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OPTIMAL PRODUCTION-DISTRIBUTION PLANNING IN SUPPLY CHAIN MANAGEMENT USING A HYBRID SIMULATION-ANALYTIC APPROACH

Young Hae Lee
Sook Han Kim

Department of Industrial Engineering
Hanyang University
Ansan, Kyunggi-do, 425-791, SOUTH KOREA

ABSTRACT

Production-distribution planning is the most important activity in supply chain management (SCM). To solve this planning problem, either analytic or simulation approaches have been used. However these two approaches have their own demerits in problem solving. In this paper, we propose a hybrid approach which is a specific problem solving procedure combining analytic and simulation methods to solve production-distribution problems in supply chains. The machine capacity and distribution capacity constraints in the analytic model are considered as stochastic factors and are adjusted by the proposed specific process according to the results from an independently developed simulation model which includes general production-distribution characteristics.

1 INTRODUCTION

Production-distribution planning is one of the most important activities in supply chain management (SCM). To implement SCM in real logistic world, supply chains have been modeled in analytic ways using deterministic or stochastic methods. Cohen and Lee (1988) use three different cost-based stochastic sub-models: material control sub-model, production sub-model, distribution sub-model to develop a model for establishing a material requirement policy for all materials for every shop in the supply chain production system. Thomas and Griffin (1996) define three categories of operational coordination: buyer and vendor, production and distribution, inventory and distribution. They introduce various deterministic models according to these categories. Vidal and Goetschalckx (1997) review the strategic production-distribution models. They focus on global supply chain models with emphasis on mixed integer programming models. Petrovic et al. (1998) describe fuzzy modeling and simulation of a supply chain in an uncertain environment. Customer demand and supply of raw material are interpreted and represented by fuzzy sets.

However, most of realistic problems are not simple to apply these analytic ways only. Simulation is preferred when an analytic solution can not give proper values for performance evaluations. Therefore, the hybrid procedure integrating analytic and simulation model for solving production-distribution planning problem is a useful idea.

The objective of this paper is to develop an integrated multi period, multi product, multi shop production and distribution model in supply chain to satisfy the retailer's demand while keeping inventories as low as possible. We formulated the problem as an analytic model which minimizes the sum of production cost, distribution cost, inventory holding and deficit costs, subject to capacity and inventory balance constraints and propose a hybrid method combining mathematical programming and simulation model to solve this problem.

2 PRODUCTION-DISTRIBUTION PROBLEM IN SUPPLY CHAIN

Production-distribution in supply chains can take on many forms. In general, there are two distinctive models: production and distribution models, designed to be linked together and considered as a production-distribution model in supply chain. These models are operationally connected and closely related with each other.

The first shop of production model produces n different products that are used in the production of m different products at the second shop of production model. An example is a general manufacturing system where the first shop consists of fabricating machines machining a number of different types of parts and the second shop contains assembling machines that use the parts in producing several types of products.

The distribution model contains stack buffers where all products produced in production model are temporarily stored and intermediate warehouses storing all kinds of products and retailers that are the origin of demand. Products are transported in unit size from stack buffers either to warehouses or to retailers directly or moved from warehouses to retailers to satisfy their demands. The problem is to meet the production and distribution requirements at minimum costs of production, distribution and inventory, subject to various resource constraints. The structure of a multi period, multi product, multi shop production and distribution system in supply chain environment is described in Figure 1.

3 ANALYTIC MODEL DEVELOPMENT

The production and distribution system are connected and interrelated with each other. Therefore, these models should be modeled in an integrated way. We formulate this situation as a linear programming model explained in Appendix A.

4 A HYBRID SIMULATION – ANALYTIC APPROACH

The hybrid simulation-analytic approach consists of building independent analytic and simulation model of the total system, developing their solution procedures, and using their solution procedures together for problem solving.

Generally, assigning the capacity which is total operation time for production and distribution and which also represents machine center capacity and distribution center capacity in the analytic model is a difficult task. Therefore in many researches, the capacity is known and fixed. But in the real systems significant difference exits between capacity and the required time to achieve the production and distribution plan.

