Target Inventory Strategy in Multistage Supply Chain by Particle Swarm Optimization

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Abstract

In recent years, the automobile industry has been advancing the cost cut by a merger, the introduction of foreign capital, promotion of competition of a supplier, etc. We are satisfied a variety of customer specification in product and service, without dropping the productive efficiency in great need of mass customization in supply chain management. There is need for a business model to realize mass customization in the automobile industry. In this paper, we propose the setting method of the optimum order quantity by particle swarm optimization for supply chain management. Proposed method provides new optimal model in logistics of supply chain management from supplier to maker. And we set up the optimum order quantity from which the profits of the whole supply chain management become the maximum by using particle swarm optimization.

Keywords: Supply chain management; Logistics; Mass customization; Particle swarm optimization

1. Introduction

In recent years, the automobile industry has been advancing the cost cut by a merger, the introduction of foreign capital, promotion of competition of a supplier, etc (Ueno et al., 2004). It becomes very important in future to remove waste of the production business and to realize needs of an individual customer and the conformity nature to a change of a market. In particular, we are satisfied a variety of customer specification in product and service, without dropping the productive efficiency in great need of mass customization in supply chain management (SCM) (Biller et al., 2001; Gilmore et al., 2000; Jing-Sheng Song et al., 2002; Pine, 1993).

Particle Swarm Optimization (PSO) (Ide et al., 2004; Kitamura et al., 2005; Kitayama et al., 2005; Rahmat-Samii et al., 2003) is one of the methods of solving a continuous nonlinear optimization problem efficiently developed by Kennedy through the simulation of the simplified social model. It is known as a result of much old numerical simulations that it is possible to calculate the semi optimal solution which is equivalent to the global optimal solution of multimodal function of a continuous variable or it in high accuracy.

In this paper, we propose the setting method of the optimum order quantity by PSO for supply chain management. Proposed method provides new optimal model in logistics of supply chain management which consisted of a retailer, a wholesaler, a distributor and a factory. And we set up the optimum order quantity from which the profits of the whole supply chain management become the maximum by using PSO.

2. Outline of Supply Chain Management

SCM is the strategic management technique which aims at optimization of the whole business process, or an information system for it. In a manufacturing industry or a distribution industry, the flow of the goods supply to final demand from production is mainly caught with supply chain. And information is mutually shared and managed between the section and company which participates in it.

The concrete purpose for a company is improvement of customer satisfaction by appointed date of delivery shortening, and maximization of cash flow by reduction of stock including circulation stock.

The basis of the concept of supply chain management is attaining not individual optimization of a supplier but whole optimization. Although final demand and sales force are weak, in order to lower a manufacture unit price, even if it increases the quantity of production, a dead stock will be increased as a result. And even if it builds a conversely powerful sales network, if goods supply cannot be performed by the defect of the shortage of parts, or a production plan, the opportunity

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of sale will be lost. The theme of SCM practice is how this futility is canceled.

The basic form of SCM solution is performing demand estimating from sales performance information, such as POS data, and synchronizes and optimizes production plan, inventory plan, selling plan and supplement plan based on this. By these plans, it is performing production and physical distribution. However, for that purpose, each supplier needs to build the structure which exchanges high data of precision on real time.

3. Model Formulation

3.1 Basic Model of Single Stage in Supply Chain

It is thought that consumer causes demand for one retailer. Here, demand at stage \( i \) in period \( t \) is shown by normal distribution \( D_i^t \in N(d, \sigma^2) \) with average \( d \) and variance \( \sigma^2 \). Demand forecast \( \hat{d}_i^t \) during lead time at stage \( i \) is formulated by

\[
\hat{d}_i^t = L_i \hat{d}_i^t
\]

(1)

Where, \( L_i \) is lead time for stage \( i \) and \( \hat{d}_i^t \) is demand forecast at stage \( i \) in period \( t \) using moving average method with period \( p \).

\[
\hat{d}_i^t = \frac{\sum_{j=1}^{p} D_i^{t-j}}{p}
\]

(2)

Standard deviation of demand forecast during lead time at stage \( i \) is given by \( \tilde{\sigma}_i^t = \sqrt{L_i \sigma} \). Under there environment, demand variable level at stage \( i \) in period \( t \) is expressed by

\[
y_i^t = \hat{d}_i^t + a_i^t \tilde{\sigma}_i^t
\]

(3)

where, \( a_i^t \) is control parameter about customer satisfaction at stage \( i \). And, order quantity \( O_i^t \) at stage \( i \) in period \( t \) is given by

\[
O_i^t = D_i^t + y_i^{t+1} - y_i^t
\]

(4)

3.2 Formulation of Multistage Supply Chain

We formulate fundamental model which is discussed in this paper. In problem definition and formulation, we consider these quantities such as \( D_i^t, y_i^t, O_i^t, S_i^t \), where \( S_i^t \) denotes inventory at stage \( i \) in period \( t \). Figure 1 shows four steps of simple supply chain. Index \( i \) expresses retailer by 1, wholesaler by 2, distributor by 3, and factory by 4. We consider price of product, \( p_D^i \), order and logistics cost, \( p_P^i \), restocking fee in order, \( p_r^i \), restocking fee in demand, \( p_u^i \), holding cost, \( p_p^i \), and stock out cost, \( p_e^i \), per unit.

