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CONSTRAINED STOCHASTIC JOINT REPLENISHMENT PROBLEM WITH OPTION CONTRACTS IN SPARE PARTS REMANUFACTURING SUPPLY CHAIN

Liang, Y.[*,**]; Qiao, P. L.[*]; Luo, Z. Y.[*] & Song, L. L.[***]
[*] School of Computer Science and Technology, Harbin University of Science and Technology, Harbin, China
[**] School of Information Engineering, Eastern Liaoning University, Dandong, China
[***] China United Network Communications CO., LTD. Dandong city Branch, China
E-Mail: qiaopl@hrbust.edu.cn

Abstract
In a real business environment, the stochastic joint replenishment with resource restrictions commonly adopts the wholesale sales mechanism. The mechanism causes conflicts of interest between the supplier and the service provider. In order to effectively compete in an uncertain business environment, the option contract is a viable mechanism for coordination between the supplier and the service provider. This paper proposes a fixed-cycle joint replenishment policy based on the option contracts. Stochastic joint replenishment problem of spare parts considers the forward supply process and the reverse recycling process in the remanufacturing supply chain. The optimization model of stochastic joint replenishment problem is developed with a fixed-cycle joint replenishment policy based on the option contracts. According to characteristics of the optimization model, the adaptive immune genetic algorithm is established for solving the optimization problem. Finally, the validity of the optimization model and algorithm are illustrated by data.
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Key Words: Stochastic Joint Replenishment Problem, Resource Restriction, Option Contracts, Adaptive Immune Genetic Algorithm

1. INTRODUCTION

The costs of inventory management comprise a considerable portion of the total operation costs for supply chain logistics management. Proper inventory management can reduce this portion of costs to an enterprise’s capital and improve flexibility of enterprise’s operation, while at the same time maintaining an appropriate level of customer service. The traditional mode of inventory management is not adapted to the needs and methods of a modern enterprise. Hence, the modern inventory management is proposed for adapting to the modern enterprise management, such as Just-in-Time (JIT). The method with the modern theory of single-variety item inventory management has obtained partial achievements.

In order to adapt to multi-variety demands and orders of small batch items, the enterprises need an effective inventory management to deal with multi-variety items demand. When an enterprise coordinates the replenishment of multi-variety items, cost saving in inventory management can be obtained. The joint replenishment problem (JRP) is the study of coordinating inventory replenishment of a group of items jointly ordered from a single items supplier. Joint replenishment of multi-variety items can decrease the average multi-variety items inventory costs, and grow the each-variety items ordering quantity at the same time.

In order to provide service and repair of all sold items for customers, after-sales service providers need to maintain an inventory of the necessary spare parts. Inventory management of spare parts is the important process in the manufacturing items after-sales service, especially in automobile, computer equipment, medical equipment, and other types of equipment manufacturing and other industries. Service providers provide after-sales service of items for customers involving many varieties of spare parts. Single-variety item inventory management would reduce profit of spare parts inventory management and increase operation costs of spare parts inventory management. Hence, spare parts inventory is managed with the joint replenishment policy in the remanufacturing supply chain.

Compared with traditional spare parts supply chains, research on JRP for the spare parts remanufacturing supply chain considers not only the forward joint replenishment problem of new spare parts, but also reverse joint recovery problem of used spare parts. According to the numerical characteristics of the demands of spare parts, the spare parts JRP is divided into deterministic JRP and stochastic JRP. This paper proposes the joint replenishment policy based on the option contracts for stochastic JRP of spare parts and establishes the relevant model for optimization.

The remaining content of this paper is organized as follows: In Section 2 the related research literature is reviewed for constrained stochastic joint replenishment problem with option contracts in spare parts remanufacturing supply chain. In Section 3 the basic joint replenishment policy is introduced and a joint replenishment policy with an option contract mechanism is proposed for stochastic demand. In Section 4 the stochastic JRP model is established for spare parts remanufacturing supply chain. In Section 5 the adaptive immune genetic algorithm (AIGA) is proposed for solving the stochastic JRP. In Section 6 the validity the optimization model and algorithm are demonstrated by data instances. This paper is summarized in Section 7, including suggestions for future research.

2. REVIEW OF PREVIOUS LITERATURE

The research content of this paper is stochastic JRP based on the option contracts. The representative and particularly relevant literatures are reviewed to highlight our research works in this paper.

