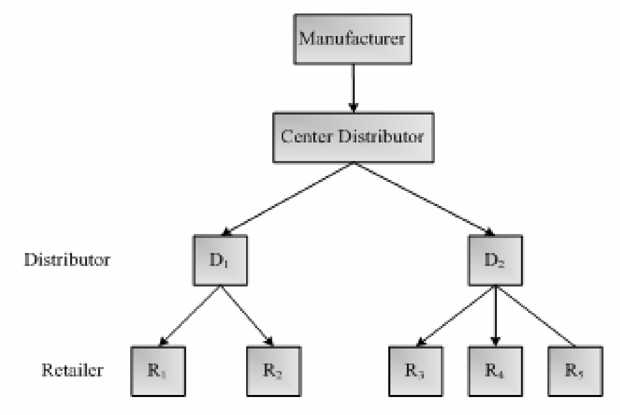

Figure 2: Supply Chain System Structure

Demands at each retailer j are approximated using a polynomial function as follows:

$$z_{r_{kj}}(t) = 82{,}590t^4 - 144{,}900t^3 + 79{,}830t^2 - 16{,}690t + 2{,}885$$

Demand at distributor D_1 is a summation of demands at retailer R_1 and R_2. A Polynomial function of the demand at distributor D_1 is:

$$z_{d_1}(t) = 165{,}200t^4 - 289{,}800t^3 + 159{,}700t^2 - 33{,}380t + 5{,}770$$

Demand at distributor D_2 is a summation of demand at retailer R_3, R_4 and R_5. Total demand at distributor D_2 has a polynomial function as follows

$$z_{d_2}(t) = 247{,}800t^4 - 434{,}700t^3 + 239{,}500t^2 - 50{,}070t + 8{,}655$$

The polynomial function of the demand at the distribution center is a summation of demand at the distributor D_1 and D_2 given by:

$$z_g(t) = 412{,}900t^4 - 724{,}500t^3 + 399{,}100t^2 - 83{,}450t + 14{,}420$$

Because there is only one distribution center therefore the demand at the manufacturer is equal to the demand at the distribution center. The polynomial function of the demand at the manufacturer is given by:

$$z_o(t) = 412{,}900t^4 - 724{,}500t^3 + 399{,}100t^2 - 83{,}450t + 14{,}420$$

The production rate at the manufacturer is assumed as 7,600 ton per year with technical production facility age is 0.93 years.

Three scenarios that include the setup or replenishment costs and holding costs per ton per year are defined and shown in Table 1. Ratios of each setup or replenishment cost to the holding cost per ton per year are shown in Table 2. Using the proposed solution procedure, the optimal solution for each scenario are given in Table 3.

Table 1: Setup or Replenishment Cost and Holding Cost for Each Scenario

		scenario 1	scenario 2	scenario 3
Each setup or replenishment cost (rupiahs)	Manufacturer: start-up cost (A_o)	6,500,000	6,500,000	6,500,000
	Manufacturer: maintenance cost (A_p)	6,000,000	6,000,000	6,000,000
	Distribution Center (A_g)	4,000,000	4,000,000	4,000,000
	Distributor 1 (Ad_1)	4,500,000	4,500,000	4,500,000
	Distributor 2 (Ad_2)	4,000,000	4,000,000	4,000,000
	Retailer 1 (Ar_{11})	100,000	350,000	400,000
	Retailer 2 (Ar_{12})	110,000	320,000	450,000
	Retailer 3 (Ar_{21})	125,000	340,000	500,000
	Retailer 4 (Ar_{22})	120,000	350,000	500,000
	Retailer 5 (Ar_{23})	120,000	350,000	550,000
Echelon holding cost per ton per year (rupiahs)	Manufacturer (H_o)	149,200	149,200	149,200
	Distribution Center (H_g)	165,700	165,700	165,700
	Distributor 1 (Hd_1)	183,600	183,600	183,600
	Distributor 2 (Hd_2)	183,000	183,000	183,000
	Retailer 1 (Hr_{11})	195,000	195,000	195,000
	Retailer 2 (Hr_{12})	195,000	195,000	195,000
	Retailer 3 (Hr_{21})	195,500	195,500	195,500
	Retailer 4 (Hr_{22})	194,000	194,000	194,000
	Retailer 5 (Hr_{23})	195,500	195,500	195,500

Table 2: Ratio of Each Replenishment Cost to Holding Cost per Ton

	Ratio of each replenishment cost to holding cost per ton		
	scenario 1	scenario 2	scenario 3
Manufacturer	83.78	83.78	83.78
Distribution Center	24.14	24.14	24.14
Distributor 1	24.51	24.51	24.51
Distributor 2	21.86	21.86	21.86
Retailer 1	0.51	1.79	2.05
Retailer 2	0.56	1.64	2.31
Retailer 3	0.64	1.74	2.56
Retailer 4	0.62	1.80	2.58
Retailer 5	0.61	1.79	2.81

