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Research on the Application System of Supply Chain Incentive Management Mechanism under Regional Economy

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Abstract. Aiming at the problem that product recovery is not considered in supply chain model, which is unfavorable to cost control of supply chain of short life period products, the Gaussian Harmony Search (GHS) recycle supply chain model establishment and optimization algorithm based on recycle cost income is put forward. Firstly, supply chain is described according to five stages and model construction of product recycle process is considered. At the same time, the minimal cost optimization target of supply chain model that is established based on storage cost, shortage cost and transfer cost is utilized. Secondly, model optimization is implemented by introducing Harmony Search Algorithm, meanwhile self-adaption search is implemented by utilizing Gaussian traversal control parameters to improve effectiveness of Harmony Search and self-adaption of algorithm. Finally, sensitivity to parameter to GHS is analyzed by standard test function and model algorithm research has been implemented. The experiment result shows that proposed algorithm can obtain the lower supply chain transportation cost.

Key words. Recycle cost, Cost estimation, Harmony Search, Gaussian, Supply chain.

1. Introduction

In order to improve income cost, manufacturer will tend to recycle surplus value of products by remanufacturing process. Products will be transformed into well-liked new products during remanufacturing by refurbishment, maintenance and update, which can save considerable cost [1-2].

Previous researchers developed supply chain management method to optimize single-stage inventory system. For example, in literature [3], the remanufacturing model based on unlimited manufacturing rate is proposed and remanufactured optimal batch could be confirmed by utilizing classic EOQ formula. In literature [4],

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the mixed production/recycle system is put forward, of which characteristics are to decide recycle to defective product and which has solved collection problem. In literature [5], the optimal configuration was implemented and the product collection channel of manufacturers with monopoly characteristics was confirmed. In literature [6], the MAX-SAT correlation problem with coverage problems characteristics was established to effectively identify product collection area. Single-stage inventory system was usually used to small-size area distribution. However, China is characterized by enormous group and relatively large megalopolis, so supply efficiency is not efficient by adopting single-stage inventory system model. Therefore, the key point of research of this paper is product recovery problem of multistage inventory system and researchers have implemented researched on the problem. For example, the same assumption to demand process of retailers in similar distribution system was implemented and queue network model with limited buffer was developed without considering setting cost of inventory in literature [7]. In literature [8], the maximum joint profit of the suppliers, manufacturers and third-party recycler and retailer was intended to be improved by setting for closed remanufacturing recycle supply chain inventory system to keep setting and ordering cost so as to ensure sufficient inventory. Continuous review of multilayer inventory control system under generalization condition was considered a warehouse and a dealer are constituted by utilizing two-level inventory systems in literature [9]. Facing with demand of customers, supply to order and warehouse is implemented and defective objects are returned to dealers for recycle, etc.

The research is implemented under two closed supply chain system frames and relevant demand product recycle problem is considered and inventory system development is implemented. The development model is constructed based on literature [9] and in proposed model, the quantity of decision is decided dynamically, which depends on quantity change of recycled products in remanufacturing process. Proposed models refer to four warehouses, while inventory level keeping of four warehouses refers to a series of cost factors, such as transportation cost and shortage cost, etc. Therefore, by taking inventory level of four warehouses as optimal input vector and by implementing model optimization by adopting Harmony Search Algorithm [10] and at the same time, to improve algorithm performance, self-adaption searching is implemented to Harmony Search step range by utilizing Gaussian traversal [11] control parameters to improve self-adaption ability of algorithm.

2. Supply chain model establishment of product recycle

2.1. Model stage description

In actual supply chain system, supply chain not only manages inventory level, at the same time, but also provides raw material and new product production; however, recycled products can bring more benefit to members of supply chain. A two-stage supply chain system constituted by manufacturer and retailer has been developed, as shown in Fig. 1. Fig. 1 includes four kinds of warehouses, such as new product warehouse of retailer (warehouse 1), new product warehouse of manufacturer (warehouse 2), recycle warehouse of manufacturer (warehouse 3) and recycle warehouse of retailer (warehouse 4).