Firstly, the literature is reviewed on the JRP with resource restrictions closely related to this paper. Research on the JRP with resource restrictions has mainly focused on a mathematical formula of optimization model and algorithm. In a real supply chain many resource restrictions include expense budgets, storage costs, transportation costs, etc. But until now, most papers have focused on the JRP with resource restrictions. Goyal introduced resource constraint to the JRP, proposing a heuristic algorithm based on the Lagrangian multiplier [1]. Moon and Cha developed two efficient algorithms to solve the JRP with resource restrictions [2]. Moon et al. considered the joint replenishment and transportation problem for a third party warehouse to handle multi-variety items, proposing two policies and developing four efficient algorithms to solve optimization model by the two policies [3]. Zhang and Huang developed a heuristic algorithm based on a modified RAND algorithm to solve the multi-buyer joint replenishment problem with budget constraints [4]. Zhang et al. proposed an optimization JRP model based on complete backordering and correlated demand. They developed a heuristic algorithm to resolve the optimization model for frequencies of minor items replenishment [5]. Lin et al. developed a model of the JRP with transport capacity constraints using optimal scheduling and dispatching, and proposed two algorithms to solve the JRP [6]. Wang et al. considered the interrelation of minor ordering costs of each item. They proposed the differential evolution algorithm (DEA), for the JRP using direct grouping and indirect grouping [7]. Tsao and Teng considered the replenishment of multi-variety items and business credit to extend the traditional inventory model to better reflect a real business environment. The paper developed a heuristic algorithm with cost balancing and a heuristic algorithm with extreme finding to solve the inventory problem [8]. Wang et al. proposed a differential evolution algorithm to solve the JRP [9]. Hong and Kim developed a genetic algorithm with cost evaluation and compared it to the RAND algorithm by experimental results [10]. Wang et al. developed a new mathematical model for the JRP based on fuzzy costs of minor replenishment and inventory holding, proposing a differential evolution algorithm based on traditional fuzzy simulation [11]. Wang et al. proposed an effectively improved fruit fly optimization algorithm (IFOA) to resolve the optimization model for the JRP [12].

Secondly, the literature is reviewed on the JRP with stochastic demands. Viswanathan proposed a new class of policies for this problem called the (*s*, *S*) policy which uses an independent and periodic check on each variety of items [13]. Nielsen and Larsen decomposed the problem based on each variety of items. In the stochastic review period they found (*s*, *S*) policy for a fixed order size *Q*, and the solution of sub-problems could be obtained by a heuristic algorithm [14]. Larsen proposed algorithms to solve the JRP based on optimal *Q*(*s*, *S*) policy when the demands of items followed a compound correlated Poisson process [15]. Mustafa Tanrikulu et al. proposed a new optimal replenishment policy; namely, (*s*, *Q*) policy. The policy of ordering replenishments delivered multi-variety items to reach a maximum number of inventory positions [16]. Johansen and Melchiors proposed a method of Markov decision theory to resolve a near-optimal result for the periodic inventory problem based on (*S*, *c*, *s*) policies [17]. Kayis et al. developed a two-variety-item inventory management model based on semi-Markov decision and proposed a simple enumeration algorithm to solve the problem [18]. Fung et al. extended the single-variety item inventory system to a real multi-variety items inventory system with stochastic constraints following the compound Poisson process, including demand of items, replenishment time and service level. They developed the mathematical optimization model based on (*T*, *S*) policy [19]. Wang and Axsäter developed an optimization policy based on the time cycle of the JRP [20].

As the above papers show, the JRP commonly adopts the wholesale sales mechanism in a real business environment. The wholesale sales mechanism can lead to conflicts of interest between the supplier and retailer. In recent years the relationship between the supplier and retailer in the supply chain has undergone significant changes [21]. Researchers have widely adopted various models of cooperative relations in real a business environment; for example, vendor managed inventory [22-24], subsidies of inventory holding cost [25, 26] and product principal-agent costs [27-29]. The mechanism of option contract is an efficient choice for coordination of the supply chain.