The procedure of the hybrid simulation-analytic approach is based on imposing adjusted capacities derived from the simulation model results. The procedure consists of the following steps:

Step 1. Obtain production and distribution rates from the analytic model.
Step 2. Input production and distribution rates to the independently developed simulation model.
Step 3. Simulate the system subject to realistic operational policies.
Step 4. If the simulation model results show that production and distribution rates obtained from step 1 can be produced and distributed within the capacity, then go to step 6. Otherwise go to step 5.
Step 5. Adjust capacity constraints for the analytic model based on the simulation results from step 3 and regenerate production and distribution rates and go to step 3.
Step 6. Production and distribution rates given by the analytic model may be considered to be optimal solutions.
Step 7. Stop.

The capacity is the right hand side of constraint equation (A-7), (A-8), (A-19), (A-20) of the analytic model(see Appendix). This solution procedure is illustrated by a flow diagram in Figure 2.

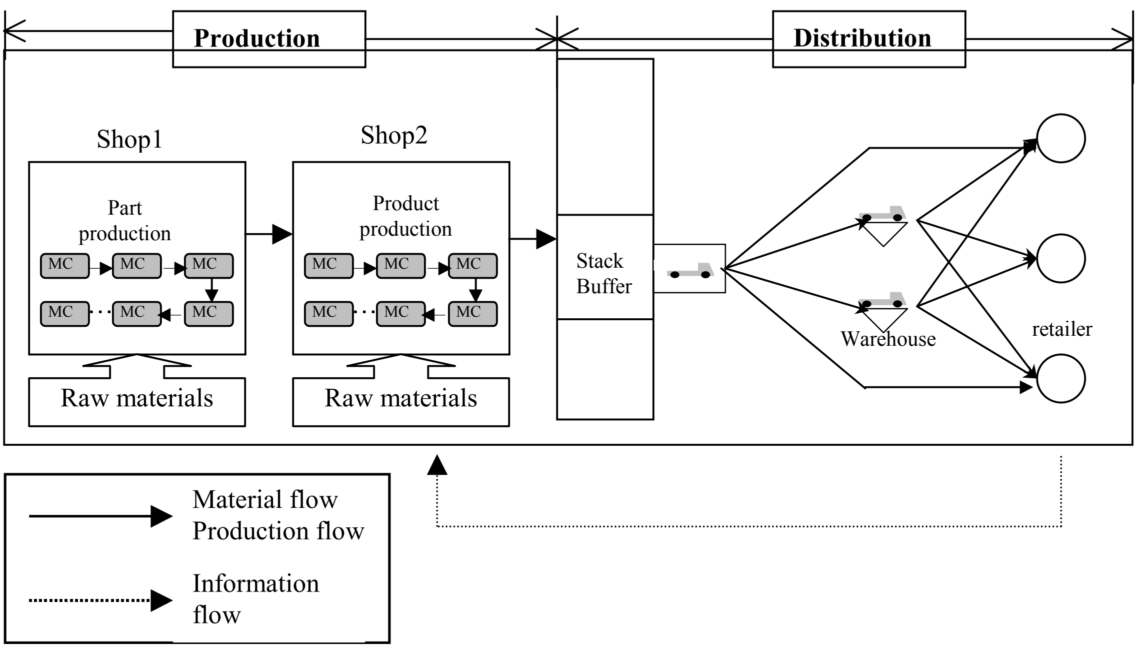


Figure 1: A Production-Distribution System under Study

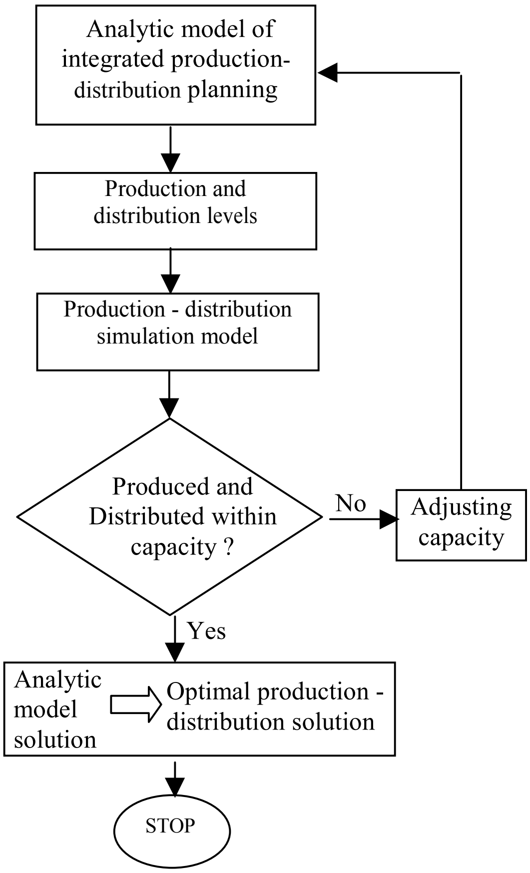


Figure 2: Hybrid Solution Procedure

Capacity in the analytic model is considered as a stochastic factor and this factor is properly adjusted by an adjusting process to obtain the optimal capacity in which production and distribution rates of analytic model can be produced and distributed through simulation.

Capacity adjustments are made through the following procedures.

Step 1. Capacity is adjusted. Initial capacity of the system is given.
Step 2. Obtain production and distribution rates from analytic model with capacity of step 1.
Step 3. Make 10 independent replications of the simulation for production and distribution rates from step 2 and obtain the 90% confidence interval for the average consumed simulation time.
Step 4. If the lower bound of 90% confidence interval from step 3 lies between the selected (criteria) capacity (= 0.95 × adjusted capacity) and the adjusted capacity from step 1, then stop. Otherwise, go to step 5.
Step 5. If the lower bound of 90% confidence interval from step 3 less than the selected capacity then go to step 6. Otherwise go to step 7.
Step 6. New capacity = capacity + 0.5 × capacity. Update the replication number and go to step 1.
Step 7. New capacity = capacity - 0.5 × capacity. Update the replication number and go to step 1.

This adjusting procedure is illustrated in Figure 3.

5 EXPERIMENTS

The hybrid simulation-analytic approach is applied to a cost minimization problem of the production-distribution system in supply chain.

