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AN INTEGRATED PLANNING OF PRODUCTION AND DISTRIBUTION FOR MULTIPLE SUPPLIERS

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Abstract: This work addresses the production and distribution of a single product supplied by multiple suppliers and demanded by multiple demanders. A production scheduling and vehicle routing model is proposed for the multiple suppliers, multi-vehicle, and vehicle capacity constraint problems. There are three stages as follows: first, distribute the least distributed amount from each supplier location; second, distribute the amount of inventory attributed to the constraint of production lower bound of each supplier location; and third, design vehicle tours by considering both production and transportation costs. The integrated production scheduling and distribution problem can obtain a lower cost solution than the combined solution of the conventional production scheduling problem and distribution planning problem. Simulation results confirm the theoretical analysis.

Keywords: Vehicle routing, production, inventory, distribution.

1. INTRODUCTION

The problem considered herein is to minimize the total production, inventory and transportation cost. The problem is composed of two subproblems. The first subproblem consists of assigning units to the different origin-destination pairs. The second subproblem is a vehicle routing problem, since the available vehicles have to be brought back to their starting point. Herein, we develop an integrated model to determine the production policies at supplier locations that are responsible for supplying enough goods to satisfy the demand of demanders, and the assignments of vehicle tours to transport the supplied goods. The model determines production quantities and inventories at supplier locations, and distribution lots and delivery routes at demander locations. In addition, reasonable assumptions are made concerning production, inventory and transport costs along with production constraints and demand requirements.

Vehicle and scheduling problems have been extensively studied over the past three decades. Among the previous literature, an extensive collection and classification of the types of problems and models of vehicle routing and scheduling were seen in the work of Bodin et al [2]. Conventionally, the production, inventory and transport aspects of goods handling have been optimized separately.

Most of the previous literature considered one supplier to multiple demanders. Multiple suppliers were taken into account in the work of F. Soumis et al [6]. Some researches discussed vehicle routing problems with time windows [1, 5]. However, the arrival time was limited to a certain range. In addition, the constraint of arrival time was substituted by penalty cost [1]. Most of the transportation and distribution models have been employed to solve the problems in a certain time range. They were seldom considered for a series of time periods. The solution of the problem was extended to discuss T time periods in the Ph. D. dissertation of P. Chandra [4]. Moreover, he took inventory and holding cost into consideration, the whole problem being extended in the time dimension [3, 4].

The work is organized as follows. In Section 1, the production scheduling and distribution problem is described precisely. The symbols employed in this work are illustrated in Section 2. Section 3 formulates the integrated model of the multi-supplier production scheduling and distribution problem. Simulation results of the integrated model are discussed in Section 4, while Section 5 concludes the work.

2. DESCRIPTION OF THE PROBLEM

Herein, we study the case where multiple suppliers distribute products to spatially distributed demanders in order to meet their non-stationary demand (Fig. 1, see page 56). The problem has the following characteristics:

1. A finite planning horizon of discrete periods.

2. Demand quantity at each demander location for every period is determined, allowing $d_j(t)$ to be the quantity of product demanded by demander j in period t.

3. The demand quantity in period t is assumed to be known, such that products are distributed by the supplier to satisfy the demand of the demander immediately in period t. The time delay that occurs in the transporting process is neglected.

4. Production cost is a function of production quantity, but it is not a linear function necessarily. The operating cost of the factory consists of a fixed cost and a variable cost. The variable cost may not be one-order function of an increasing quantity of production. For instance, to meet a certain amount of production quantity, employees may have to work overtime. Overtime pay is usually higher than normal

pay, therefore production cost may be a function of a two-order or higher-order type, even a nonlinear type. $f_i(p)$ represents the production cost at supplier location i, and is the function of production quantity p.

5. Constraints of maximum and minimum quantity of production per period exist for each supplier $L_i \le p_i(t) \le U_i \ \forall t$, where L_i and U_i represent the minimum and maximum quantity of production per period at supplier i.

6. In order to prevent equipment breakdown, inadequacy of material or an unexpected condition making the factory shut down, it is necessary for every supplier to hold a certain amount of safety stock. The inventory must not be smaller than the safety stock, and not exceed warehouse capacity at each supplier. $w_{s_i} \le a_i(t) \le W_i$ implies that the quantity of inventory $a_i(t)$ at supplier i is smaller than or equal to W_i, which is warehouse capacity at supplier i. Also, $a_i(t)$ is larger than or equal to the safety stock w_{s_i}.