We formulate problem deciding the order variable \( x_i^t \), \( x_i^{t-1}, \ldots, x_i^{t+\eta} \). As is plan start time. And \( t_D \) is plan period. \( x_i^t \) satisfies maximizing profit of total supply chain as follows;

\[
\max \sum_{i=1}^{m} \sum_{t=t_1-\eta}^{t_1+\eta} \left( p_D^i D_i^t - c_i^t \right)
\]

(5)

s.t. \( c_i^t = p_D^i S_i^t + p_P^i u_i^t + p_O^i O_i^t + p_r^i r_i^t + p_u^i u_i^t + p_p^i p_i^t + p_e^i e_i^t \)

(6)

\( z_i^{t+1} = S_i^t - y_i^t + O_i^t - r_i^t \)

(7)

\( y_i^t = D_i^t - b_i^t \)

(8)

\( S_i^t = \min(f_i(z_i^t), \hat{S}_i^t) \)

(9)

\( u_i^t = f_i(z_i^t) \)

(10)

\( O_i^t = f_i(x_i^t) \)

(11)

\( r_i^t = \min(S_i^t, f_i(x_i^t)) \)

(12)

\( D_i^t = O_i^{t-1} \)

(13)

\( b_i^t = r_i^{t-1} \)

(14)

\( L_c^t \geq L_c^{t+1} \geq 0 \)

(15)

\( \hat{S}_i^t \geq 0 \)

(16)

\( L_s^t \geq 0 \)

(17)

\( c_i^t \) denotes total cost of multistage and from eq. (9) to eq. (14) are derived by model assumptions. \( r_i^t \) denotes restocking in order, \( b_i^t \) denotes restocking in demand, \( u_i^t \) denotes quantity out of stock and \( z_i^t \) denotes inventory variable. \( \hat{S}_i^t \) denotes limit inventory in stage \( i \). And inventory quantity \( S_i^t \) must not be beyond limit inventory \( \hat{S}_i^t \) in each stage. We consider lead time of order, \( L_O^t \), restocking, \( L_s^t \), and plan, \( L_c^t \).

Figure 2(a) and figure 2(b) shows that \( L_O^t \) is a lead time which until it orders form the next stage \( i+1 \) and re-
4. Solution Method

4.1 Outline of Particle Swarm Optimization

PSO is the optimization technique based on the action of groups, such as a bird and a fish, and man's social activity. They are carried out based on continuing evolution, sharing the information which constitutes a group. PSO is the technique of calculating the optimal solution in consideration of the past search history from the best information (pbest) which a solid (Particle) has, and the optimal value (gbest) of the group (Swarm) formed from the solid. In PSO, each particle has the information about a position and speed. And it searches in a group, having an interaction. The optimal solution is calculated updating the position and speed of each particle.

4.2 Renewal of Position and Speed

By using the position \( x^k_d \) and speed \( v^k_d \) of an individual \( d \) of the \( k \)-th time search, the \( k + 1 \)-th time position \( x^{k+1}_d \) and speed \( v^{k+1}_d \) are updated by the following formula.

\[
x^{k+1}_d = x^k_d + v^{k+1}_d \quad (18)
\]
\[
v^{k+1}_d = w v^k_d + c_1 r_1 (p^k_d - x^k_d) + c_2 r_2 (g^k - x^k_d) \quad (19)
\]

\( r_1 \) and \( r_2 \) are \([0,1]\) random number. \( c_1 \) and \( c_2 \) are parameters, and it is often that they are decided to be as follows.

\[
c_1 + c_2 = 4 \quad (20)
\]

In addition, \( w \) is a parameter to be called momentum. \( p^k_d \) shows the best solution (pbest) when Individual \( d \) searches to the \( k \)-th time. On the other hand, \( p^k_g \) shows the whole group’s best solution (gbest) in the \( k \)-th search. As shown in Figure 7, each searching point generates the position information of one’s best solution (pbest) and the position information of group’s best solution (gbest).
4.3 Basic Algorithm

The basic algorithm of PSO is as follows. Figure 8 shows the algorithm of PSO.

<Step1> The number of individuals and the number of the maximum search are decided.

<Step2> The initial position $x_{d}^{k}$ and the initial speed $v_{d}^{k}$ are decided at random to each individual. And it set to $k = 1$.

<Step3> Function value is calculated to each individual.

<Step4> $p_{d}^{k}$ and $p_{g}^{k}$ are calculated.

<Step5> The speed and the position of each individual are updated according to eq. (18) and eq. (19).