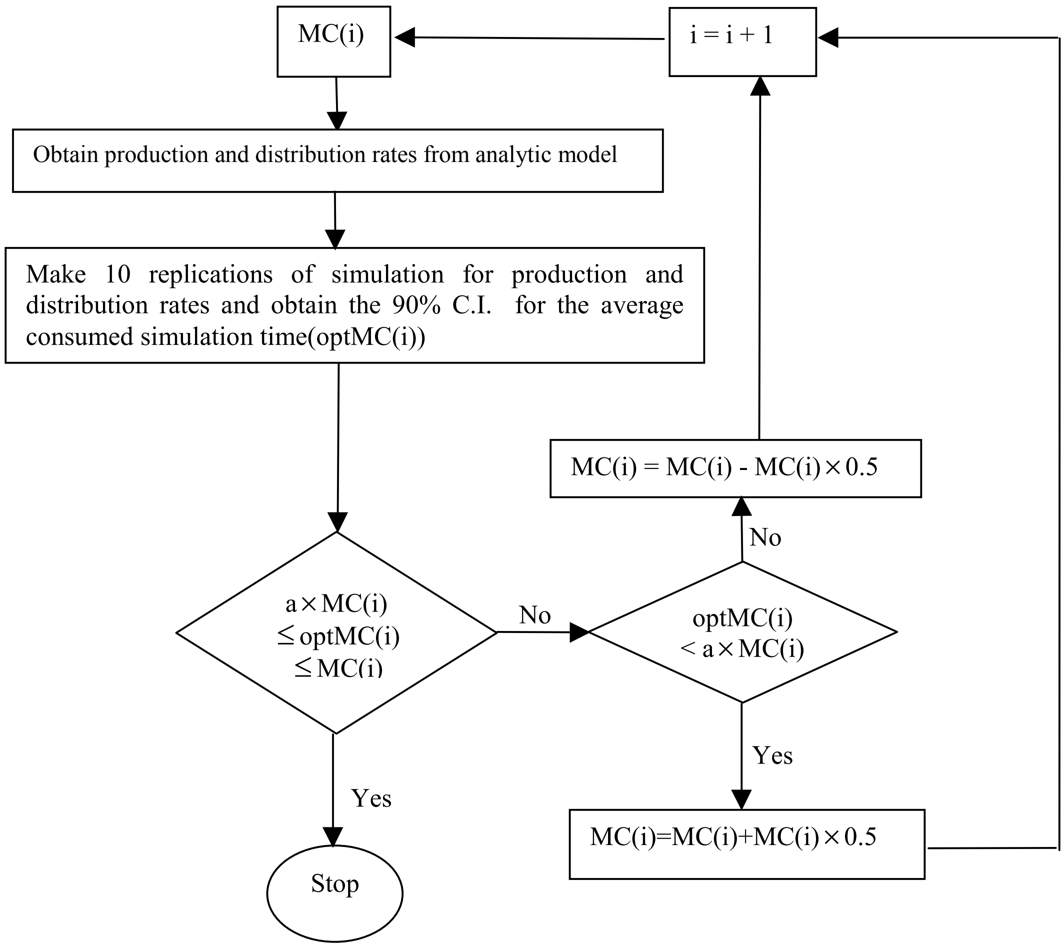
The production system consists of 2 shops, each shop has 3 machining centers, and each machining center has 1 machine having 1 input buffer and 1 output buffer. Parts and products are moved between machine centers by non-accumulating belt conveyors.

The distribution system comprises of 1 stack and 2 warehouses and 3 retailers. Products are transported along the routes by the unit vehicle which load one unit of product. Stack and each warehouse have a unit vehicle. Capacity of total system is initially 3000minutes per period.

The analytic part of the hybrid procedure is modeled as a linear program (LP). GAMS (General Algebraic Modeling System), a LP solver is adopted to implement the formulation. The demand and various cost data, process routings and process times, transportation times according to routes are given.

The simulation model of the system was developed by using simulation tool, ARENA, a C^{++} based, simulation tool. The simulation model accommodates the stochastic characteristics of production-distribution system in supply chain, such as machine and vehicle breakdowns, repair times ,queuing and transportation delays, delivery priority, routings which are difficult to be included in the analytic model. Therefore, the iterative hybrid procedure provides more realistically feasible optimal solutions.

The resulting optimal production and distribution plans through the iterations for each period are given in Table 1. The results are the same after the fifth iteration, so we considered the solution at the fifth iteration is the optimal solution. This shows that the simulation analysis of the system has not validated the initial optimal results of the analytic model. It is observed that demand fill rate in distribution is lower than demand fill rate in production. Eventually, comparing with analytic solutions, demand fill rate for retailers in production is decreased down to 45.2% and distribution fill rate for initial analytic solutions in distribution is dwindled to 27.4% In order to satisfy retailer’s demand fully, capacity should be increased. We may increase the number of machine or vehicle or total capacity.



MC(i): Capacity of i^{th} replication for the system adjusted by adjusting procedure,
MC(0) = initial capacity

optMC(i): The lower bound of 90% confidence interval of 10 replications for the average consumed simulation time in i^{th} replication
a : Rate for capacity for comparison decided by planner (0.95 in this paper)