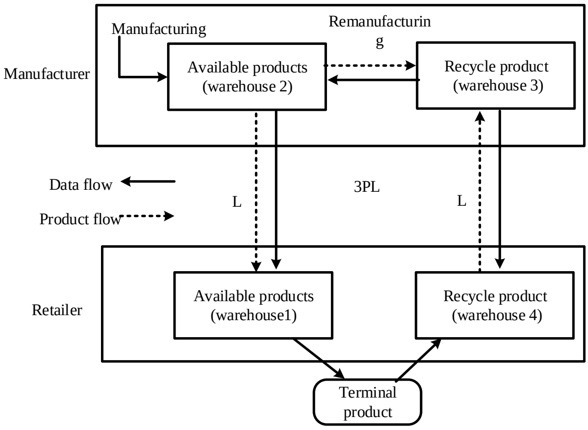


Fig. 1. Product development and recovery process

In this model, it is assumed that recovery rate of demand rate (sum) has characteristics of confirmation, fixation and evenness in the whole supply period. Products are returned to retailer warehouse by customer recycle (warehouse 4) and then recycled products are transferred to return warehouse of manufacturer (warehouse 3). In production, products produced by manufacturer have been transported to new product warehouse of retailer (warehouse 1) by new product inventory of manufacturer (warehouse 2) and are delivered to terminal customer finally.

In proposed two-stage supply chain system, detailed description can be implemented by five stages. In each stage, inventory level of warehouse is generally influenced by product circulation. See Fig. 2 for details:

Stage 1: starting point of period; stage 2: warehouse inventory has been delivered from warehouse 4 to warehouse 3 by time L2; stage 3: remanufacturing process ends; stage 4: new product production ends. When inventory of warehouse 2 is less than that of warehouse 1, the stage will be implemented; stage 5: at stage time end, products can be delivered to warehouse 1. Detailed information of all stages will be described in the follows.

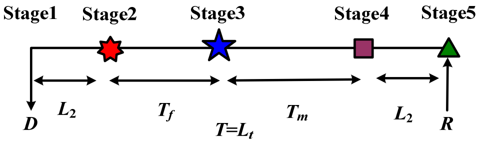


Fig. 2. Stages of recycling supply chain

2.2. Mathematical model of all stages

In the follows, mathematical model of all foresaid stages is described respectively.

Stage 1: in the beginning stage of supply chain period, products used by final customer are recycled and returned to warehouse 4, but demand products of terminal customer are provided by warehouse 1. Inventory calculation formula that warehouse 1 meets demand process of terminal customer is shown as formula (1).

$$X^{+} = \left\{ \begin{array}{cc} D & D \le I_{1O} \\ I_{1O} & D \succ I_{1O} \end{array} \right\} = \min\left(D, I_{1O}\right) . \tag{1}$$

Where, D is terminal user demand and X^{+} shows that it meets demand of part of customers and I_{iO} shows original inventory level of warehouse i, similarly hereinafter.

If demand quantity of customer is higher than inventory level of warehouse 1, supply shortage will occur, as shown in formula (2).

$$X^{-} = D - X^{+} . \tag{2}$$

Where, X^{-} shows that it does not meet demands of part of customers

The process influences inventory level of warehouse 1, inventory level change of warehouse 1 ($I_{1O} \to I_{1n}$) can be updated by utilizing formula (3) and formula (4):

$$I_{1n} = I_{1O} - X^{+} . \tag{3}$$

$$I_{1n} = \left\{ \begin{array}{cc} I_{1O} - D & D \le I_{1O} \\ 0 & D \succ I_{1O} \end{array} \right\} . \tag{4}$$

Where, I_{in} shows new inventory level, similarly hereinafter.

For new inventory of warehouse 1, order quantity of warehouse 1 is shown as formula 5.

$$Q_1 = X^{-} - I_{1n} . \tag{5}$$

Where, Q_i shows order quantity of warehouse i, similarly hereinafter.

Then, order quantity of warehouse 2 and warehouse 3 is shown as formula (6):

$$\left\{ \begin{array}{l} Q_2 = Q_1 - I_{2O} , \\ Q_3 = Q_2 - I_{3O} . \end{array} \right. \tag{6}$$

The process when products are returned to warehouse 4 can be described after end of its service life:

$$R^{k-1} = r \times D^{k-1} . \tag{7}$$

Where, R is recycled merchandise proportion per unit time and r is proportionality coefficient. Increment of inventory level in warehouse 4 caused by returned products is:

$$I_{4n} = I_{4O} + R^{k-1} . \tag{8}$$

Stage 2: stage 2 is beginning stage of supply chain and supply stage after time L_2; in the stage, inventory products are delivered to warehouse 3 from warehouse 4 and specific models are as follows:

$$S_{43} = \left\{ \begin{array}{cc} I_{4O} & I_{4O} \leq Q_3 \\ Q_3 & Q_3 \leq I_{4O} \end{array} \right\} = \min\left(I_{4O}, Q_3\right) . \tag{9}$$

Where, S_{ij} is goods transfer quantity from warehouse i to warehouse j, similarly hereinafter.