<Step6> If the number $k$ of search is below the number of the maximum search, it returns to <Step3> as $k = k + 1$. Otherwise, search is ended.

\[ x_{d}^{k+1} = x_{d}^{k} + w v_{d}^{k} + \phi (p - x_{d}^{k}) \]  

(21)

Where, $\phi$ and $p$ in eq. (21) are as follows, respectively.

\[ \phi = c_{1}r_{1} + c_{2}r_{2} \]  

(22)

\[ p = \frac{c_{1}r_{1}p_{d}^{k} + c_{2}r_{2}p_{g}^{k}}{c_{1}r_{1} + c_{2}r_{2}} \]  

(23)

It means that this newly generates a point to the inside Neighborhood the position which carried out parallel translation only of the $w v_{d}^{k}$ from the present position $x_{d}^{k}$. Eq. (21) serves as a form which multiplied the search direction vector $p - x_{d}^{k}$ by the step width $\phi$.

Moreover, $\phi$ adds two uniform random numbers from eq. (22). And the distribution of the minimum value 0, maximum $c_{1}r_{1} + c_{2}r_{2}$, and average $(c_{1}r_{1} + c_{2}r_{2}) / 2$ is followed. Therefore, it is thought that PSO has an effect method with probable step width and similar structure.

4.4 Neighborhood of PSO

From eq. (18) and eq. (19), the $k + 1$-th position $x_{d}^{k+1}$ of Individual $d$ can change as follows

\[ x_{d}^{k+1} = x_{d}^{k} + w v_{d}^{k} + \phi (p - x_{d}^{k}) \]  

(21)

As for momentum, the amount of parallel translation from the present position $x_{d}^{k}$ of Individual $d$ means becoming small as search progresses, so that clearly from eq. (21).

4.5 Outline of Momentum

In PSO, momentum becomes small gradually according to the following formula as search progresses.

\[ w = w_{\text{max}} - \frac{k (w_{\text{max}} - w_{\text{min}})}{k_{\text{max}}} \]  

(24)

Where, $w_{\text{max}}$ and $w_{\text{min}}$ are maximum and minimum of momentum, and $k_{\text{max}}$ is the maximum number of search. Using the following value from the result of many numerical computations is recommended.

\[ w_{\text{max}} = 0.9 \]  

(25)

\[ w_{\text{min}} = 0.4 \]  

(26)

4.6 The Best Value Save Type Mode

$p_{g}$ in eq. (19) expresses the individual (gbest) which gives the best value in the whole group’s inside in the k-th search. However, this serves as an individual that gives the best value in the inside of the point updated by eq. (18) and eq. (19). That is, pbest is saved until the objective function is updated. However, gbest is updated for every number of searches. Thereby, not only global search capability but local search capability is decreased. Consequently, settling might be delayed. Then, it crowds together toward the best solution obtained in old search, the whole moves, and a model whose local search capability improves is also proposed. This is called the best value save type model. It is the model which replaced $p_{g}$ in eq. (19) as follows.

\[ v_{d}^{k+1} = w v_{d}^{k} + c_{1}r_{1}(p_{d}^{k} - x_{d}^{k}) + c_{2}r_{2}(p_{g}^{k} - x_{d}^{k}) \]  

(27)

$p_{g}$ expresses the individual which gives the best value obtained by old search. That is, $p_{g}$ is not changed until the best value of $p_{d}^{k}$ in old search is updated. As a result, local search capability improves.
5. Numerical Example

In this section, the proposed model is solved using PSO. Figure 9 shows the outline of dynamics. We set the plan start time $t_s = 20$, plan period $t_p = 10$ and lead time of period to build a plan $L_t^i = 5$. In other words period 16-30 are prediction periods.

Table 1 shows the comparison when giving $x^i_t$ by the normal distribution and PSO. In the case of a normal distribution, it is the case where distribution is changed by an average of 30. Each stage and total at that time, average, standard deviation, the best value, and the worst value are shown. And it shows the result of PSO. In an average and the best value, it turns out except stage 1 that the way as a result of PSO is good. However, the value of stage 1 is worse than worst. This is considered that *** is the cause. Figures from 10 to 15 are the result of a normal distribution when a best solution comes out by total, and as a result of PSO. As for these graphs, the solid lines shows stage 1, the dashed lines shows stage 2 and the dotted lines shows stage 3. Figures 10 and 11 are result of quantity out of stock. From these figures, in result of PSO, the times of stock out are small. And the quantity of stock out is small, too. Figures 12 and 13 are result of inventory quantity. In result of PSO, it turns out expect stage 3 that there is little inventory quantity. Figures 14 and 15 are result of order quantity. In result of PSO, it turns out that the quantity of order is not changed sharply.

Table 1. Comparison of Results

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<thead>
<tr>
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<th>Stage1</th>
<th>Stage2</th>
<th>Stage3</th>
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<td>331343</td>
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</tbody>
</table>
6. Conclusions

In this paper, we proposed the setting method of the optimum order quantity by PSO for supply chain management. Proposed method provided new optimal model in logistics of supply chain management which consisted of a retailer, a wholesaler, a distributor and a factory. And it is thought effective to set up the optimal order quantity from which the profits of the whole supply chain management become the maximum by use of PSO.

References