7. Vehicle capacity is fixed during every period, and cp is the capacity of each delivery vehicle.

8. All the vehicles leave from one supplier location and return to the same supplier location. In addition, all the vehicles arrive at one demander location and leave from the same demander location.

9. Transportation cost is in proportion to the distance of vehicle travel. We can get the distance between two locations whose coordinates are given. The distance multiplied by cost per unit distance is the transportation cost between two locations. For instance, the cost of direct travel from location (x_k, y_k) to location (x_l, y_l) is $c_{kl} = c_0 \times \sqrt{(x_k - x_l)^2 + (y_k - y_l)^2}$, where c_0 is the cost per unit distance.

10. In objective functions, total cost includes production cost, inventory holding cost and vehicle routing cost.

$$c_{total}(t) = c_{prod.}(t) + c_{inv.}(t) + c_{vrp}(t)$$

where

$$c_{prod.}(t) = \sum_{i=1}^{m} f_i(p_i(t))$$

$$c_{inv.}(t) = \sum_{i=1}^{m} a_i(t) \cdot h_i$$

$$c_{vrp}(t) = \sum_{\substack{k=1 \\ k \ne l}}^{m+n} \sum_{l=1}^{m+n} c_{kl} \cdot r_{kl}(t) = \sum_{\substack{k=1 \\ k \ne l}}^{m+n} \sum_{l=1}^{m+n} c_0 \times \sqrt{(x_k - x_l)^2 + (y_k - y_l)^2} \cdot r_{kl}(t).$$

3. EXPLANATION OF SYMBOLS

$a_i(t)$ = inventory at supplier location i in period t;

c_{kl} = cost of direct travel from location k to location l;

$c_{total}(t)$ = total cost in period t;

$c_{prod.}(t)$ = production cost in period t;

$c_{inv.}(t)$ = inventory cost in period t;

$c_{vrp}(t)$ = vehicle routing cost in period t;

cp = capacity of each delivery vehicle;

$d_j(t)$ = demand quantity at demander j in period t;

h_i = inventory holding cost per unit product per period at supplier location i;

i = index of supplier location $= 1,2,\ldots,m$;

j = index of demand location $= m+1, m+2,\ldots,m+n$;

$e,k,l = 1,2,\ldots,m, m+1, m+2,\ldots,m+n$

where $e,k,l = 1,2,\ldots,m$ represent supplier locations and

$e,k,l = m+1, m+2,\ldots,m+n$ represent demander locations;

L_i = minimum quantity of production per period at supplier location i;

m = number of supplier locations;

n = number of demander locations;

$p_i(t)$ = quantity of product produced at supplier location i in period t;

$q_i(t)$ = quantity of product distributed from supplier location i in period t;

$r_{kl}(t)$ = number of direct routes from location k to location l in period t;

$\lceil s \rceil$ = smallest integer no less than s;

$\lfloor s \rfloor$ = largest integer no more than s;

T = number of time period;

U_i = maximum quantity of production per period at supplier location i;

$v_i(t)$ = remainder number of vehicle routes from supplier location i in period t;

$v_i^0(t)$ = least number of vehicle routes from supplier location i in period t;

W_i = warehouse capacity at supplier location i;

w_{S_i} = safety stock at supplier location i.

4. PRODUCTION SCHEDULING AND DISTRIBUTION PROBLEM (PSD)

By considering the production cost, inventory holding cost and transport route cost completely, the problem involves searching for the minimum cost.

4.1. Model of PSD

Objective function

$$\min Z = \sum_{t=1}^{T}\sum_{i=1}^{m} f_i(p_i(t)) + \sum_{t=1}^{T}\sum_{i=1}^{m} h_i \cdot a_i(t) + \sum_{t=1}^{T}\sum_{\substack{k=1\\k\neq l}}^{m+n}\sum_{l=1}^{m+n} c_{kl}\cdot r_{kl}(t) \quad (1)$$

subject to

$$f_i(p_i(t)) > 0 \qquad i = 1.2.\dots m;\quad t = 1.2.\dots.T \quad (2)$$

$$L_i \le p_i(t) \le U_i \qquad i = 1.2.\dots m;\quad t = 1.2.\dots.T \quad (3)$$