Inventory update formula of warehouse 3 and warehouse 4 is as follows:

$$\left\{ \begin{array}{l} I_{3n} = I_{3O} + S_{43} \\ I_{4n} = I_{4O} - S_{43} \end{array} \right. \tag{10}$$

In stage 2, storage cost, shortage cost and transfer cost influence total inventory cost of warehouse 4. When remanufacturing process ends, inventory quantity of warehouse 3 and 2 shall be updated:

$$S_{32} = \left\{ \begin{array}{cc} I_{3O} & I_{3O} \leq Q_2 \\ Q_2 & Q_2 \leq I_{3O} \end{array} \right\} = \min\left(I_{3O}, Q_2\right) . \tag{11}$$

$$\left\{ \begin{array}{l} I_{3n} = I_{3O} - S_{32} \, , \\ I_{2n} = I_{2O} + S_{32} \, . \end{array} \right. \tag{12}$$

Total time required by remanufacturing process is:

$$T_r = t_r + L_r \times S_{32} \, . \tag{13}$$

Stage 3: in the stage, holding cost, shortage cost and transfer cost influence total cost of model. Inventory is transferred from warehouse 2 to warehouse 1 by using inventory batch in batches to meet demands of final customers, as shown in Fig. 2. Inventory calculation formula is as follows:

$$S_{21} = \left\{ \begin{array}{cc} I_{2O} & I_{2O} \leq Q_1 \\ Q_1 & Q_1 \leq I_{2O} \end{array} \right\} = \min\left(I_{2O}, Q_1\right) = Q_1 \, . \tag{14}$$

$$\left\{ \begin{array}{l} I_{2n} = I_{2O} - S_{21} \\ I_{1n} = I_{1O} + S_{21} \end{array} \right. \tag{15}$$

According to formula (14), at any time, warehouse 2 may not meet all reception orders of warehouse 1. Therefore, when inventory of warehouse 2 is less than that of warehouse 1, manufacturer will produce new products. It is assumed that there is enough time to produce new products and to transport them to warehouse 1. Schematic diagram of the stage is shown in Fig. 2.

Manufacturing time includes fixed setting time and variable manufacturing time:

$$T_m = t_m y + L_m \times x \, . \tag{16}$$

Where, t_m is production preparation time and L_m is variable unit manufacturing time and T_m is total manufacturing time.

If foresaid conditions are met, new products will be produced and inventory level of warehouse 1 will be increased correspondingly:

$$I_{1n} = I_{1O} + x\,. \tag{17}$$

Limit condition of manufacturing time is:

$$\begin{aligned} 2L_2 + T_r + T_m &\leq T\,(2 \times L_2) + (t_r + L_r \times S_{32}) + (t_m y + L_m \times x) \\ &\leq (T = L_1)\,x \leq \frac{L_1 - ((2 \times L_2) + (t_r + L_r \times S_{32}) + t_m y)}{L_4}\,. \end{aligned} \tag{18}$$

Where, T_r is total time of production preparation.

As previously mentioned, each recycled product can be transformed into available products and the quantity of new products is:

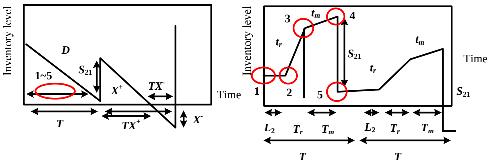
$$x = \frac{L_1 - ((2 \times L_2) + (t_r + L_r \times S_{32}) + t_m y)}{L_m}\,. \tag{19}$$

Stage 4 and stage 5: production cost influences total cost of warehouse 2. If there is limit of production time or the quantity of remanufacturing products is more than order quantity of warehouse 1, it is impossible for manufacturer to decide to produce new products.

