An Optimal Model and Algorithm of Collaborative Production-Distribution Planning for Distributed Decision-Making Environment

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Abstract: As optimal performance and applicability of the existing production-distribution planning models are limited in a distributed decision-making environment, a two-echelon collaborative planning model is proposed in this paper. The model contains planning fields of the buyer and the supplier and considers adjustable delivery quantities. A coordinative process based on Particle Swarm Optimization (PSO) is designed to solve the model. By adopting the process, the optimization can be achieved and only partial information is needed to be shared. Computational experiments show that the model and algorithm can solve the problem very well and have a good optimal performance.

Keywords: Production-Distribution System, Supply Chain, Collaborative Planning, Distributed Decision, PSO

I. Introduction

In a production-distribution system, the order plans of the buyers, which are determined by the Economic Order Quantity model, often require manufacturers to pay a higher cost, and delivery plans of manufacturers determined by economic production quantity may not meet the buyers' demands. Thus in order to improve the effectiveness of the supply chain, the buyers and suppliers needed to collaboration to make production and inventory decision [1]. On the other hand, the development of global economic causes the enterprises located in different regions to establish a flexible and relatively loose cooperative relationship of supply chain. In this relationship, the suppliers and the buyers seek effective cooperation with consideration of independent decision-making power and more privacy.

From point of view of the buyers' number in a distribution system, the supply chain production- distribution problem can be divided into two types [2]: One is a single supplier and single buyer (SS-SB), the other is a single supplier and multiple buyers (SS-MB). In the case of a single buyer, most models (such as [3-4]) consider the supplier as a vendor, rather than the manufacturer, and the procurement/ supply decision is making based on final production, and ignore the influence of the fix production rate to the inventory cost. In a multi-buyers case, the supplier can be a vendor[5-6] (distribution system), and can also be a manufacturer (production-distribution system). For the multi-buyers production-distribution systems, Lu[7] proposed an integrated inventory model, which is used to determine the best production time points of the supplier and the best order time points of the buyers to minimize the total cost of procurement. Yao and Chiou[8] extend the work of Lu, they develop an effective heuristic algorithm based on the optimal solution structure of the model. Bylka[9] determine production sequence of the supplier and order sequence of the buyers by using turnpike policy for a production-distribution system with dynamic demands. Sharker and Diponegoro[10] seek the optimal production and delivery plan, which the start time of production is variable in a cycle, by using a surrogate network model. Some other studies, such as [11-12], also propose their model for production-distribution problem of SS-MB. From these studies, existing models and methods tend to assume that the order demands that the buyers provide to the supplier is fixed, or directly transfer external demands of buyers to demands to supplier, and do not consider inventory costs of the buyers. However, in a production-distribution system which the supplier and the buyers are autonomous, the buyers can adopt non-fixed order quantities and the order cycles of the buyers are often not synchronized with the production cycle of the manufacturer. The inventory optimization of production-distribution system from the perspective of the manufacturer will limit room of plan adjustment and effect of optimization. On the other hand, in distributed decision-making environment of supply chain, some information such as the detail external demands of buyer will be not shared directly with the manufacturer.

As a result, a new collaborative model of production-distribution planning for distributed decision-making environment is proposed in this paper. The model adopts a dynamic adjustment policy on delivery quantities and contains sub-models of the buyers and the manufacturer. In this model, the delivery quantities are variable and the optimization objective include inventory cost and shortage cost of the buyers. A coordination algorithm based on particle swarm optimization is design for solving the model. The algorithm adopts an adaptive iterative function and a random adjustment policy with variable rate. In the process of coordination, the optimal solution will be obtained by iterative adjustment of the alternative delivery plans and information sharing of the partners' total cost. Computational experiments are used to analyze validity and optimization performance of the model and algorithm.