$$a_i(t) = a_i(t-1) + p_i(t) - q_i(t) \qquad i = 1.2.\dots m;\quad t = 1.2.\dots.T \quad (4)$$

$$a_i(0) = w_{S_i} \qquad i = 1.2.\dots m \quad (5)$$

$$w_{S_i} \le a_i(t) \le W_i \qquad i = 1.2.\dots m;\quad t = 1.2.\dots.T \quad (6)$$

$$\sum_{i=1}^{m} q_i(t) = \sum_{j=m+1}^{m+n} d_j(t) \qquad t = 1.2.\dots.T \quad (7)$$

$$\sum_{j=m+1}^{m+n} r_{ij}(t) \ge \left\lceil q_i(t) / cp \right\rceil \qquad i = 1.2.\dots m;\quad t = 1.2.\dots.T \quad (8)$$

$$\sum_{\substack{e=1\\e\neq k}}^{m+n} r_{ek}(t) = \sum_{\substack{l=1\\l\neq k}}^{m+n} r_{kl}(t) \qquad k = 1.2.\dots.m+n;\quad t = 1.2.\dots.T \quad (9)$$

$$\sum_{j=m+1}^{m+n}\sum_{i=1}^{m} r_{ij}(t) \ge \left\lceil \sum_{j=m+1}^{m+n} d_j(t) \Big/ cp \right\rceil \qquad t = 1.2.\dots.T \quad (10)$$

$$q_i(t) \ge 0 \ \ \& \text{ integer} \qquad i = 1.2.\dots.m;\quad t = 1.2.\dots.T \quad (11)$$

$$r_{kl}(t) \ge 0 \ \ \& \text{ integer} \qquad k = 1.2.\dots.m+n;\quad l = m+1.m+2.\dots.m+n; \quad t = 1.2.\dots.T \quad (12)$$

4.2. Algorithm

The integrated model of production scheduling and distribution considers not only inventory amounts at the front period, but also the constraints of minimum production quantity and maximum warehouse capacity at supplier locations. The minimum quantity of distributed products at every supplier location must be computed and distributed.

A. Initialization and Preparedness

$t = 0$,

Step 1: $t = t + 1$,

IF $t > T$ THEN

stop.

FOR $k = 1$ TO $m + n$

FOR $l = 1$ TO $m + n$

$r_{kl}(t) = 0$.

Sort transport costs from supplier locations to demander locations by increment to form an ordered set C.

FOR $j = m + 1$ TO $m + n$

IF $d_j(t) = 0$ THEN

delete all elements c_{ej} $(e = 1, 2, \ldots, m)$ from set C.

Step 2: FOR $i = 1$ TO m

IF $a_i(t-1) + L_i > W_i$ THEN

begin

$q_i(t) = (a_i(t-1) + L_i) - W_i$,

$v_i^0(t) = \left\lceil q_i(t) / cp \right\rceil$,

$p_i(t) = L_i$,

$a_i(t) = W_i$.

end

ELSE

begin

$q_i(t) = 0$,

$v_i^0(t) = 0$,

$p_i(t) = L_i$,

$a_i(t) = a_i(t-1) + L_i$.

end

Step 3: FOR $i = 1$ TO m

$$v_i(t) = \left\lfloor (U_i + a_i(t-1)) / cp \right\rfloor - v_i^0(t) .$$

B. The Least Distributed Amount

Step 4: $C_L = C$,

FOR $i = 1$ TO m

IF $v_i^0(t) = 0$ THEN

delete all elements $c_{ik} (k = m+1, m+2, \ldots, m+n)$ from set C_L .

Step 5: REPEAT

select an element c_{ij} from set C_L in sequence

UNTIL $d_j(t) \neq 0$.

Construct a vehicle route $i - j - i$,

$rc = rc - d_j(t)$,

$r_{ij}(t) = r_{ij}(t) + 1$,

$r_{ji}(t) = r_{ji}(t) + 1$,

$d_j(t) = 0$.

Step 6: REPEAT

REPEAT

find a location k not in any route, its demand quantity $d_k(t) \neq 0$ and

$d_k(t) \leq rc$

UNTIL the value $c_{ik} + c_{kj} - c_{ij}$ of pair (i, j) in the route is minimum.