Fig. 7 has provided stage 5 of model. Holding cost is the most important cost. Within time L_2, inventory batch is transported from warehouse 2 to warehouse 1.

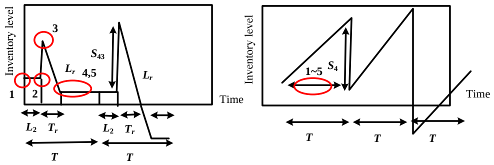
2.3. *Inventory level of all warehouses*

Change of inventory level of all warehouses is mainly introduced in the section, as shown in Fig. 3.



(a)Warehouse 1

(b)Warehouse 2



(c)Warehouse 3

(d)Warehouse 4

Fig. 3. Inventory level of all warehouses

In each figure of Fig. 3, period change condition of inventory level caused by inventory circulation has been displayed. Five stages from stage 1 to stage 5 of supply process have been marked by numbers in Fig. 3. There are coupling and mutual restriction relationships among inventory level of four warehouses; therefore, it is key to realize the minimal cost by reasonably keeping warehouse inventory level and at the same time, retailer recycle warehouse (warehouse 4) will be influenced by the quantity of recycled merchandises.

Therefore, it involves total cost optimization target based on warehouse inventory level, where cost of each warehouse consists of holding cost, shortage cost and transfer cost and will be influenced by decision value of warehouse inventory level, where warehouse 2 and 3 also refer to manufacturing and remanufacturing costs. Its mathematical model can be represented as:

$$\min C_{total} = C_{t1} + C_{t2} + C_{t3} + C_{t4} \tag{20}$$

Where:

$$C_{t1} = \frac{C_{b1} X^{-2}}{2D} + \frac{C_{h1} \left(I_1 - I_1 - X^{+}\right) X^{+}}{2D} \tag{21}$$

$$\begin{aligned} C_{t2} = {} & \frac{C_{b2}\left(Q_1 - S_{21} - yx\right)}{T} + C_{p2} S_{21} \\ & + \frac{C_{h2}}{T} \left(\begin{aligned} & I_2 L_2 + T_r \frac{\left(I_2 + S_{32}\right) + I_2 - (1-y) S_{21}}{2} \\ & + T_m(y) \frac{\left(I_2 + S_{32}\right) + \left(I_2 + S_{32} + x - S_{21}\right)}{2} \\ & + \left(\left(T - \left(T_r + T_m(y) + L_2\right)\right) \times \left(I_2 + S_{32} - S_{21} + xy\right)\right) \end{aligned} \right) \end{aligned} \tag{22}$$

$$\begin{aligned} C_{t3} = {} & \frac{C_{b3}\left(Q_2 - S_{32}\right)}{T} + C_{p3} S_{32} \\ & + \frac{C_{h3}}{T} \left(\begin{aligned} & I_3 L_2 + \frac{\left(2\left(I_3 + S_{43}\right) - S_{32}\right)\left(t_r + L_r S_{32}\right)}{2} \\ & + \left(T - \left(T_r + L_2\right)\right)\left(I_3 + S_{43} - S_{32}\right) \end{aligned} \right) \end{aligned} \tag{23}$$

$$\begin{aligned} C_{t4} = {} & \frac{C_{b4}\left(Q_3 - S_{43}\right)}{T} + C_{p4} S_{43} \\ & + C_{h4} \left(\frac{2\left(I_4 - S_{43}\right) + R}{2} \times \frac{I_4 - S_{43} + R}{\left(I_4 - S_{43} + R\right) + \left(Q_3 - S_{43}\right)} \right) \end{aligned} \tag{24}$$

Constraint condition is:

$$S_{32} - Q_2 \leq My, y = 0, 1\,. \tag{25}$$

$$I_i - Q_{i-1} \leq Q_i \leq 0, i = 2, 3, 4\,. \tag{26}$$

$$x = \frac{L_1 - 2L_2 - (t_r + L_r S_{32}) - t_m y}{L_m}\,. \tag{27}$$

$$R^{k-1} = r \times D^{k-1}\,. \tag{28}$$

$$S_{ij} = \min\left(I_i, Q_j\right) \approx \left\{ \begin{array}{c} Q_j \geq S_{ij} \\ I_i \geq S_{ij} \end{array} \right\}. \tag{29}$$

Where, C_{hi} is unit storage cost of warehouse i and C_{bi} is unit shortage cost of warehouse i and C_{pi} is unit transportation cost of warehouse i. Because independent variables in the optimal model are Q_i, x and y and total cost is a convex function, the optimal solution can be ensured to be obtained.