II. Formulation of the models

A production-distribution system consisting of a manufacturer and J buyers is considered. The period of planning is Z. The buyers adopt the policy of fixed order cycle and variable order quantity to make purchase plan. If the available products of a buyer can't meet his demands, the buyer has to pay shortage cost. The manufacturer makes production plan according to order information of the buyers and production capability. The production plan contains more than one production cycle. The objective of collaborative planning is to obtain the optimal delivery plan and production plan to minimize the total cost of the production-distribution system. The planning models of the buyers and the manufacturer are respectively described as the following.

Planning model of buyers

To take buyer j ($j \in 1,...,J$) as an example, assuming that demand rate of j, that is demand per unit time, is forecasted to be D_j, the purchase plan will be made based on it. The purchase plan is made up of a serial of order cycles. The interval of j is donated as L_j, then the cycle number $N_j = \lfloor Z / L_j \rfloor$ and there is only one order in each cycle. The order quantity of buyer j in l th cycle ($l \in N_j$) is represented by X_{jl}, the initial inventory and initial shortage cost of cycle l are denoted as I_{jl0} and O_{jl} respectively, then available product quantity of buyer j in cycle l is $A_{jl} = I_{jl0} + X_{jl} - O_{jl}$ and $I_{jl0}O_{jl} = 0$. Start time and end time of cycle l are denoted as T_{bjl} and T_{ejl}, then the buyer's demand in cycle l is $D_j(T_{ejl} - T_{bjl}) = D_jL_j$.

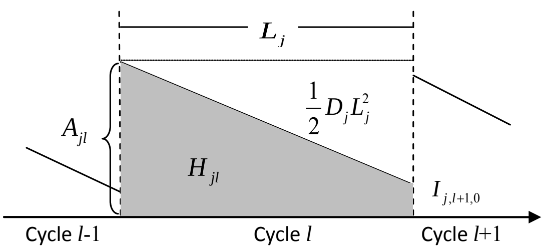

Figure I. Inventory in cycle l when available quantity can meet demand

In cycle l, when $A_{jl} \ge D_jL_j$, the available product of buyer j can meet demand, then the time weight inventory quantity $H_{jl} = A_{jl}L_j - D_jL_j^2/2$, that is the shaded area in Figure 1. The time weight quantity of shortage $G_{jl} = 0$, ending inventory of the cycle $I_{j,l+1,0} = A_{jl} - D_jL_j$, and ending quantity of shortage $O_{j+1,l} = 0$.

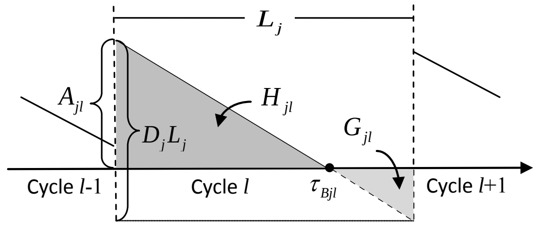

Fig. 2 Variation of buyer's inventory when available product can't meet demand

When $0 \le A_{jl} < D_jL_j$, available product of buyer j can't meet demand, and the time point that the stock is exhaustion is represent by τ_{Bjl}. It can be observed from Figure 2, the relationship between τ_{Bjl} and A_{jl} satisfy $(\tau_{Bjl} - T_{bjl})/L_j = A_{jl}/D_jL_j$, and we can get $\tau_{Bjl} = T_{bjl} + A_{jl}/D_j$ through transposition. At this time, the quantity of time weight inventory of cycle l $H_{jl} = A_{jl}(\tau_{Bjl} - T_{bjl})/2$, namely, the shaded area above the timing axis in Figure 2. The quantity of time weight shortage is $G_{jl} = (D_jL_j - A_{jl})(T_{ejl} - \tau_{Bjl})/2$, that is, the shaded area below the timing axis in Figure 2. Moreover, the ending inventory of cycle l $I_{j,l+1,0} = 0$ and the ending shortage of cycle l $O_{j+1,l} = D_jL_j - A_{jl}$.