Thirdly, the literature is reviewed related to the coordination of the supply chain based on the option contract mechanism. In order to provide flexible management in response to stochastic demands of products, Barnes-Schuster et al. researched the mechanism of option contract to coordinate the product supply channel. They proposed the model of a two-stage supply chain to illustrate the basic principle of the option contract mechanism [30]. Hazra and Mahadevan considered the capacity of a buyer reserving from multiple suppliers for an uncertain demand of items. The paper developed a capacity reservation model to explore the research contents of the buyer's reserving capacity and the number of suppliers [31]. Zhao et al. considered the coordination between the manufacturer and retailer based on the option contract mechanism. The mechanism could avoid incurring potential inventory costs and respond flexibly to fluctuations in product market demands [32]. Chen and Parlar developed a new optimization model of the newsvendor problem for hedging against shortages in ordering quantities [33]. Yang and Qi proposed a contract mechanism for coordinating the supply chain with a general three-step strategy. In the paper, several types of well-known contract mechanisms were shown and were regarded as their method of application [34]. Hu et al. separately developed the optimization model based on a single directional option mechanism and the optimization model based on a bidirectional option mechanism for retailer purchasing products from the supplier, and then they compared with the two models [35]. Zhao et al. proposed a bidirectional option contract mechanism for coordination between the manufacturer and retailer; namely, the call option and the put option. They developed the retailer's optimal ordering strategy model based on a bidirectional option contract [36]. Wee and Wang studied a newsvendor problem based on the combined mechanisms of partial backorder and option contracts. When the market demands of items exceeded the ordering quantity of items, the retailer may order option quantity of items from the supplier for fulfilling the demand of backorders of products [37].

This paper focuses on a stochastic JRP and a joint replenishment policy is deployed based on option contracts to handle the optimization problem for JRP. In comparison with the existing literature on JRP, the specific purpose of this paper is the following: to integrate the option contract mechanism into the constrained stochastic joint replenishment problem (CSJRP), and to propose an adaptive immune genetic algorithm for solving the CSJRP.

3. JOINT REPLENISHMENT POLICY FOR STOCHASTIC DEMAND

3.1 Basic stochastic joint replenishment policy

For the stochastic JRP, the stochastic characteristic of demands and the order lead time make it difficult to research and resolve. It is usual to consider the time of ordering in advance as deterministic values, and apply some known probability distribution to describe the stochastic demand. Furthermore, Poisson distribution and compound Poisson distribution always apply for market demands. The optimum joint replenishment policy for stochastic demand can, theoretically, be determined by resolving a very large Markov decision model. However, since the size of the state and the decision space grow exponentially with the number of item numbers, it seems intractable to resolve the model for more than five items. At present, the more mature the policies of stochastic JRP mainly include (S, c, s) policy, (Q, S) policy, (T, S) policy.

There are three parameters for item i in the (S, c, s) policy; namely S_i, c_i and s_i, where $S_i > c_i > s_i$. The service provider checks continuously the status of inventory. Under the (S, c, s) policy, when the stock of item i is below the purchasing level s_i-value, it is replenished by normal purchasing, and when the stock of item j is below the joint purchasing level c_j-value, the stocks of both item i and item j are replenished by joint purchasing. After the completion of the replenishment purchasing, the stock of item i meets the inventory level S_i-value. Usually, the cost of normal replenishment purchasing F is higher than the cost of joint replenishment purchasing f. During the period of product demand, the frequency of normal product purchasing meets the Poisson process. During an exceptional period, the frequency of joint product purchasing also meets the Poisson process.

Under the (Q, S) policy, when the storage capacity of all varieties of items reaches the purchasing group level s_0-value, as determined through continuous checking of item inventory, service providers need to purchase items. The stocks of item i meet the inventory level S_i-value after the completion of the replenishment purchasing, where Q is the quantity of purchased items each time.

The (T, S) policy for stochastic joint replenishment problem adopts the replenishment cycle T to check the item inventory. Under the (T, S) policy, in each basic replenishment cycle time T, an inventory with multiple varieties of items is checked and replenished jointly. The stock of item i reaches the largest inventory S_i in replenishment time t_i, where $t_i = T \cdot k_i$. Time constants L is set in advance for the unmet items demands in the process of joint replenishment. L is the time interval between the purchase ordering and the replenished product storage. Although the (T, S) policy for CSJRP has not been an optimal joint replenishment policy, it may still be the better joint replenishment policy. The model based on (T, S) policy is easy to implement in real joint replenishment process and is a good approximation model.

3.2 Joint replenishment policy with option contracts

For deterministic JRP, most researchers adopt the (T, K) policy to establish the optimization model. Under the (T, K) policy, in the indirect grouping strategy (IGS) for JRP, it charges the costs of major ordering during a time period of cycle T, and the time period of ordering single-variety items is the integer multiples of the time period. Necessary conditions of the (T, K) policy for JRP are deterministic demand of items and conditions of no shortage.

The stochastic JRP faces stochastic demand of items and conditions of shortage. However, there are more uncertain factors in a real business environment. To compete effectively in an uncertain business environment, the flexibility to respond to changes in market demand for certain items must be developed. In order to adapt to uncertain market demands, it is particularly important for manufacturers handling special products based on a relatively longer production time and a shorter sales season. Hence, decisions made in supply chain management are no longer the responsibility of product manufacturers alone, but now result from the cooperation between manufacturers and retailers. The option contract mechanism can accommodate fluctuating market demand, and thus implementing an efficient supply chain. We propose (T, K) policy with an option contract mechanism in a constrained stochastic JRP for the spare parts remanufacturing supply chain.