3. GHS supply chain optimization of recovery cost and income

3.1. GHS algorithm design

In HS optimization, music elements are introduced, of which parameters involved mainly include: storage scale (c_{HMS}), storage parameter (c_{HM}), reference rate index (c_{HMCR}), interval proportion adjustment parameter (c_{PAR}) and width distance adjustment parameters (c_{bw}), etc. Element creation process of Harmony Search Algorithm obtains vector individual update process by element creation: vectors existing in c_{HM} are obtained randomly and new vector individuals are obtained by utilizing c_{HMCR}. Then, vector individual adjustment is implemented based on c_{PAR} and c_{bw}, as shown in formula (30):

$$\left\{ \begin{array}{ll} x_{new,i} = x_{r,i} \pm c_{rand} \times c_{bw} & if\ c_{rand} < c_{PAR} \\ x_{new,i} = x_{r,i}, & if\ c_{rand} \geq c_{PAR} \end{array} \right. \tag{30}$$

However, there is problem of not high differentiation degrees in adjacent periods in group evolution process during search process for fixed c_{bw} value adopted by standard HS search process. Therefore, improvement parameter is to set variable step range c_{bw} parameter; besides, creation and improvement to elements are implemented by Gaussian traversal and self-adaption adjustment process of vector element individual is obtained based on PAR and parameter c_{bw}. Influence of parameter c_{bw} to HS search process is very large and too large value is unfavorable to HS depth search, but too small value c_{bw} is unfavorable to HS breadth-first search. Scientific change strategy is to select large and small parameter values in adjacent periods of HS search and to realize influenceive control of algorithm performance. Change strategy of control parameter α is:

$$\alpha = 1 - \lambda \times t_{current}/t_{max}\,. \tag{31}$$

Creation and improvement to HS element are implemented based on Gaussian traversal and depth search to existing position is implemented by small step and breadth-first search to unknown position is implemented by utilizing large step and creation and improvement process by adopting Gaussian traversal g and control parameter α are as follows:

$$\begin{cases} x_{new,i} = x_{r,i} \pm g \times a \times c_{bw}, & if\ c_{rand} < c_{PAR} \\ x_{new,i} = x_{r,i}, & if\ c_{rand} \geq c_{PAR} \end{cases} \tag{32}$$

In formula (32), $g \sim \mathcal{N}\left(\mu, \sigma^2\right)$, influence of traversal variance distribution of Gaussian function g on HS is very large. See Fig. 5 for traversal distribution form.

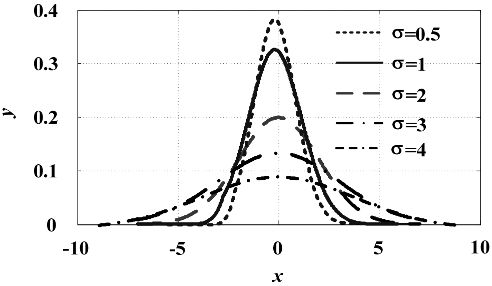


Fig. 4. Gaussian traversal

3.2. *Theory analysis*

It is assumed that individual x_i in HM algorithm storage parameter is distributed in one-dimension form:

$$c_{HM} = x = \{x_1, \cdots, x_{HMS}\}^T \ . \tag{33}$$

Then, adaptive value of individual x_i is:

$$y = \{y_1, \cdots, y_{HMS}\}^T \ . \tag{34}$$

Group variance distribution of the adaptive value is:

$$E\left(y\left(c_{var}\right)\right) = E\left(\frac{\sum\limits_{l=1}^{c_{HMS}} \left(y_l - \bar{y}\right)}{c_{HMS}}\right) = E\left(\overline{y^2}\right) - E\left(\bar{y}^2\right) \ . \tag{35}$$

Where,

$$\begin{aligned} E\left(\overline{y^2}\right) =& c_{HMCR} \cdot \overline{x^2} + c_{HMCR} \cdot c_{PAR}/3 \\ &+ \left(1 - c_{HMCR}\right)\left(a^2 + ab + b^2\right)/3 \end{aligned} \tag{36}$$

$$E\left(\bar{y}^2\right) = E\left(\left(y_i\right)^2 + \frac{\left(c_{HMS} - 1\right) \cdot \left(E\left(y_i\right)\right)}{c_{HMS}}\right)^2 . \tag{37}$$