Insert k between i and j,

$rc = rc - d_k(t)$,

$d_k(t) = 0$,

$r_{ik}(t) = r_{ik}(t) + 1$,

$r_{kj}(t) = r_{kj}(t) + 1$,

$r_{ij}(t) = r_{ij}(t) - 1$,

delete all elements c_{ek} $(e = 1,2,\ldots,m)$ from set C_L

UNTIL $rc = 0$ or there is no demander location in which demand quantity is smaller than rc .

IF all $d_j(t) = 0$ $(j = m+1, m+2, \ldots, m+n)$ THEN

go to step 1.

ELSE IF $C_L \neq 0$ THEN

go to Step 5.

C. Distributing Inventory of Suppliers

Step 7: FOR $i = 1$ TO m

IF $a_i(t) \neq 0$ THEN

begin

compute $c_{\bar{ik}} = c_{ik} - cp \cdot h_i$ $(k = m+1, m+2, \ldots, m+n)$

sort them by increment to form an ordered set C_I .

end

Step 8: REPEAT

select one element $c_{\bar{ij}}$ from set C_I in sequence

UNTIL $d_j(t) \neq 0$.

Construct a vehicle route $i - j - i$,

$rc = rc - d_j(t)$,

$r_{ij}(t) = r_{ij}(t) + 1$,

$r_{ji}(t) = r_{ji}(t) + 1$,

$d_j(t) = 0$.

Step 9: REPEAT

REPEAT

derive a location k not in any route, its demand quantity $d_k(t) \neq 0$ and $d_k(t) \leq rc$

UNTIL the value $c_{ik} + c_{kj} - c_{ij}$ of pair (i, j) in the route is minimum.

Insert k between i and j,

$rc = rc - d_k(t)$,

$d_k(t) = 0$,

$r_{ik}(t) = r_{ik}(t) + 1$,

$r_{kj}(t) = r_{kj}(t) + 1$,

$r_{ij}(t) = r_{ij}(t) - 1$,

delete all elements c_{ek} $(e = 1,2,\ldots,m)$ from set C_I

UNTIL $rc = 0$ or there is no demander location in which demand quantity is smaller than rc .

IF all $d_j(t) = 0$ $(j = m+1, m+2, \ldots, m+n)$ THEN

go to Step 1.

ELSE IF $C_I \neq 0$ THEN

go to Step 8.

D. Considering Production Cost

Step 10: FOR $i = 1$ TO m

IF $v_i(t) = 0$ THEN

delete all the elements c_{ik} $(k = m+1, m+2, \ldots, m+n)$ from set C .

ELSE

compute $\Delta f_i = f_i(p_i(t) + cp) - f_i(p_i(t))$.

FOR $j = m+1$ TO $m+n$

IF $d_j(t) = 0$ THEN

delete all the elements c_{ej} $(e = 1,2,\ldots,m)$ from set C .

Step 11: REPEAT

derive two adjacent elements c_{ij} and c_{kl} $(i \neq k)$ from set C in sequence

UNTIL $\Delta f_i + c_{ij} \leq \Delta f_k + c_{kl}$ and $d_j(t) \neq 0$.

IF there is no such pair of adjacent elements THEN

get the last element c_{ij} from set C .

Construct a vehicle route $i - j - i$,

$rc = cp - d_j(t)$,

compute Δf_i again,

$p_i(t) = p_i(t) + cp$,

$v_i(t) = v_i(t) - 1$,

$d_j(t) = 0$,

$r_{ij}(t) = r_{ij}(t) + 1$,

$r_{ji}(t) = r_{ji}(t) + 1$,

delete all elements c_{ej} $(e = 1,2,\ldots,m)$ from set C .

IF $v_i(t) = 0$ THEN

delete all elements c_{ik} $(k = m+1, m+2, \ldots, m+n)$ from set C .

Step 12: REPEAT

REPEAT

obtain a location k not in any route, its demand quantity $d_k(t) \neq 0$ and $d_k(t) \leq rc$

UNTIL the value $c_{ik} + c_{kj} - c_{ij}$ of pair (i, j) in the route is minimum.

Insert k between i and j,

$rc = rc - d_k(t)$,

$d_k(t) = 0$,

$r_{ik}(t) = r_{ik}(t) + 1$,

$r_{kj}(t) = r_{kj}(t) + 1$,

$r_{ij}(t) = r_{ij}(t) - 1$,

delete all elements $c_{ek}(e = 1,2,\ldots,m)$ from set C_I

UNTIL $rc = 0$ or there is no demander location in which demand quantity is smaller than rc .