Figure 3: Capacity Adjustment Procedure

Table 1: Experimental Results for Production System

			Periods	Demands	Initial Analytic Model Solutions	Iterative Solutions for Production					
						1	2	3	4	5	6
Production Levels	Part	1	1		645	540	540	336	302	245	245
			2		645	600	613	336	302	245	245
			3		330	480	467	336	302	245	245
		2	1		968	810	810	503	453	367	367
			2		968	900	919	503	453	367	367
			3		494	720	701	503	453	367	367
	Product	1	1	75	75	75	75	34	30	24	24
			2	80	80	80	80	14	5	0	0
			3	60	60	60	60	54	50	44	44
		2	1	60	86	60	60	50	45	37	37
			2	70	81	70	73	70	70	61	61
			3	60	23	60	57	30	25	17	17
Adjusted capacity (min)					3000	2143.5	1531.5	838.8	754.9	611.5	611.5
Average demand fill rate for retailer (%)					100	100	100	62.2	55.6	45.2	45.2

Table 2: Experimental Results for Distribution System

	Products	Periods	Distribution Routes	Initial Analytic Model Solutions	Iterative Solutions for Distribution					
					1	2	3	4	5	6
Distribution Plans	1	1	L – P	70	56	10	0	0	0	0
			L – Q	5	0	0	0	0	0	0
			P – Q	70	56	10	0	0	0	0
		2	L – P	17	75	64	30	30	30	30
			L – Q	43	0	0	0	0	0	0
			P – Q	17	60	60	30	30	30	30
		3	L – P	67	65	46	20	20	20	20
			L – Q	13	0	0	0	0	0	0
			P – Q	67	80	50	20	20	20	20
	2	1	L – P	53	73	85	51	45	36	36
			L – Q	17	0	0	0	0	0	0
			P – Q	53	70	70	51	41	29	29
		2	L – P	60	57	25	21	15	7	7
			L – Q	0	0	0	0	0	0	0
			P – Q	60	60	40	20	20	15	15
		3	L – P	50	60	45	31	25	17	17
			L – Q	10	0	0	0	0	0	0
			P – Q	50	60	45	30	25	17	17
Adjusted capacity (min)				3000	2143.5	1531.5	838.8	754.9	611.5	611.5
Average distribution rates for initial analytic solutions (%)				100	95.3	67.9	37.3	33.6	27.4	27.4

L: Stack, P: Warehouse , Q: Retailer
Optimal capacity: 611.5 minutes

6 CONCLUSIONS

In this paper, we presented a hybrid method combining the analytic and simulation model for an integrated production-distribution system in supply chain environment.

The hybrid method uses advantages of both modeling methods while avoiding demerits of both methods. The solution procedure of independently developed analytic and simulation model were used together to solve the problem.

We also presented an efficient algorithm that can find more realistic and optimal capacity for production and distribution. Through experiments of the hybrid method, it is verified that the initial analytic solutions can not be accepted in the real world system having stochastic characteristics which are not included in analytic model. Hybrid method provides more realistic optimal solutions for the integrated production-distribution planning in supply chain that are quite different from the initial analytic solutions.

Finding the optimal capacities through hybrid method satisfying fluctuated customer demands in supply chain during certain time period under real world situation is a further research area.

APPENDIX A

The mathematical formulation

Indices and Constants

t : period index (t = 1,2,3, …,T)
i : part index in shop1 of production model (i = 1,2,3,…,N)
j :product index in shop2 of production model (j = 1,2,3,…,M)
v : machine index for shop1 (v = 1,2,3,…,V)
u : machine index for shop2 (u = 1,2,3,…,V)
k : raw material index for shop1 (k = 1,2,3,…K)
r : raw material index for shop2 (r = 1,2,3,…,R)
l : stack point index
p : warehouse index(p =1,2,3,…,P)
q : retailer index(q =1,2,3,…,Q)
D_{jt} : demand for product j in period t
a_{ij} : number of units of part i used to make one unit of product j
d_{ki} : number of units of raw material k used to make one unit of part i
g_{rj} : number of units of raw material r used to make one unit of product j
b_{kt} : available amount of raw material k in period t