Then, one-dimension distribution of foresaid adaptive value is as follows:

$$\begin{aligned} E\left(y\left(c_{var}\right)\right) = &\left(1 - \frac{1}{c_{HMS}} \cdot c_{HMCR} \cdot E\left(x\left(c_{var}\right)\right)\right) \\ &+ c_{HMCR} \cdot \left(1 - c_{HMCR}\right) \cdot \bar{x}^2 + \frac{c_{bw}^2}{3} \cdot \\ &c_{HMCR} \cdot c_{PAR} + \frac{\left(1 - c_{HMCR}\right)}{12}\left(a - b\right)^2 . \end{aligned} \tag{38}$$

In formula (38), [a, b] is value interval of x and $x\left(c_{var}\right)$ is distribution variance of individual x and $y\left(c_{var}\right)$ is adaptive value distribution variance of individual x. If value $E\left(y\left(c_{var}\right)\right)$ is too large, then it shows that HS algorithm pays more attention to search process, but it will cause search process divergency. If value $1/c_{HMS}$ is too small and meets $c_{HMCR} \rightarrow 1$, then formula (39) is equivalent to:

$$E\left(y\left(c_{var}\right)\right) = c_{HMCR}\left(E\left(x\left(c_{var}\right)\right) + \frac{c_{bw}^2 \cdot c_{PAR}}{3}\right) . \tag{39}$$

Referring to HS element creation process, formula (40) is further equal to:

$$E\left(y\left(c_{var}\right)\right) = c_{HMCR} \cdot \left(E\left(x\left(c_{var}\right)\right) + \frac{c_{bw,0}^2 \alpha^2 g^2 \cdot c_{PAR}}{3}\right) . \tag{40}$$

In formula (40), control parameter α takes value by adopting gradual reduction mode, which is beneficial to $E\left(y\left(c_{var}\right)\right)$ process convergence and will avoid HS process divergency. Gaussian function g makes element creation have traversal distribution characteristics and it can be ordered that $\alpha^2 g^2$ reduction mode is more energetic and will realize balance between HS algorithm search and development.

3.3. Model optimization steps

Step 1: (initialization) inventory level of all warehouses is taken as optimal input vector $X = [x_1, x_2, x_3, x_4]$ and input vector data are stored in HM and its value interval is set. Then, harmony group with size HMS is obtained by formula (41), which is stored in HM. Initialization formula is:

$$x_{r,i} = x_{l,i} + c_{rand} \times \left(x_{u,i} - x_{l,i}\right) . \tag{41}$$

In formula (1), $x_{u,i}$ and $x_{l,i}$ are respectively upper and lower limits of the i variable value in vector individual

Step 2: (element creation) vector individual update process is obtained by element creation: vector in c_{HM} is obtained randomly and at the same time, new warehouse inventory level vector individual is obtained by utilizing c_{HMCR}. Then, vector individual adjustment is implemented based on c_{PAR} and c_{bw}, as shown in formula (31):

$$\begin{cases} x_{new,i} = x_{r,i} \pm c_{rand} \times c_{bw}, & if\; c_{rand} < c_{PAR} \\ x_{new,i} = x_{r,i}, & if\; c_{rand} \geq c_{PAR} \end{cases} \tag{42}$$

Step 3: (individual update) adaptive value calculation is implemented to element individual, which is compared with original individual and element individual with advantageous adaptive value is kept to realize individual update to HM algorithm.

Step 4: (algorithm termination) If present optimal adaptive value individual meets termination setting, HS algorithm will be stopped and the optimal warehouse inventory level will be output, otherwise, it will return to step 2.