IF all $d_j(t) = 0$ $(j = m+1, m+2, \ldots, m+n)$ THEN

go to Step 1.

ELSE

go to Step 11.

5. EXPERIMENTAL RESULTS

We designed a program in C language on a Pentium 166. There are ten supplier locations and eighty demander locations in the simulations. The production cost function is assumed to be a two-order function at each supplier location, as Table 1 presents (p. 56). The upper bounds and lower bounds of production quantities, inventory holding costs, safety stock and warehouse capacity are also listed in Table 1. The coordinates and demand quantity of each demander location in every period were obtained randomly. Since transport cost is proportional to transport distance, the distance between two points is multiplied by the coefficient of transport cost, giving the transport cost between the two points.

We input some pairs of different values of c_0, cp, m and n, and ran the above example to obtain results, as listed in Tables 2, 3, 4, 5 (pp. 57, 58). Certainly, the distribution cost must increase as c_0 values increase. Increasing vehicle capacity cp can extend the length of vehicle routing to obtain a better solution.

To observe the performance of PSD, we can compute the percentage of saving cost = (cost of production scheduling model + cost of distribution planning model - cost of PSD model) / (cost of production scheduling model + cost of distribution planning model) × 100%, as indicated in the final column of Table 2. The differences in production cost, inventory cost and distribution cost will impact the value of saving cost percentages. Saving cost percentages are different for different value pairs c_0, cp, m and n. In addition, saving cost percentages increase as the difference between m and n increase.

6. CONCLUSION

The problem considered herein not only prepares a minimum cost production and transportation plan but also expands it into the distribution problem of a single product with multiple suppliers and multiple demanders. The three stages in the PSD model are as follows: first, distribute the least distributed amount from each supplier locations; second, distribute the amount of inventory caused by the constraint of production lower bound of each supplier location; and third, design vehicle tours by simultaneously considering both production cost and transportation cost. Interestingly, the integrated production scheduling and distribution problem can obtain a lower cost solution than the combined solution of the traditional production scheduling problem and distribution planning problem. Simulation results correspond to the theoretical analysis.

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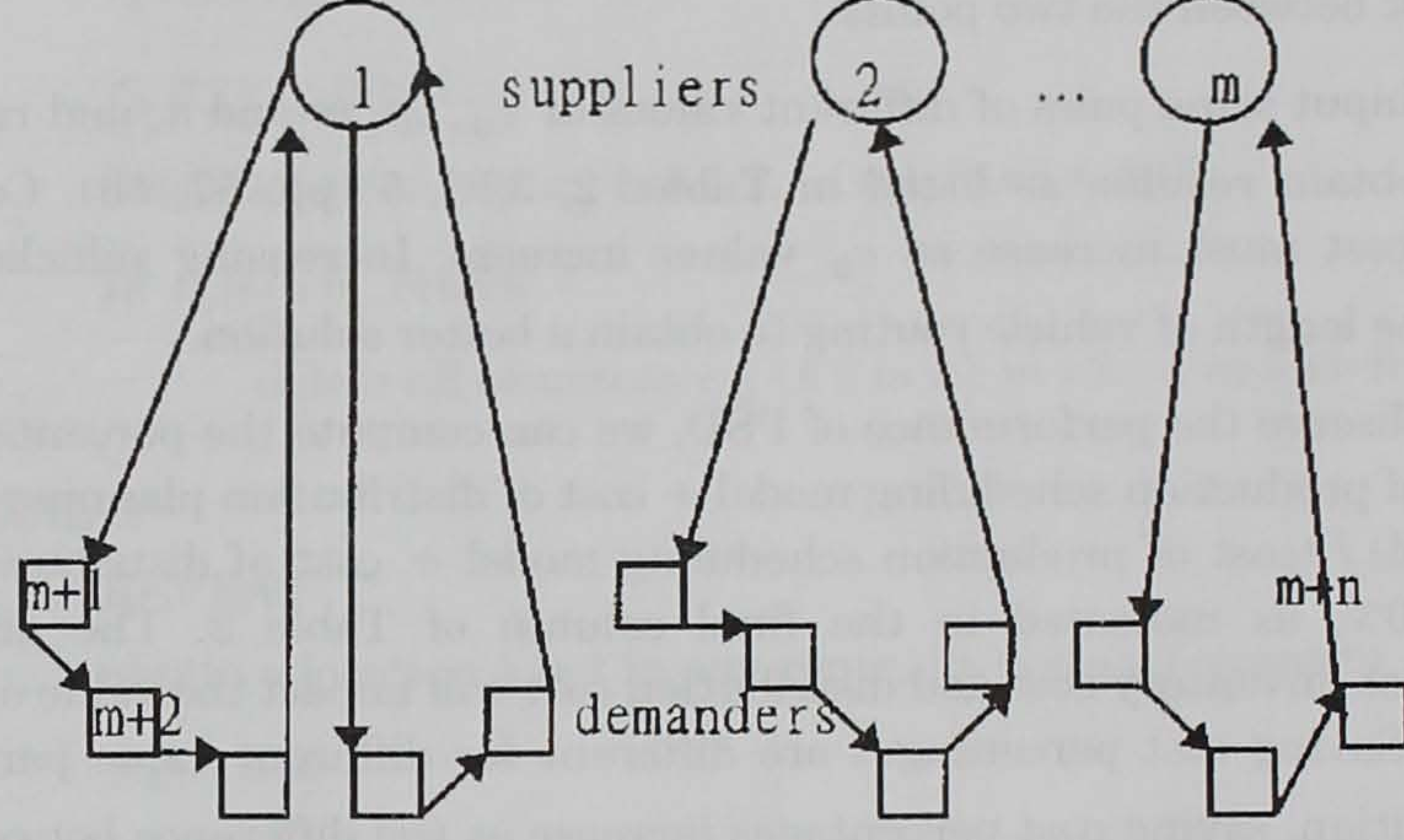