Similarly, when $A_{jl} < 0$, time weight inventory $H_{jl} = 0$, time weight shortage $G_{jl} = D_jL_j^2/2 - A_{jl}L_j$, ending inventory $I_{j,l+1,0} = 0$ and ending shortage $O_{j+1,l} = D_jL_j - A_{jl}$.

Therefore, the buyers' planning model (BPM) can be expressed as

$$\min\ C_{Bj} = a_{Bj}m_j + h_{Bj}\sum_l H_{jl} + s_{Bj}\sum_l G_{jl} \qquad (1)$$

$$s.t.\ I_{j,l+1,0} = \max\left(0,(A_{jl} - D_jL_j)\right), \quad \forall j \in 1,...,J, l \in 1,...,m_j, \qquad (2)$$

$$O_{j+1,l} = \max\left(0,(D_jL_j - A_{jl})\right), \quad \forall j \in 1,...,J, l \in 1,...,m_j, \qquad (3)$$

$$A_{jl} = I_{jl0} + X_{jl} - O_{jl}, \quad \forall j \in 1,...,J, l \in 1,...,m_j, \qquad (4)$$

$$I_{j,1,0} + \sum_l X_{jl} = D_jL_j, \quad \forall j \in 1,...,J, l \in 1,...,m_j, \qquad (5)$$

$$X_{jl} \ge 0, I_{jl0} \ge 0, \quad \forall j \in 1,...,J, l \in 1,...,m_j. \qquad (6)$$

Object function (1) contains three parts, that is, order cost, inventory cost and shortage cost; a_{Bj}, h_{Bj} and s_{Bj} are unit order cost, unit inventory cost and unit shortage cost respectively; and the value of time weight inventory H_{jl} and time weight shortage G_{jl} are computed according to the former analysis. (2) and (3) are balance equations on inventory and shortage, which determine quantity relationship of inventory and shortage between consecutive order cycles. (4) calculate available quantity of the product in cycle l . (5) ensure the order amount can meet requirement of total demand.

Planning model of the manufacturer

There are a serial of production cycles for the manufacturer in the period of plan Z . Let N be the cycle number, L_M be the interval of the cycles, and T_{bi} , T_{ei} be start time and end time of cycle i ($i \in 1,...,N$) respectively, then $T_{ei} - T_{bi} = L_M$ and $T_{ei} = T_{b,i+1}$. Each production cycle includes a continuous production process. Let τ_{bi} , τ_{ei} be start time and end time of production in cycle i , then $T_{bi} \le \tau_{bi} < \tau_{ei} \le T_{ei}$. Let P be production rate of the manufacturer, that is production quantity per unit time, then the time weight production quantity in cycle i is $P(\tau_{ei} - \tau_{bi})$.

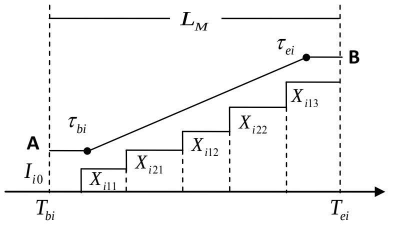

Fig. 3 Inventory of manufacturer in production cycle i

Time weight inventory of manufacturer in production cycle i can be expression in Figure 3, in which the curve AB indicates quantity of finished product at each time point of the cycle without considering delivery, the ladder-shaped curve indicates the quantity of product that has been delivered at each time point, then the space between the curve AB and the ladder-shaped curve corresponds to the time weight inventory. Let I_{i0} be initial inventory in cycle i , then cumulated inventory without consider delivery is $I_{i0}L_M + P(\tau_{ei} - \tau_{bi})^2/2 + P(\tau_{ei} - \tau_{bi})(T_{ei} - \tau_{ei})$, that is shade area below curve AB in Figure 3. Let K_j be the number of delivery the manufacturer need to do for buyer j , T_{ijk} be the time of k th delivery ($k \in K_j$), X_{ijk} be the quantity of the delivery, then cumulated delivery quantity is $\sum_{(j,k)} X_{ijk}(T_{ei} - T_{ijk})$, namely, the area below the ladder-shaped curve in Figure 3. Therefore, the time weight inventory in cycle i can be calculated as follows:

$$H_i = I_{i0}L_M + P(\tau_{ei} - \tau_{bi})^2/2 + P(\tau_{ei} - \tau_{bi})(T_{ei} - \tau_{ei}) - \sum_j \sum_k X_{ijk}(T_{ei} - T_{ijk}). \tag{7}$$

Production quantity that have been delivery from start time of cycle i to any time point t in the cycle is represented by $\sum_{(j,k)|T_{ijk} \le t} X_{ijk}$, in which $(j,k)\,|\,T_{ijk} \le t$ indicates X_{ijk} in cycle i will be summed up for j and k if $T_{ijk} \le t$. Then inventory of the finished product at time point t can be expressed as:

$$I(t) = \begin{cases} I_{i0} + P(\tau_{ei} - \tau_{bi}) - \sum_{(j,k)|T_{ijk} \le t} X_{ijk}, & \text{when } \tau_{ei} < t \le T_{ei}, \\ I_{i0} + P(t - \tau_{bi}) - \sum_{(j,k)|T_{ijk} \le t} X_{ijk}, & \text{when } \tau_{bi} < t \le \tau_{ei}, \\ I_{i0} - \sum_{(j,k)|T_{ijk} \le t} X_{ijk}, & \text{when } T_{bi} \le t \le \tau_{bi}, \end{cases} \tag{8}$$

The manufacturer's planning model (MPM) can be expressed as:

$$\min\ C_M = a_M N + h_M \sum_i H_i \tag{9}$$

$$s.t.\ (7),(8)$$

$$I(T_{ijk}) \ge 0, \qquad \forall i = 1,...,N,\ j = 1,...,J,\ k = 1,...,K_j, \tag{10}$$

$$I_{i0} + (\tau_{ei} - \tau_{bi})P - \sum_j \sum_k X_{ijk} = I_{i+1,0}, \qquad \forall i = 1,...,N, \tag{11}$$

$$T_{bi} \le \tau_{bi} \le \tau_{ei} \le T_{ei} \qquad \forall i \in 1,...,N, \tag{12}$$

$$X_{ijk} \ge 0, I_{i0} \ge 0, \qquad \forall i = 1,...,N,\ j = 1,...,J,\ k = 1,...,K_j. \tag{13}$$

The objective function (9) contains two parts, namely, the production preparation costs and inventory costs, and a_M , h_M represent setup cost and inventory cost respectively. (10) is the constraint of minimal inventory at time points of delivery. (11) is inventory balance equation, which determine inventory relationships between consecutive production cycles.

III. Solving of collaborative planning

The former models of manufacturer and buyers are non-linear optimization model, and the manufacturer model, which can be seen to be a machine scheduling problem[15], is a typical NP-hard problem. In addition, the manufacturer's production cycle and the buyers' order cycle have different interval and they make their schedule according to perspective of respective cycle, then BPM and MPM cannot be directly merged, thus it is difficult using the general non-linear algorithm to solve it. Therefore, a coordinative optimization method based on particle swarm optimization (PSO) is designed to solve the problem.

Encoding and the fitness function

The variable needed to be determined for the collaborative production-distribution planning contains delivery quantities between the manufacturer and the buyers, start time and end time of production of manufacturer. The delivery plan corresponds to X_{ijk} in MPM of the manufacturer and X_{jl} in BPM of the buyers. In order to encode the delivery quantities, they are sorted by delivery time, and then we can get a sequence. Let X_s ($s \in 1,...,S$) indicate the sequence and S be total number of the deliveries, and the sequence X_s is encoded to a particle in real-number. Since in the iterative process, the alternative delivery plans X_s can be regard as known numbers, then τ_{bi} and τ_{ei} can be calculated through substitute X_s into MPM. Therefore τ_{bi} and τ_{ei} do not be encoded directly. The algorithm for solving MPM is described in section 3.3.