Under (T, K) policy with an option contract mechanism, in each replenishment cycle time T, inventories with multiple varieties of items are checked and jointly replenished. The service provider reserves the option capacity of spare parts to the manufacturer and pays the option costs. The stock of item i meets the real demands for spare parts in replenishment time t_i, where $t_i = T \cdot k_i$. After completing the spare parts joint replenishment, the service provider pays to the supplier in order to meet the quantity to be purchased of the actual product.

4. STOCHASTIC JRP WITH OPTION CONTRACTS

In the paper, we propose the (T, K) policy with an option contract mechanism for the study of the stochastic JRP for the spare parts remanufacturing supply chain. In the model presented in this study, there are N varieties of spare parts for joint replenishment of the remanufacturing supply chain, and the demands of single-variety spare parts are defined with an option contract mechanism. According to IGS for CSJRP, the replenishment would proceed within the regular replenishment time period T. The replenishment time period of single-variety spare parts is the integer multiples of the time periods. The replenishment for single-variety spare parts meets some basic cycles of the demands. S denotes the major common ordering cost in the time cycle T, and s_i denotes the minor ordering cost in the time cycle T. Under the premise of meeting the demands for items, the minimum model of total relevant joint replenishment costs per unit time has been established in existing research. The CSJRP for the spare parts remanufacturing supply chain considered not only forward joint replenishment of new spare parts, but also reverse joint recovery process of used spare parts.

To discuss the CSJRP with an option contract mechanism, the following notation is used:

- F_i – the stochastic demand function of item i, $F_i = \xi[G_i - \alpha(o_i + e_i)], \xi \in [0,2]$
- i – item number, $i \in [1, n]$
- q_i – actual demands for item i, $q_i = \Phi^{-1}(\delta)\sqrt{V(F_i)} + E(F_i)$
- Q_i – demand rate for item i with option contracts, $Q_i = \xi[G_i + \alpha(o_i + e_i)], \xi \in [0,2]$
- D_i – quantity of recycle for used item i, $D_i = \beta \cdot q_i$
- S – major ordering costs of JRP
- s_i – item i's minor ordering costs of JRP
- h_i – item i's costs per unit of holding inventory
- t_i – item i's costs per unit of waste items for recycling

T – decision variable; basic replenishment time period
k_i – decision variable; item i's integer multiples of basic time period
K – set of variable k_i
e_i – item i's exercise price with option contracts
o_i – item i's option price with option contracts
v_i – salvage value of unsold item i for both the manufacturer and the retailer
pr_i – item i's recycled price
EF – limit fund of real multi-variety items joint replenishment

The total relevant costs function of the CSJRP with option contracts for the spare parts remanufacturing supply chain is obtained by:

$$Min\, TC(T,K) = \frac{S + \sum s_i/k_i}{T} + \sum_{i\in N}(q_i k_i T h_i/2) + \sum_{i\in N}(D_i k_i T t_i/2) \tag{1}$$

s. t.

$$\sum_{i\in N}\{Q_i k_i T o_i + [(Q_i - q_i)k_i T e_i] - D_i k_i T \cdot pr_i - [(Q_i - q_i)k_i v_i]\} \le EF \tag{2}$$

$$T \in R^+,\ \ k_i \in Z^+, i = 1,2,\cdots,n \tag{3}$$

Eq. (1) shows the minimization model of the total relevant costs of the CSJRP with option contracts per unit time in the spare parts remanufacturing supply chain. Constraint Eq. (2) shows resource constraint with option contracts. Constraint Eq. (3) defines the range of decision variable T and decision variable k_i.

5. ADAPTIVE IMMUNE GENETIC ALGORITHM FOR STOCHASTIC JRP

It has been proved that polynomial-time algorithms cannot deal with the JRP. Hence, the JRP is proven to be a non-deterministic polynomial hard problem. There are two kinds of algorithms to solve the constrained JRP, namely heuristic algorithm (e.g., RAND algorithm) and intelligent algorithm [38, 39] (e.g., genetic algorithm [40, 41]).

In the paper we solve the CSJRP with AIGA to determine one decision variable T and the set of decision integer variable k_i. T denotes the basic replenishment time period for the CSJRP, and k_i denotes item i's basic replenishment time period T. The AIGA for the CSJRP is as follows.