Figure 1: Distribution of multiple suppliers

Table 1: Coordinates and constraints of suppliers

supplier	x	y	function of production cost	lower bound of production quantity	upper bound of production quantity	inventory holding cost	safety stock	warehouse capacity
1	30	50	$100+p+0.001p^2$	40	230	5.0	10	55
2	40	10	$50+3p+0.001p^2$	30	200	4.0	10	45
3	20	30	$80+2p+0.0015p^2$	50	250	3.0	10	30
4	10	80	$70+2.5p+0.001p^2$	60	200	2.0	10	60
5	50	90	$60+2p+0.002p^2$	30	210	4.0	10	50
6	60	20	$90+1.5p+0.002p^2$	50	240	3.0	10	45
7	70	100	$80+2p+0.001p^2$	40	260	2.0	10	65
8	80	40	$60+2.5p+0.003p^2$	40	230	4.0	10	55
9	90	60	$75+1.5p+0.002p^2$	30	250	3.0	10	45
10	100	70	$50+2.5p+0.003p^2$	50	230	3.0	10	50

Table 2: Comparison of simulations to the example by changing c_0 value

c_0	cp	m	n	Model 1		Model 2		Model 3				Saving cost %
				Prod. cost	Inv. cost	Distr. cost	Number of routes	Prod. cost	Inv. cost	Distr. cost	Number of routes	
0.1	20	4	80	20188.16	1300.00	3630.22	383	15591.60	1300.00	2869.08	287	21.33
				19616.75	1300.00	4207.10	391	15480.80	1300.00	3125.77	295	20.77
				22911.87	1200.00	3257.43	390	18396.40	1200.00	2864.72	322	17.93
				20863.25	1400.00	4352.07	401	16303.60	1400.00	3257.37	303	22.24
				20919.82	1300.00	3213.47	399	16608.40	1300.00	2961.35	304	17.94
0.2				19142.65	1600.00	6194.60	394	13048.80	1600.00	4780.42	303	27.87
				17380.63	1500.00	5440.75	398	13366.60	1500.00	4889.03	321	18.77
				21771.57	1200.00	5895.94	388	18133.40	1200.00	5278.93	322	14.74
				19891.80	1300.00	6282.65	400	16338.60	1300.00	5077.35	309	17.32
				21173.96	1200.00	6570.01	371	16858.40	1200.00	5527.55	287	18.51
0.5				18314.66	1500.00	18200.37	401	13295.20	1500.00	13288.08	313	26.13
				21462.43	1500.00	15764.94	401	18334.80	1500.00	12668.29	333	16.07
				20258.74	1400.00	14773.78	397	17153.00	1400.00	12370.31	320	15.12
				20498.50	1300.00	16657.42	398	17201.20	1300.00	13561.83	317	16.62
				20545.83	1200.00	17872.73	387	17127.20	1200.00	14012.36	320	18.37
1.0				20302.49	1000.00	32691.54	380	17392.40	1000.00	26901.05	319	16.11
				17817.55	1300.00	37344.44	404	13638.40	1300.00	25077.24	317	29.13
				19674.78	1200.00	27396.61	381	17444.40	1200.00	24265.09	327	11.11
				21162.23	1200.00	34470.37	405	18111.60	1200.00	24642.03	325	22.66
				17496.97	1500.00	27629.47	401	14342.00	1500.00	23290.28	328	16.02