b_{rt} : available amount of raw material r in period t
C_{it} : cost to produce a unit of part i in period t
C_{jt} : cost to produce a unit of product j in period t
C_{kt} : cost to buy a unit of raw material k in period t
C_{rt} : cost to buy a unit of raw material r in period t
H_{it} : cost to hold a unit of part i in period t
H_{jt} : cost to hold a unit of product j in period t
H_{kt} : cost to hold a unit of raw material k in period t
H_{rt} : cost to hold a unit of raw material r in period t
π_{it} : unit cost of sales lost for part i in period t
π_{jt} : unit cost of sales lost for product j in period t
π_{kt} : unit cost of deficit for raw material k in period t
π_{rt} : unit cost of deficit for raw material r in period t
a_{iu} : processing time to produce a unit of part i on machine center u
a_{jv} : processing time to produce a unit of product j on machine center v
MC_{ut} : capacity of machine center u in period t
MC_{vt} : capacity of machine center v in period t
DEM_{qjt} : demand for product j from retailers q in period t
SL_{jt} : storage cost of product j at stack point in period t
SP_{pjt} : storage cost of product j at warehouse p in period t
SQ_{qjt} : storage cost of product j at retailer q in period t
SLL_{jt} : shortage cost of product j at stack point in period t
SPP_{pjt} : shortage cost of product j at warehouse p in period t
SQQ_{qjt} : shortage cost of product j at retailer q in period t
LPC_{p} : the cost of transporting any product from stack point to warehouse p
LQC_{q} : the cost of transporting any product from stack point to retailer q
PQC_{pq} : the cost of transporting any product from warehouse p to retailer q
TQ_{qt} : product holding capacity at retailer q in period t
TP_{pt} : product holding capacity at warehouse p in period t
SB_{t} : product holding capacity at stack buffer in period t
TC_{t} : the distribution capacity at stack point in period t
TC_{pt} : the distribution capacity at warehouse p in period t
a_{p} : distribution time to transport any product from stack point to warehouse p
b_{q} : distribution time to transport any product from stack point to retailer q
c_{pq} : distribution time to transport any product from warehouse p to retailer q

Decision Variables

X_{it} : number of units of part i at shop1 in period t
Y_{jt} : number of units of product j at shop2 in period t
I_{it}^{+} : amount of end of period inventory of part i in period t
I_{it}^{-} : amount of end of period deficit of part i in period t
I_{jt}^{+} : amount of end of period inventory of product j in period t
I_{jt}^{-} : amount of end of period deficit of product j in period t
E_{kt} : number of units of raw material k in period t
F_{rt} : number of units of raw material r in period t
I_{kt}^{+} : amount of end of period inventory of raw material k in period t
I_{kt}^{-} : amount of end of period deficit of raw material k in period t
I_{rt}^{+} : amount of end of period inventory of raw material r in period t
I_{rt}^{-} : amount of end of period deficit of raw material r in period t
LP_{pjt} : amount of product j transported from stack point to warehouse p in period t
LQ_{qjt} :amount of product j transported from stack point to retailer q in period t
PQ_{pqjt} :amount of product j transported from warehouse p to retailer q in period t
L_{jt} :amount of product j stored at stack point in period t
P_{pjt} :amount of product j stored at warehouse p in period t
Q_{qjt} :amount of product j stored at retailer q in period t
L_{jt}^{+} : amount of end of period inventory of product j at stack point in period t
L_{jt}^{-} : amount of end of period deficit of product j at stack point in period t
Q_{qjt}^{+} : amount of end of period inventory of product j at retailer q in period t
Q_{qjt}^{-} : amount of end of period deficit of product j at retailer q in period t

P_{pjt}^{+} : amount of end of period inventory of product j at warehouse p in period t

P_{pjt}^{-} : amount of end of period deficit of product j at warehouse p in period t