Step 1: Antigen recognition. The optimization objective is the minimization model of total inventory operating costs for a spare parts remanufacturing supply chain.

Step 2: Population initialization. A set of decision variables k_i are integer, where k_i denotes n-digit integer. Decision variable T is determined by decision variables k_i.

To solve the CSJRP with option contract mechanism, Moon and Cha [2] used:

$$T^* = min(T^0, T^1), T^0 = \sqrt{\frac{C_1}{C_2}}, \mathrm{T}^1 = \frac{B}{C_3} \tag{4}$$

Eq. (1) can be transformed as the following:

$$Min\, TC(T,K) = \frac{S + \sum s_i/k_i}{T} + \sum_{i\in N}(q_i h_i + D_i t_i)\cdot k_i T/2 \tag{5}$$

Eq. (2) can be transformed as the following:

$$\sum_{i\in N}[Q_i o_i + (Q_i - q_i)e_i - D_i \cdot pr_i - (Q_i - q_i)v_i]\cdot k_i T \le EF \tag{6}$$

where $C_1 = S + \sum s_i/k_i$, $C_2 = \frac{\sum(q_i h_i + D_i t_i)}{2}$, $C_3 = \sum[Q_i o_i + (Q_i - q_i)e_i - D_i \cdot pr_i - (Q_i - q_i)v_i]\cdot k_i$ are constants.

The range of the feasible solutions for decision variable k_i is $k_i \in [k_i^{LB}, k_i^{UB}]$. Let k_i^{LB} denote the lower limit of decision variable k_i, where $k_i^{LB} = 1$. Let k_i^{UB} denote the upper limit of decision variable k_i, where $k_i^{UB}(k_i^{UB} - 1) \le \frac{2s_i}{D_i h_i T_{min}^2} \le k_i^{UB}(k_i^{UB} + 1)$.

Let T_{min} denote item i's minimum replenishment time period. The optimal value of T_{min} is obtained by the formula of traditional EOQ model, where $T_{min} = min\sqrt{2s_i/D_i h_i}$.

Hence, the individual length of the population is n. According to the population size for the CSJRP and the number of genes per antibody (chromosome), antibodies (chromosomes) of the population are randomly generated. Let $Gene(i)$ denote No. i gene of the chromosome v_i, where $Gene(i) \in [1, k_i^{UB}]$.

Step 3: Calculating the degree of affinity. The degree of affinity degree is the connection between antigen and antibody. The expression of the degree of affinity is as follows:

$$aff(v_i) = \frac{1}{Z(v_i) + 1} \tag{7}$$

Value of $aff(v)$ is between 0 and 1. $Z(v)$ denotes the correlation variable of antibodies (chromosomes) and antigen (objective function).

Step 4: Immune selection. Immune selection operator T_s determines the antibodies to enter the immune clone operation based on antibody incentive degree $sim(v)$.

Step 5: Clone operator. Clone operator T_c reproduces selected antibodies with immune selection operator.

Step 6: Adaptive immune genetic operators. Adaptive immune genetic operators include the operators of crossover and mutation. The expressions of adaptive immune genetic operator probabilities are as follows:

$$p_c = e^{2(A(v)-1)}, \; p_m = 0.1e^{2(A(v)-1)} \tag{8}$$

$A(v)$ denotes total antibody similarity degree of the whole population, where $A(v) \in [0,1]$. Let p_c denote crossover probability. Let p_m denote mutation probability.

When a parent antibody is selected from the population, the crossover operator is applied with probability p_c. We choose the point location of an antibody with one-point crossover and generate the child antibody. When a child antibody is generated, the mutation operator chooses one gene of a child antibody with p_m and replaces one gene chosen from the antibody at random. The value of p_m is the range of random numbers between 0 and 1.

Step 7: Vaccine extraction and vaccination. The operators keep the optimal antibody individual.

Step 8: Clone inhibition. After the above steps, the clone inhibition operator selects the antibody population again. The operator inhibits a low degree of affinity in the antibody and keeps a high degree of affinity degree in antibodies in the new population.

Step 9: Generating a new generation of population.

Step 10: Confirmation of termination conditions. If termination conditions meet the maximum, the algorithm is finished and outputs the optimal solution of CSJRP for a spare parts remanufacturing supply chain. If termination conditions do not meet the maximum, the algorithm continues to implement Steps 3~9.

6. EXAMPLES OF DATA INSTANCES

The numerical examples referred by Moon and Cha [2] were used to verify program operation process and performance of AIGA. Samples of data are given in Table I. Four groups of stochastic real market demands for spare parts are given in Table II. We have assumed EF = \$ 25,000 and S = \$ 200.