Table 3: Comparison of simulations to the example by changing cp value

c_0	cp	m	n	Model 1		Model 2		Model 3				Saving cost %
				Prod. cost	Inv. cost	Distr. cost	Number of routes	Prod. cost	Inv. cost	Distr. cost	Number of routes	
0.2	10	4	80	8534.83	1500.00	4812.90	360	7487.90	1500.00	3855.18	281	13.50
				10223.41	1200.00	6601.98	367	8549.00	1200.00	4848.78	282	19.02
				9013.49	1400.00	5603.07	372	7808.20	1400.00	4299.22	286	15.67
				8677.75	1400.00	5497.71	368	7336.40	1400.00	4420.93	273	15.33
				8882.61	1600.00	5371.67	371	7489.50	1600.00	4108.30	282	16.76
	20			19908.79	1200.00	6655.27	365	16116.40	1200.00	5289.59	299	18.58
				18912.57	1500.00	7358.37	412	14334.40	1500.00	5425.23	334	23.45
				21933.89	1400.00	8006.46	415	16591.20	1400.00	5770.22	321	21.94
				19683.59	1500.00	6243.97	400	13456.00	1500.00	5045.69	310	27.07
				23489.84	1300.00	7101.73	427	19383.20	1300.00	6334.53	343	15.28
	30			37578.44	1200.00	8995.32	398	27024.00	1200.00	6589.54	325	27.13
				38770.82	1500.00	6804.35	412	23786.90	1500.00	5834.38	362	33.89
				35279.73	1300.00	6333.31	391	27127.00	1300.00	5161.19	335	21.73
				35489.22	1400.00	6061.80	397	27628.00	1400.00	6873.48	325	16.41
				39950.66	1400.00	9187.52	411	29089.00	1400.00	6866.26	333	26.09
	40			49748.39	1200.00	6296.36	413	39175.00	1200.00	6599.31	367	17.94
				61722.24	1500.00	7604.78	392	32012.00	1500.00	5692.46	334	44.65
				62833.36	1100.00	8957.78	402	40813.20	1100.00	6751.99	350	33.24
				55076.51	1300.00	7197.55	418	44728.00	1300.00	6292.17	358	17.70
				49939.19	1300.00	8094.66	413	39385.00	1300.00	6371.42	352	20.69
	50			64145.52	1400.00	7819.42	417	46110.00	1400.00	6041.67	342	27.01
				68990.72	1500.00	7520.67	419	49585.00	1500.00	6496.00	363	26.19
				68118.98	1200.00	6964.08	402	59617.50	1200.00	7054.11	349	11.03
				69256.32	1300.00	7745.80	395	55155.00	1300.00	7022.17	340	18.98
				60579.77	1200.00	7789.77	402	42925.00	1200.00	5913.39	328	28.07

Table 4: Comparison of simulations to the example by changing the number of suppliers