Objective Function

Min

$$Z=\sum_{t=1}^{T}\left\{\begin{array}{l}\sum_{i=1}^{N}C_{it}X_{it}+H_{it}I_{it}^{+}+\pi_{it}I_{it}^{-}+\sum_{j=1}^{M}C_{jt}Y_{jt}+H_{jt}I_{jt}^{+}+\pi_{jt}I_{jt}^{-}\\ \sum_{k=1}^{K}C_{kt}E_{kt}+H_{kt}I_{kt}^{+}+\pi_{kt}I_{kt}^{-}+\sum_{r=1}^{R}C_{rt}F_{rt}+H_{rt}I_{rt}^{+}+\pi_{rt}I_{rt}^{-}\\ \sum_{j=1}^{M}SL_{jt}L_{jt}^{+}+SLL_{jt}L_{jt}^{-}+\sum_{j=1}^{M}\sum_{p=1}^{P}SP_{jpt}I_{jpt}^{+}+SPP_{jpt}I_{jpt}^{-}\\ +\sum_{j=1}^{M}\sum_{q=1}^{Q}SQ_{jqt}I_{jqt}^{+}+SQQ_{jqt}I_{jqt}^{-}+\sum_{j=1}^{M}\sum_{p=1}^{P}LPC_{P}LP_{jpt}\\ +\sum_{j=1}^{J}\sum_{q=1}^{Q}LQC_{q}LQ_{jqt}+\sum_{j=1}^{M}\sum_{p=1}^{P}\sum_{q=1}^{Q}PQC_{pq}PQ_{jpqt}\end{array}\right\},\forall i,j,p,q,t$$

Subject to:

$$I_{jt}=I_{jt-1}+Y_{jt}-D_{jt},\forall j,t \qquad \text{(A-1)}$$

$$I_{it}=I_{it-1}+X_{it}-\sum_{j=1}^{M}a_{ij}Y_{jt},\forall i,t \qquad \text{(A-2)}$$

$$I_{rt}=I_{rt-1}+F_{rt}-\sum_{j=1}^{M}g_{rj}Y_{jt},\forall r,t \qquad \text{(A-3)}$$

$$I_{kt}=I_{kt-1}+E_{kt}-\sum_{i=1}^{N}d_{ki}X_{it},\forall k,t \qquad \text{(A-4)}$$

$$\sum_{j=1}^{M}g_{rj}Y_{jt}\le b_{rt},\forall r,t \qquad \text{(A-5)} \qquad \sum_{i=1}^{N}d_{ki}X_{it}\le b_{kt},\forall k,t$$

$$\text{(A-6)} \qquad \sum_{j=1}^{M}a_{jv}Y_{jt}\le MC_{vt},\forall v,t \qquad \text{(A-7)}$$

$$\sum_{i=1}^{N}a_{iu}X_{it}\le MC_{ut,}\forall u,t \qquad \text{(A-8)} \qquad I_{jt}=I_{jt}^{+}-I_{jt}^{-},\forall j,t$$

$$\text{(A-9)} \qquad I_{it}=I_{it}^{+}-I_{it}^{-},\forall i,t \qquad \text{(A-10)}$$

$$I_{rt}=I_{rt}^{+}-I_{rt}^{-},\forall r,t \qquad \text{(A-11)} \qquad I_{kt}=I_{kt}^{+}-I_{kt}^{-},\forall k,t$$

$$\text{(A-12)} \qquad \sum_{p}^{P}LP_{pjt}+\sum_{q}^{Q}LQ_{qjt}-L_{jt-1}\le Y_{jt}+L_{jt},\forall j,t \qquad \text{(A-}$$

$$\text{13)} \qquad LQ_{qjt}+\sum_{p}^{P}PQ_{pqjt}-Q_{qjt-1}\ge DEM_{qjt}+Q_{qjt},\forall q,j,t \qquad \text{(A-}$$

14)

$$P_{pjt-1}+LP_{pjt}=\sum_{q}^{Q}PQ_{pqjt}+P_{pjt},\forall p,j,t \qquad \text{(A-15)}$$

$$\sum_{j=1}^{M}Y_{jt}\le SB_{t},\forall t \qquad \text{(A-16)}$$

$$\sum_{j=1}^{M}LQ_{qjt}+\sum_{p=1}^{P}\sum_{j=1}^{M}PQ_{pqjt}\le TQ_{qt},\forall q,t \qquad \text{(A-17)}$$