We solved the CSJRP by AIGA. The maximum generation of the antibody population is 100. The size of the antibody population is 30. Crossover probability p_c and mutation probability p_m are generated by adaptive characteristics of the immune antibody population.

Table I: Data for CSJRP model of spare parts with option contracts.

Item	s_i	h_i	t_i	e_i	o_i	v_i	pr_i	G_i	Q_i
1	$ 45	$ 1	$ 0.5	$ 4.25	$ 2	$ 0.8	$ 2	10000	11000
2	$ 46	$ 1	$ 0.5	$ 4.25	$ 2	$ 0.8	$ 2	5000	5600
3	$ 47	$ 1	$ 0.5	$ 4.25	$ 2	$ 0.8	$ 2	3000	3400
4	$ 44	$ 1	$ 0.5	$ 4.25	$ 2	$ 0.8	$ 2	1000	1300
5	$ 45	$ 1	$ 0.5	$ 4.25	$ 2	$ 0.8	$ 2	600	800
6	$ 47	$ 1	$ 0.5	$ 4.25	$ 2	$ 0.8	$ 2	200	350

Table II: Four groups of stochastic actual market demand for spare parts.

Item	***g1***	***g2***	***g3***	***g4***
1	9000	9350	10000	9750
2	4700	4870	5000	4600
3	2700	2890	3000	2650
4	970	950	1000	910
5	560	540	600	500
6	180	190	200	140

For the constrained stochastic joint replenishment problem (CSJRP), calculation results for four groups of stochastic joint replenishment by four recycling rates are given in Table III.

Table III: Calculation results for four groups of stochastic joint replenishment by four recycling rates with AIGA.

Rate of recycling	**Item groups**	***K***	***T****	***TC***
$\beta = 0.90$	*g1*	1,1,1,3,1,4	0.1743	$ 5816.3
	g2	1,1,1,2,3,2	0.1726	$ 5863.2
	g3	1,1,1,3,2,3	0.1738	$ 5937.7
	g4	1,1,1,2,3,3	0.1732	$ 5834.5
$\beta = 0.85$	*g1*	1,1,1,2,2,4	0.1748	$ 5590.6
	g2	1,1,1,2,3,3	0.1746	$ 5579.6
	g3	1,1,1,2,3,3	0.1751	$ 5601.3
	g4	1,1,1,1,4,3	0.1742	$ 5583.5
$\beta = 0.80$	*g1*	1,1,2,1,2,2	0.1758	$ 5428.4
	g2	1,1,1,2,3,2	0.1754	$ 5421.7
	g3	1,1,2,2,1,2	0.1767	$ 5431.3
	g4	1,1,1,3,2,3	0.1762	$ 5429.5
$\beta = 0.75$	*g1*	1,1,2,1,3,4	0.1771	$ 5403.8
	g2	1,1,1,2,3,3	0.1769	$ 5410.5
	g3	1,2,1,2,3,2	0.1783	$ 5417.1
	g4	1,2,1,1,2,4	0.1769	$ 5412.6

Fig. 1 shows the calculation results for group *g1* of stochastic joint replenishment by four recycling rates.

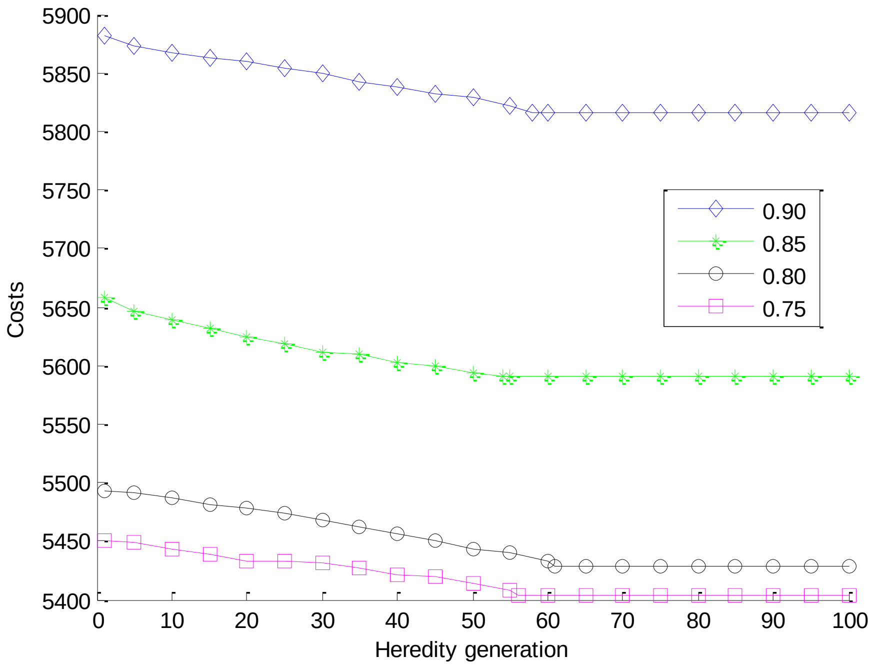

Figure 1: Convergence curve of calculation results for group *g1* of stochastic joint replenishment by four recycling rates.