4. Experimental analysis

4.1. Parameter selection experiment

Algorithm test will be implemented by selecting two groups of standard functions, of which characteristics are multimodal and high-dimensional characteristics and it presents multi-local extremum property and function is shown in formula (42) and relevant parameters of function are shown in Table 1.

$$\begin{aligned} f_1(X) &= \sum_{i=1}^{n} \left[x_i^2 - 10\cos(2\pi x_i) + 10\right], \\ f_2(X) &= \left[\sum_{i=1}^{n} x_i^2 - \prod_{i=1}^{n} \cos\left(x_i/\sqrt{i}\right) + 1\right] \Big/ 4000. \end{aligned} \tag{43}$$

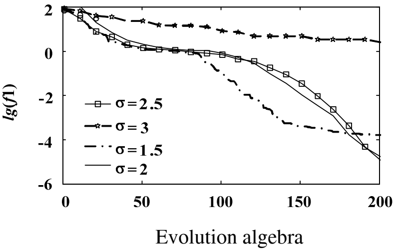
Table 1. Parameter settings

f	Dimension	Value interval	Optimal value
$f1$	20	[-5.12, 5.12]	0
$f2$	20	[-600, 600]	0

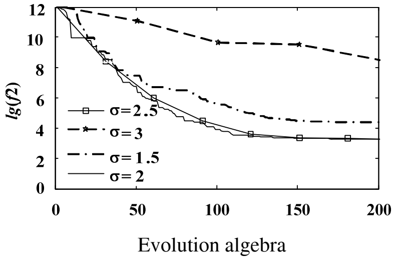
After adding control parameter α and Gaussian function g to HS search process, it can be seen that contribution of parameter λ to control parameter α is relatively large and contribution of variance parameter σ_g to parameter g is relatively large. Relevant parameters are set as follows: $c_{HMS} = 100$, $c_{HMCR} = 0.95$ and $c_{PAR} = 0.7$ and total optimization algebra is set as $t = 200$ and $\lambda = 0.3$. See Fig. 5 for results.

It can be seen by comparing data of Fig. 5a with that of Fig.5b that algorithm convergence performance is the optimal relatively when variance is selected as $\sigma_g = 2$. At the same time, after theory analysis, parameter α is controlled and it can be ordered that c_{bw} will be monotone decreasing to ensure that relatively large value

c_{bw} is selected in initial stage and relatively small value c_{bw} is selected in later stage. However, value with too strong regularity is unfavorable to creation of algorithm convergence process. Solution is to improve random characteristics of parameter c_{bw} by utilizing Gaussian function g, but it is not better when random degree is larger and value $\sigma_g = 2$ is the optimal according to results in Fig. 5.



(a) f1 Function



(b) f2 Function

Fig. 5. Influence of variance σ value on algorithm

4.2. Model experiment

Performance of developed model is verified by algorithm in the section. The algorithm parameters are set as follows:

$D = 1000$, $C_{b1} = 100$, $C_{b2} = 60$, $C_{b3} = 40$, $C_{b4} = 10$, $C_{h1} = 40$, $C_{h2} = 50$, $C_{h3} = 70$, $C_{h4} = 80$, $C_{p2} = 2$, $C_{p3} = 3$, $C_{p4} = 1$, $I_1 = 900$, $I_2 = 1000$, $I_3 = 500$, $I_4 = 800$, $r = 0.1$, $t_m = 5$, $t_r = 3$, $L_2 = 10$, $L_1 = 24$, $L_m = 2L_r = 1$

$D = 1000$, $C_{b1} = 100$, $C_{b2} = 60$, $C_{b3} = 40$, $C_{b4} = 10$, $C_{h1} = 40$, $C_{h2} = 50$, $C_{h3} = 70$, $C_{h4} = 80$, $C_{p2} = 2$, $C_{p3} = 3$, $C_{p4} = 1$, $I_1 = 900$, $I_2 = 1000$, $I_3 = 500$, $I_4 = 800$, $r = 0.1$, $t_m = 5$, $t_r = 3$, $L_2 = 10$, $L_1 = 24$, $L_m = 2$ and $L_r = 1$.

Algorithms in literature [12], literature [13] and literature [14] are selected for comparison algorithms and the follows are selected for comparison indexes: (1) S_{43}, S_{32} and S_{21} of the best condition; (2) value of total cost; (3) order quantity Q_3, Q_2 and Q_1. See table 2 for comparison results. Comparison result of table 2:

Table 2. Comparison results

Index	Literature [12]	Literature [13]	Literature [14]	Algorithm of this Paper
Index (1)	(I_4, Q_2, I_2)	(I_4, Q_2, I_2)	(I_4, Q_2, I_2)	(I_4, Q_2, I_2)
Index (2)	48273	49584	48635	45463
Index (3)	(3957,268,1364)	(3867,293,1493)	(3859,283,1453)	(3796,242,1137)

It can be known from Table 2 that identification results of foresaid comparison algorithms are basically the same in index (1) and index (3), which are not main optimization indexes. There is obvious difference in several algorithms in value of total costs of index (2) and value of total cost in algorithms proposed in this Paper is less than three comparison algorithms in literature [12∼14], which has embodied cost advantages of algorithm proposed.