Table 3: The Optimal Result Using Solution Procedure

		scenario 1	scenario 2	scenario 3
Cycle	Manufacturer (T_o)	0.071	0.072	0.071
	Distribution Center (T_g)	0.071	0.072	0.071
	Distributor 1 (Td_1)	0.071	0.072	0.071
	Distributor 2 (Td_2)	0.071	0.072	0.071
	Retailer 1 (Tr_{11})	0.0237	0.036	0.071
	Retailer 2 (Tr_{12})	0.0237	0.036	0.071
	Retailer 3 (Tr_{21})	0.0355	0.036	0.071
	Retailer 4 (Tr_{22})	0.0355	0.072	0.071
	Retailer 5 (Tr_{23})	0.0355	0.072	0.071
Integer multiple	Distribution Center (N_g)	1	1	1
	Distributor 1 (Nd_1)	1	1	1
	Distributor 2 (Nd_2)	1	1	1
	Retailer 1 (Nr_{11})	3	2	1
	Retailer 2 (Nr_{12})	3	2	1
	Retailer 3 (Nr_{21})	2	2	1
	Retailer 4 (Nr_{22})	2	1	1
	Retailer 5 (Nr_{23})	2	1	1
Total system cost		731,500,000	763,900,000	774,500,000

The ratio of each setup or replenishment cost to the holding cost per ton per year in the manufacturer, distribution center and distributor 1 and 2 is made constant. The decreasing of ratio of replenishment cost to the holding cost in retailer decrease will increase replenishment frequency. It means retailers have smaller inventory because the holding cost is higher.

The consequence of considering the deterministic time-dependent demand is that the level of maximum inventory is not similar for each replenishment period as shown in Table 4 and Table 5. Table 4 indicates the level of maximum inventory at the manufacturer, distribution center and distributor D_1 and D_2 for each replenishment period. Table 5 indicates the level of maximum inventory per each replenishment policy at retailer R1 and R2 that each has an integer of multiplication is 3, and at retailer R3, R4 and R5 that each has an integer of multiplication is 2.

Table 4: The Level of Maximum Inventory at Manufacturer, Distribution Center and Distributor

Period	Manufacturer	Distribution center	Distributor D1	Distributor D2
1	859.02	859.02	343.76	515.63
2	663.35	663.35	265.53	398.26
3	611.02	611.02	244.69	366.92
4	652.26	652.26	261.52	391.91
5	649.21	649.21	260.55	390.28
6	596.27	596.27	239.70	358.79
7	490.56	490.56	197.82	295.71
8	347.36	347.36	141.04	210.26
9	200.16	200.16	82.77	122.52
10	100.59	100.59	43.67	63.51
11	118.46	118.46	51.69	75.136
12	341.77	341.77	142.04	210.23
13	876.67	876.67	357.21	532.52

Table 5: The Level of Maximum Inventory at Retailers

Period	Retailer	
	R1 & R2	R3,R4 & R5
1	64.141	93.311
2	56.712	78.565
3	51.024	69.077
4	43.901	61.296
5	42.018	61.002
6	40.981	61.959
7	40.604	63.45
8	40.713	64.871
9	41.153	65.733
10	41.782	65.658
11	42.473	64.383
12	43.115	61.76
13	43.611	57.752
14	43.878	52.438
15	43.85	46.007
16	43.475	38.767
17	42.716	31.135
18	41.551	23.643
19	39.972	16.937
20	37.989	11.777
21	35.623	9.035
22	32.912	9.698
23	29.91	14.866
24	26.683	25.753
25	23.315	43.686
26	19.903	70.107
27	16.56	106.569
28	13.414	
29	10.606	
30	8.294	
31	6.652	
32	5.865	
33	6.137	
34	7.685	
35	10.741	
36	15.553	
37	22.382	
38	31.505	
39	43.216	
40	57.82	
41	75.64	

6. Conclusion

This paper has proposed an integrated production-distribution model for 4-echelon supply chain systems. In this model, the manufacturer has a continuous production process and the retailers have a time-dependent demands pattern. The effect of considering time-dependent demand is that the level of maximum inventory is not equal for each replenishment period at the manufacturer, distribution center, distributors and retailers.

The proposed model is based on an assumption that no stock-out is permitted and the production capacity is large enough to supply all customer demands. Further research using a probabilistic time-dependent demand would contribute to our understanding of the behavior of this system. A supply rationing policy can be considered in this model as an extended model if the production capacity is less than customer demands.

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