c_0	cp	m	n	Model 1		Model 2		Model 3				Saving cost %
				Prod. cost	Inv. cost	Distr. cost	Number of routes	Prod. cost	Inv. cost	Distr. cost	Number of routes	
0.2	20	2	80	22199.28	800.00	7776.68	375	16940.80	800.00	5884.66	292	22.99
				19539.67	600.00	8214.45	384	14220.80	600.00	5940.38	299	26.78
				29021.11	700.00	10326.94	389	19593.60	700.00	7347.22	311	30.98
				26034.69	800.00	7971.12	388	19866.00	800.00	6464.68	311	22.05
				17005.28	800.00	7354.70	374	10967.60	800.00	5388.80	300	31.81
		4		20624.11	1300.00	8123.27	398	16156.00	1300.00	6328.28	302	20.84
				20869.26	1300.00	6420.86	393	17229.00	1300.00	5147.81	317	17.19
				19578.18	1300.00	7441.71	401	16372.80	1300.00	5530.60	324	18.07
				17021.88	1400.00	6209.99	395	12742.40	1400.00	4866.77	296	22.83
				19324.84	1200.00	7716.20	307	15475.60	1200.00	5776.96	307	20.50
		6		17780.58	2000.00	5690.53	377	14702.00	2000.00	4594.13	297	16.39
				20168.85	2100.00	7304.18	400	17664.80	2100.00	5588.84	321	14.27
				20630.52	1800.00	6326.96	406	18425.20	1800.00	5050.18	332	12.11
				19579.12	2100.00	5997.80	402	16352.40	2100.00	4621.51	333	16.63
				18763.75	1900.00	5300.71	406	16462.80	1900.00	4657.89	356	11.34

Table 5: Comparison of simulations to the example by changing the number of demanders

c_0	cp	m	n	Model 1		Model 2		Model 3				Saving cost %
				Prod. cost	Inv. cost	Distr. cost	Number of routes	Prod. cost	Inv. cost	Distr. cost	Number of routes	
0.2	20	2	40	9691.83	500.00	3493.14	185	8744.20	500.00	2956.18	162	10.85
				9980.52	600.00	4955.04	195	8425.20	600.00	3681.83	258	18.21
				7658.27	900.00	3512.82	196	5640.40	900.00	2706.19	147	23.40
				11210.92	800.00	2902.94	195	9440.80	800.00	2506.15	159	14.53
				12327.97	700.00	5074.85	208	10424.80	700.00	3823.63	169	17.42
			60	16300.37	500.00	5773.78	299	13580.40	500.00	4871.37	255	16.05
				17103.08	600.00	5642.02	285	14468.80	600.00	4806.61	240	14.85
				17019.16	600.00	5030.59	283	12033.20	600.00	4750.10	217	23.25
				18709.75	700.00	7314.63	290	13604.00	700.00	5178.07	229	27.10
				14085.27	500.00	8182.26	297	11015.60	500.00	5793.18	226	23.98
			80	23423.23	600.00	7548.78	377	18638.40	600.00	6105.16	308	19.73
				19210.73	500.00	8134.10	379	14856.40	500.00	5553.17	299	24.91
				24159.23	700.00	8604.08	376	17618.60	700.00	6356.92	293	26.26
				27731.26	500.00	10869.04	389	16370.00	500.00	7897.73	295	36.67
				16678.65	700.00	7615.76	366	10242.40	700.00	4689.28	272	37.46
		4	40	9355.08	1300.00	3854.99	207	8442.80	1300.00	2954.46	161	12.49
				10415.25	1200.00	4879.40	201	9253.60	1200.00	3910.65	159	12.92
				11491.62	1200.00	3601.28	205	10578.60	1200.00	2891.14	171	9.96
				10900.80	1200.00	4167.10	191	9789.20	1200.00	2957.42	153	14.27
				11359.10	1400.00	4318.76	202	9612.80	1400.00	3065.66	153	17.56
			60	15189.99	1400.00	4170.76	289	13409.40	1400.00	3678.82	247	10.95
				14735.43	1300.00	6517.03	288	12067.60	1300.00	4956.61	224	18.75
				12891.43	1500.00	4419.43	294	10450.40	1500.00	3635.34	234	17.14
				15664.39	1100.00	6901.54	287	13391.20	1100.00	5368.76	230	16.08
				14813.98	1200.00	5189.37	285	12701.40	1200.00	4333.29	234	14.00
			80	20686.98	1100.00	6699.66	385	17358.00	1100.00	5533.36	313	15.78
				18154.06	1300.00	6068.41	407	14477.20	1300.00	5387.06	338	17.08
				20390.28	1200.00	5658.96	396	17627.60	1200.00	4942.46	333	12.77
				20737.22	1200.00	7369.71	390	17459.60	1200.00	6016.92	327	15.80
				21862.33	1300.00	6491.11	412	17615.60	1300.00	5681.41	322	17.05