The objective of collaborative production-distribution planning is to obtain optimal total cost of the production-distribution system, and therefore the fitness of the algorithm is defined as sum of the manufacturer's cost and the buyers' cost. The fitness function is defined as

$$fitness = C_M + \sum_j C_{Bj} = a_M N + h_M \sum_i H_i + \sum_j \left(a_{Bj} m_j + h_{Bj} \sum_l H_{jl} + s_{Bj} \sum_l G_{jl} \right) \quad (14)$$

Velocity function and position function

A weight velocity function is adopted for the algorithm. Let $x_r = (x_{r1}, x_{r2}, ..., x_{rs}, ..., x_{rS})$ be the position vector of particle r and each particle correspond to an alternative delivery plan which contains S times of delivery. Let $v_r = (v_{r1}, v_{r2}, ..., v_{rs}, ..., v_{rS})$ be the velocity vector which records adjustment quantity of position. Let $p_r = (p_{r1}, p_{r2}, ..., p_{rs}, ..., p_{rS})$ be local best solution of particle r and $p_g = (p_{g1}, p_{g2}, ..., p_{gs}, ..., p_{gS})$ be global best solution. Therefore, the velocity function is defined as

$$v_{is}(t+1) = w(t) v_{is}(t) + c_1 r_1 (p_{is}(t) - x_{is}(t)) + c_2 r_2 (p_{gs}(t) - x_{is}(t)). \quad (15)$$

The w in the function is inertial weight which usually slightly less than 1. An variable weight function is defined as $w(t) = 0.9 - 0.2(t-1)/(T-1)$, in which T is the maximal number of iteration. c_1 and c_2 are cognitive factors which are usually assigned with constants in [0,4] and we can adjust them according to trend of iteration. Random factors r_1 and r_2 are random numbers in the range of [0,1].

Total amount of the buyers' velocity variation by (15) is usually not 0, hence the new delivery plans by direct using the velocities can usually not meet quantity balance of each buyer's total demand. Therefore, a reasonable adjustment mechanism should be adopted for the position function. Let D_j be delivery numbers of buyer j in the whole plan period, x_{rjd} and v_{rjd} be position and velocity of buyer j 's d th delivery in alternative plan r (the r th particle), then the position function is defined as

$$x_{rjd}(t+1) = x_{rjd}(t) + v_{rjd}(t+1) - \left(\sum_d v_{rjd}(t+1) \right) / D_j \quad (16)$$

The item $\left(\sum_d v_{rjd} \right) / D_j$ of the function is the average of buyer j 's extra variation relative to delivery numbers. After adding this item, the new alternative plans by (16) will meet the quantity balance of each buyer's total demand.

Computation of start time and end time of production

Because the BPM and MPM cannot be combined directly, a heuristic based on the principle of Minimizing production lead time is designed according to the delivery plan X_{ij} for computation of start time τ_{bi} and end time τ_{bi} of production. With τ_{bi} and τ_{bi}, the total cost of the manufacturer can be calculated by substitute τ_{bi} and τ_{bi} into (9). Then total cost of the manufacturer will be used as a part of fitness. The pseudo code of the heuristic is described as following.