Next, analysis is implemented to algorithm sensitivity by taking a set of fixed parameters (Q_i, x, y) for example and by providing the optimal values of total cost $C_t\,(Q_i, x, y)$ and by observing change of the optimal value $C_t\,(Q_i, x, y)$ with (Q_i, x, y). Holding cost and shortage cost are selected as two important parameters for sensitivity degree analysis. See Fig. 6∼7 for results.

When shortage cost from warehouse 1-4 increases, total cost will increase correspondingly, that is to say that shortage cost will directly influence total cost. It can be found from influence result of shortage cost on total cost that influence of shortage cost in warehouse 1 is larger than that of other warehouses. It can be known by analysis that there are two largest reasons for influence of warehouse 1 on total cost: (1) demand of warehouse 1 compared with customer, in immediate reaction position. Therefore, shortage cost price of goods distributed from the warehouse is higher than that of other warehouses. (2) In transfer process from warehouse 2 to warehouse (3), the goods shortage phenomenon is gradually decreasing, which can be obtained by analysis on target function (20).

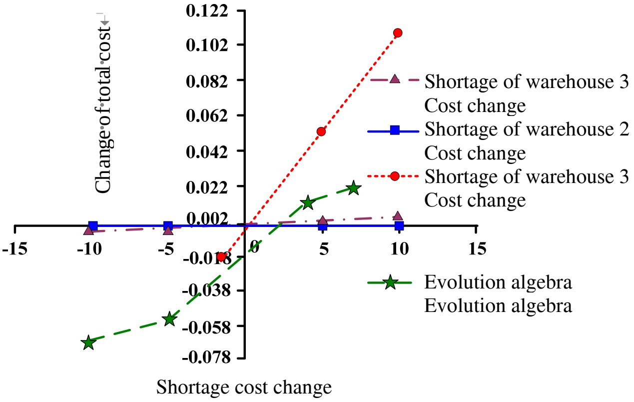


Fig. 6. Influence of shortage cost on total cost

As shown in Fig. 7, with increase of storage cost of warehouses 1∼3, total cost will increase correspondingly, where influence of storage cost in warehouses 1∼2 on

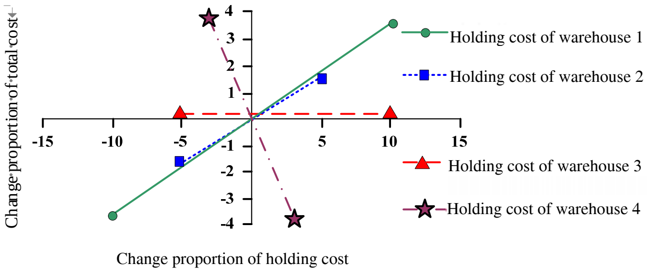


Fig. 7. Influence of holding cost on total cost

total cost is relatively large. Different from warehouses 1∼3, when storage cost of warehouse 4 increases, total cost will decrease. Main reason is that with increase of storage cost in warehouse 4, $Q_i - S_{ij}$ increases correspondingly, but $I_4 - S_{43}$ decreases correspondingly and expression of total cost, $Q_3 - S_{43}$ is in denominator position, but $I_4 - S_{43}$ is in numerator position; therefore, total cost will decrease with increase of storage cost of warehouse 4.

5. Conclusion

A kind of GHS recycle supply chain model establishment and optimization algorithm based on recycle cost income is proposed in this paper. The supply chain process is disintegrated to build model by utilizing five stages and considering product recycle process, to optimize model by introducing Harmony Search Algorithm. The experimental results show that algorithm proposed can obtain lower supply chain transportation cost.

Next, the following aspects shall be researched mainly: (1) object function design to reduce demand response time to the maximum; (2) model development problem considering warehouse space limit; (3) recycle recreation expansion considering different kinds of remanufacturing process models; (4) model expansion problem of multi-type product recycle.

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