$$\sum_{j=1}^{M}LP_{pjt}\le TP_{pt},\forall p,t \qquad \text{(A-18)}$$

$$\sum_{p}^{P}\sum_{j}^{M}a_{p}\times LP_{pjt}+\sum_{q}^{Q}\sum_{j}^{M}b_{q}\times LQ_{qjt}\le TC_{t},\forall t \qquad \text{(A-19)}$$

$$\sum_{q}^{Q}\sum_{j}^{M}c_{pq}\times PQ_{pqjt}\le TC_{pt},\forall p,t \qquad \text{(A-20)}$$

$$L_{jt}=L_{jt}^{+}-L_{jt}^{-},\forall j,t \qquad \text{(A-21)}$$

$$Q_{qjt}=Q_{qjt}^{+}-Q_{qjt}^{-},\forall q,j,t \qquad \text{(A-22)}$$

$$P_{pjt}=P_{pjt}^{+}-P_{pjt}^{-},\forall p,j,t \qquad \text{(A-23)}$$

$$I_{jt}^{+},I_{jt}^{-},Y_{jt}\ge 0,\forall j,t\ ,\ I_{it}^{+},I_{it}^{-},X_{it}\ge 0,\forall i,t\ ,$$

$$I_{rt}^{+},I_{rt}^{-},F_{rt}\ge 0,\forall r,t\ ,\ I_{kt}^{+},I_{kt}^{-},E_{kt}\ge 0,\forall k,t \qquad \text{(A-24)}$$

$$L_{jt}^{+},L_{jt}^{-},P_{jt}^{+},P_{jt}^{-},Q_{jt}^{+},Q_{jt}^{-}\ge 0,\forall j,t\ ,$$

$$LP_{pjt},LQ_{qjt},PQ_{pqjt}\ge 0,\forall p,q,j,t \qquad \text{(A-25)}$$

The objective of the model is to minimize the overall cost: production cost, transportation cost, inventory cost, shortage cost. Constraint equation (1), (2) are the balance equations for the product and part inventory. Constraint equation (3), (4) are the balance equations for the inventory of raw materials for products and the inventory of raw materials for parts. Constraint equation (5), (6) are the resource availability constraints for product and parts. Constraint equation (7), (8) are machine center capacity constraints. Constraint equation (9), (10) are the net inventory equations for products and parts. Constraint equation (11), (12) are the net inventory equations for raw materials for products and parts. Constraint equation (13) is the availability constraints for the stack. Constraint equation (14) is the demand constraint for retailers. Constraint equation (15) is the balance equation for the warehouse. Constraint equation (16), (17), (18) are the product holding capacity for stack buffer and warehouses and retailers. Constraint equation (19), (20) are the distribution capacity constraints for the stack and warehouses. Constraint equation (21), (22), (23) are the net inventory equations for the stack and warehouses and retailers. Constraint equation (24), (25) enforce the non-negativity restriction on the decision variables.

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AUTHOR BIOGRAPHIES

YOUNG HAE LEE is a Professor in the Department of Industrial Engineering, Hanyang University, Korea, and a president of the Korean Society of Supply Chain Management, a vice president of the Korean Society for Simulation. He received his B.S. from Korea University, and M.S. and Ph.D. from University of Illinois at Chicago in 1983 and 1986. He spent a sabbatical year at Osaka University, 1990-1991, and Purdue University, 1997-1998. His areas of interest are Simulation Optimization, Simulation Output Analysis, and Simulation in Manufacturing and Logistics. He is a senior member of IIE, INFORMS and a member of SCS. His email and web addresses are `<yhlee@email.hanyang.ac.kr>` and `<pis.hanyang.ac.kr>`.

SOOK HAN KIM is a Ph.D. student in the department of Industrial Engineering, Hanyang University, Korea. He obtained his M.S. in Operations Research from Naval Postgraduate School, Monterey, California, USA in 1991. He served in Korea-US Combined Forces Command as an operation analyst operating analysis wargame models for many years. His research interests are Web-based Simulation, Supply Chain Management, Wargame. His email address is `<shkim@pis.hanyang.ac.kr>`.