for i in all Production Cycles
  for j in all Deliveries of the Production Cycle
    $\tau_{bi} = 0$; $\tau_{ei} = 0$;
    # The initial inventory of the cycle can meet requirement
    # of the deliveries
    if $I_{i0} \ge \sum_{k=1}^{j} X_{ik}$ continue;
    else if $I_{i0} + P(T_{ij} - T_{bi}) \ge \sum_{k=1}^{j} X_{ik}$
    # The production capability in current cycle can meet the
    # demands
      $\tau_{bi} = T_{ij} - \left(\sum_{k=1}^{j} X_{ik} \right) / P$; $\tau_{ei} = T_{ij}$;
    else
    # The production capability in current cycle can't meet
    # demand, thus part of production have be transferred to
    # the former cycles.
      if i = 1 then return -1;
      else
        $\tau_{bi} = T_{bi}$; $\tau_{ei} = T_{ij}$;
        # The production quantity need to be transfer
        $A = \sum_{k=0}^{j} X_{ik} - \left(I_{i0} + P(T_{ij} - T_{bi}) \right)$;
        for m = i to 1 with step -1
          if $P(T_{em} - \tau_{em}) \ge A$
            $\tau_{em} = \tau_{em} + A/P$; $A = 0$;
          else if $P\left(L_M - (\tau_{em} - \tau_{bm})\right) \ge A$
            $\tau_{em} = T_{em}$;
            $\tau_{bm} = T_{bm} + \left(L_M - (\tau_{em} - \tau_{bm})\right) - A/P$; $A = 0$;
          else
            $\tau_{em} = T_{em}$; $\tau_{bm} = T_{bm}$;
            $A = A - P\left(L_M - (\tau_{em} - \tau_{bm})\right)$;

Coordination process of problem solving

The coordinative process is design based on the above model and PSO algorithm for the production- distribution planning problem. By using this process, the total optimal plan will be obtained and only need to share total cost information of the manufacturer and the buyers. In the process, the act of planning manager can be independent third party or implement by the manufacturer.

Step 1: Initial the algorithm. To define maximal iteration number and the scale of particle swarm.

Step 2: If the buyers' demand are steady, an initial order plan will be determined through EOQ model. If the buyers' demands are dynamic, the initial order plan will be transferred from actual external demands by $X_{jl} = D_j L_j$ (see BPM model). Then the buyers submit the initial order plan to the planning manager.

Step 3: The planning manager use transformation of (16) to generate initial particle swarm, namely a group of alternative delivery plan. The transform approach of (16) is to let $v_{rjd}(t+1) = x_{rjd}(t)\alpha_{rjd}$, in which $x_{rjd}(t)$ correspond to initial order plan of the buyers and α_{rjd} is a random number of average distribution in a range, such as [-0.2,0.2]. Then the planning manager shares the alternative delivery plans with the manufacturer and the buyers.

Step 4: The buyers calculate their total cost by (1). The manufacturer calculates his production plan by heuristic in section 3.3 and then calculates his total cost by (9). The buyers and the manufacturer submitted their total cost information to the planning manager respectively.

Step 5: The planning manager calculates fitness through (14) and records the local optimization and the global optimization fitness values and the corresponding delivery plans of them. Then constraint of iterative number will be check. If the iterative number meets maximal number of iteration then stop coordinative process and return the global optimal plan. Otherwise go next step.

Step 6: The planning manager calculate new velocities by (15) and obtain new alternative delivery schedules by (16). Then go step 4.

IV. Computational experiment

Take a manufacturer and three buyers for example, and 50 unit time for the period of plan Z. Two kinds of external demand of the buyers are considered: steady demand and dynamic demand. For steady demand, the buyers have fixed demand rate during the entire planning period. Under this condition, the demand rate D_j of a buyer are assigned as a random number in [10,20], unit order fee is 100 and unit inventory cost is 0.5. Then The interval of order cycle L_j and initial order plan X_j are determined by the classical EOQ model, namely, $L_j = \sqrt{2a_{bj} / h_{Bj} D_j}$ and $X_{jl} = \sqrt{2a_{Bj} D_j / h_{Bj}}$. For dynamic demand, demand rates in deferent cycles of a buyer are deferent. Under this condition, the order intervals of the buyers are assigned as $\{4,5,6\}$ respectively, the demand rate are random numbers in [10,20], and the initial order quantity $X_{jl} = D_{jl} L_j$. The number of the manufacturer's production cycle N is assigned as 5, production rate (output per unit time) is 75, and unit setup cost a_M and unit inventory cost h_M are assigned as 100 and 0.5 respectively.