Fig. 2 shows the calculation results for four groups of stochastic joint replenishment by $\beta = 0.85$.

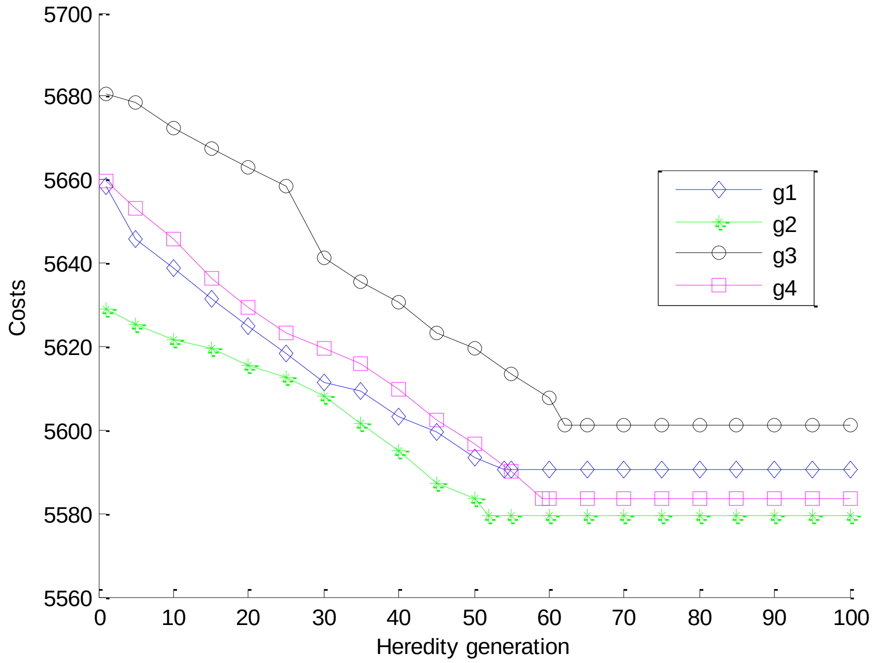

Figure 2: Convergence curve of calculation results for four groups of stochastic joint replenishment ($\beta = 0.85$).

In order to highlight the advantages of AIGA, we solved the CSJRP using the simple genetic algorithm (SGA). The maximum generation of antibody population is 100. The size of the antibody population is 30. The probability of crossover operator is 40 %. The probability of mutation operator is 5 %.

For the constrained stochastic joint replenishment problem, calculation results for group *g1* of stochastic joint replenishment by four recycling rates are given in Table IV.

Table IV: Calculation results for group *g1* at different recycling rates by SGA.

Rate of recycling	***K***	***T****	***TC***
β = 0.90	1,1,1,2,2,3	0.1745	$ 5889.5
β = 0.85	1,1,2,2,2,3	0.1767	$ 5623.3
β = 0.80	1,1,1,2,2,4	0.1735	$ 5435.7
β = 0.75	1,1,1,2,2,3	0.1791	$ 5414.7

Fig. 3 shows the calculation results for group *g1* of stochastic joint replenishment by SGA.