The models and algorithm based on PSO are implemented by Matlab. The scale of particle swarm is 40, maximal iteration number is 100 and the cognitive factors $c_1 = 0.5$ and $c_2 = 1.5$. In the process computational experiments, 10 instances are generated according to the condition of external demand and each instance is solved 5 times. Then the date come from iteration process are averaged for steady demand, dynamic demand and all experiments respectively.

Table I. Variable of fitness value follow difference iteration cycle

	Initiation	20	40	60	80	100
B_k	12488.79	12102.28	11876.93	11604.40	11479.64	11428.47
r_k (%)	-	3.09	1.86	2.29	1.08	0.45
M_k	12711.37	12316.01	11982.40	11663.33	11490.20	11429.71
g_k	222.58	213.72	105.46	58.93	10.56	1.23

In order to analyze the convergence performance of the collaborative planning algorithm, the best fitness of each iteration cycle B_k and the mean of fitness of each particle M_k are taken each 20 times of iteration as samples. The decrease rate r_k of a sample related to the last sample is computed by $r_k = (B_{k-1} - B_k) / B_{k-1}$, the gap between mean score and best score is defined as $g_k = M_k - B_k$, and the results of computation are showing in table 1, in which first line is iteration times. As can be seen from the table, along with the increase in the number of iterations, the best score decreased gradually, and the rate of decline has been slowing, and the gap between the mean and the best score is rapidly reduced, until the gap to the best score is only 1.23, which shows the convergence of algorithm are good.

In order to analyze the effectiveness and optimal performance of the collaborative method, the manufacturer's cost C_M, the buyers' cost C_B and total cost C before and after collaborative planning are compared. Before collaborative planning, the buyers calculate their optimal order plans by EOQ model if the demands are steady and by BPM model if the demands are dynamic. The manufacturer seeks his optimal production plan by MPM model and the algorithm in section 3.3 according to the buyers' order plans.

Table II. Variation of the manufacturer's cost, the buyers' cost and total cost through collaborative planning

	Before collaborative planning			After collaborative planning			Reduction on total cost (%)
	C_M	C_B	C	C_M	C_B	C	
Steady demand	6473.84	5800.00	12273.84	4763.14	6665.32	11428.46	6.89
Dynamic demand	7373.90	5923.17	13297.08	4293.32	7653.56	11946.88	10.15

The results are show in table 2. From the table data, the costs of buyers are increased through collaborative planning regardless of steady demand or dynamic demand, this is because the order plans of the buyers before collaboration are local optimization, and the adjustments of the plans will inevitably increase the costs of the buyers. Meanwhile, the collaboration process reduce the cost of the manufacturer, and the reduction of the manufacturer' cost are always higher than the increase of the buyers' cost. As can be seen from the table, the reduction of total cost through collaborative planning reaches 6.89% when demand is steady and 10.15% when demand is dynamic, which shows that the method of collaborative planning has good optimization performance, and the effect of optimization is relatively better under the condition of dynamic demand.

V. Conclusion

The paper proposes a collaborative planning model, which contains sub-models of the manufacturer and the buyers, for the production-distribution system with independent and autonomous partners. In this model, inventory cost and shortage cost of the buyers are considered. Based on PSO, an algorithm, which includes a coordinative optimization process, is designed for solving the collaborative planning model. Through the process of coordination, the optimal solution can be obtained without the need to share detail demands of the buyers. Computational experiments show that the cooperative planning method, which contains the models and the algorithm, has good convergence and optimal performance, and it is more effective under condition of dynamic demand than the condition of steady demand.

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