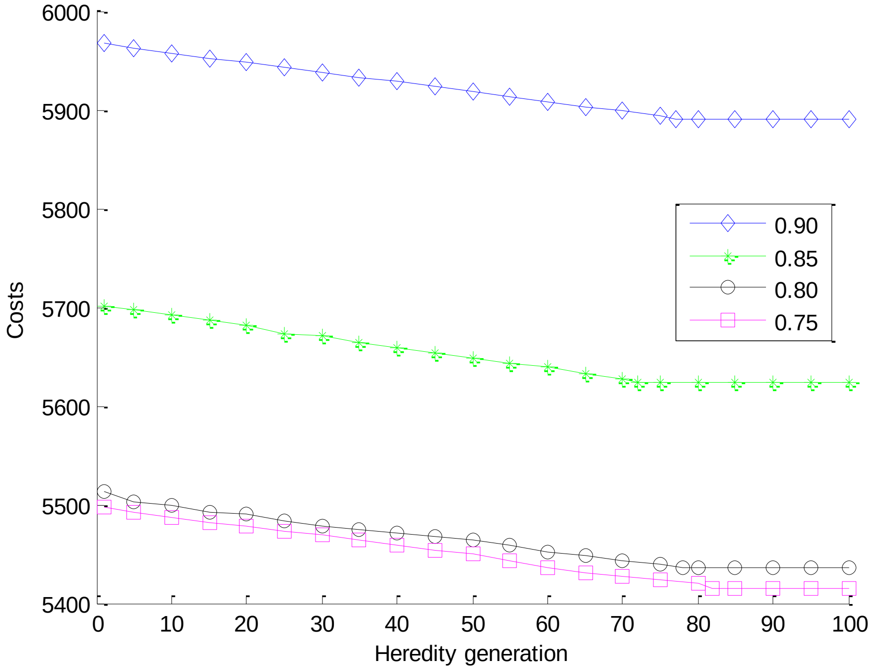

Figure 3: Convergence curve of calculation results for group *g1* of stochastic joint replenishment by SGA.

When solving CSJRP with SGA, the simple genetic algorithm has certain defects when applied to the CSJRP as follows. The algorithm has poor local search capacity and premature convergence, and designates crossover probability, mutation probability and vaccine statically, which makes the search perform slowly and even may come to a standstill. According to the defects of the simple genetic algorithm, we take advantage of the theory in a biological immune system to adjust the crossover and mutation probabilities adaptively and generate vaccines dynamically. The paper proposes AIGA to avoid the defects and improve the solution efficiency. Fig. 4 shows the comparison between the adaptive immune genetic algorithm and the simple genetic algorithm.

7. CONCLUSIONS

The costs of inventory management comprise a considerable proportion of the total operation costs for supply chain logistics management. Proper inventory management can reduce this portion of costs to an enterprise's capital and improve flexibility of the enterprise's operation. We propose the fixed-cycle inventory replenishment policy with option contracts and develop the optimization policy model for the stochastic joint replenishment problem in a spare parts remanufacturing supply chain. To resolve the developed model, AIGA is proposed to resolve the optimization model.

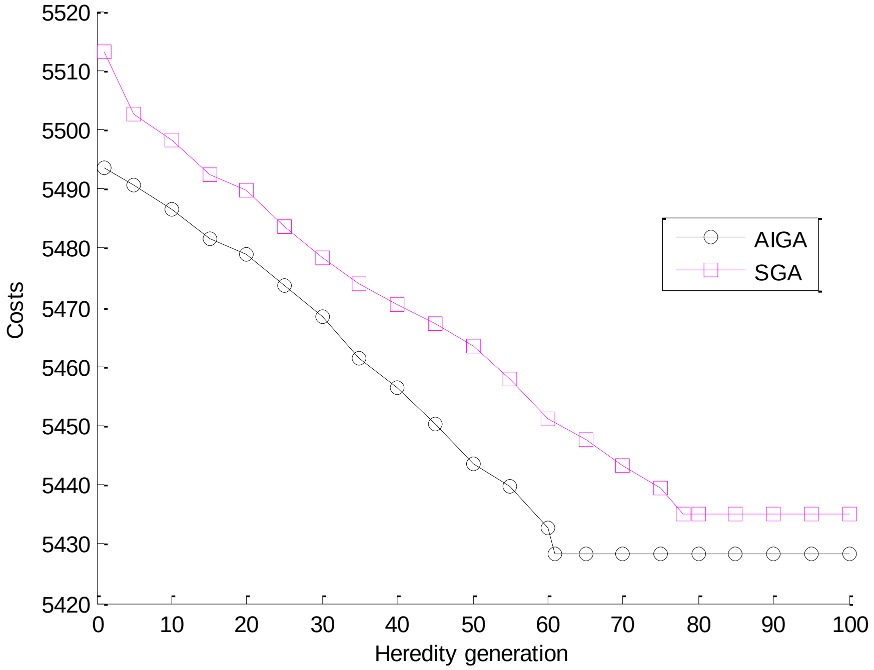

Figure 4: Comparison convergence curve of AIGA and SGA for stochastic joint replenishment problem.

The proposed AIGA outperforms SGA in solving problems in models under the same conditions. Future research on CSJRP may be focused on the dynamic demands of multi-variety items for joint replenishment. In addition, we propose a new fixed-cycle joint replenishment policy based on a bidirectional option contract mechanism for the CSJRP.

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