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Research on Dual Source Inventory Control Based on the Recycling of Rural Electronic Products

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ABSTRACT
The recycling and reuse of waste electronic products in rural areas is an effective means to increase resource utilization and improve the rural living environment. Taking a manufacturing company in rural areas as the main research body, this paper analyzes the source of the company's electronic product parts inventory, which includes new parts purchased from upstream suppliers and waste parts through recycling. Under the condition that stockout is allowed, it is necessary to comprehensively consider the impact of the recycling price on the recycling volume. Aiming at the lowest system unit inventory cost in a single recycling cycle, this paper constructs a dual source inventory model, and uses genetic algorithms to find the optimal purchase batch, optimal recycling batch and corresponding recycling prices, so as to provide ideas for manufacturing companies to implement dual source inventory control strategies.

Keywords: *Rural areas, Dual source inventory, Recovery price, Stockout allowed.*

1. INTRODUCTION

In December 2008, in order to cope with the rapid decline in the export demand of consumer electronic products caused by the global financial crisis, China promulgated the important measure of actively expanding domestic demand of home appliances to the countryside, which set off an upsurge of home appliances to the countryside. And ordinary home appliances, mobile phones, computers and other electronic products enter ordinary people's homes one after another. However, after several or decade years of use, many electronic products in rural areas have been at the peak of upgrading or elimination. Moreover, people's awareness of environmental protection in rural areas is still relatively weak, and these endangered electronic product parts have not been recycled in time, which is contrary to the concept of "beautiful countryside" advocated today. On the contrary, recycling these waste electronic products can not only improve the utilization rate of limited resources and bring considerable economic benefits to enterprises, but also greatly improve the living environment in rural areas.

The logistics technology generated to realize the recycling of waste products, namely reverse logistics, is a logistics activity including product return, material substitution, material reuse, waste treatment, reprocessing, maintenance and remanufacturing. This concept was first put forward by Stock [1]. Coupled with the emphasis of various countries on environmental protection and green ecology, reverse logistics has gradually attracted extensive attention of scholars in China and foreign countries. However, in rural areas, the high cost has become the biggest obstacle to the smooth implementation of reverse logistics, and inventory is a key factor affecting logistics cost. Therefore, more and more domestic and foreign scholars turn their attention to the research on reverse logistics inventory control. Schrady [2] is the first scholar to set foot in this field. Based on the traditional EOQ model, it is assumed that the demand rate and recovery rate of products are certain, and the inventory of new products and recycled products should be considered at the same time. He established a deterministic inventory model similar to EOQ model to determine the optimal batch for ordering and recycling. According to Heyman [3], it is assumed that the demand and recovery process obeys Poisson distribution. By quantifying the uncertainty of time and quantity and adding constraints, the optimal parameters of the inventory model can be obtained. On the premise of considering the randomness of recycled products, Simpson [4] proposed to distinguish repairable product inventory from qualified product inventory, and considered that it is necessary to balance the cost savings brought by product recycling with the additional transportation costs and inventory costs. Based on Schrady's model, Richte K [5] assumed that the demand rate and product recovery rate were continuous and determined, and discussed the relationship between the optimal control parameters and the recovery rate of waste products under different control strategies. Huang Zuqing [6] studied the optimal inventory control model based on periodic and quantitative processing methods for returned products. Di Weimin [7] established a two-level production inventory optimization model for the recovery center and treatment plant, and obtained the average cost related to the production inventory per unit time of the recovery logistics system, which is helpful to reduce the recovery logistics cost. Liang Ling et al. [8] assumed that the lead time of production, recycling and remanufacturing obeyed a certain probability distribution, and considered the product inventory and recycled parts inventory, constructed a "dual source" ordering decision model to optimize the manufacturer's expected lead time, production batch and remanufacturing batch. Liu Zhifeng [9] established a reverse logistics inventory model based on PULL strategy and found out the key parameters affecting the average total inventory cost.

The researches on recycling logistics inventory above mainly adopt the regular or quantitative recycling model of one-time procurement and multiple recycling. This model is suitable for the situation of large amount of waste products and high recycling frequency, but the renewal rate of electronic products in rural areas is relatively slow and the interval between two adjacent recycling is long. If the previous recycling model is still used to study rural waste electronic products, it will deviate from reality and lack practical significance. Therefore, this paper constructs a recycling model of one-time recycling and multiple purchases for a manufacturing enterprise in rural areas, considers the two recycling methods of quantitative recycling and regular recycling, studies the change of inventory level of the enterprise in a recycling cycle, and determines the best procurement batch and the best recycling batch in a single cycle on the basis of considering the change of recycling price, so as to minimize the unit inventory cost.

2. REVERSE LOGISTICS DUAL SOURCE INVENTORY CONTROL MODEL

2.1 Problem Description

In order to help enterprises better understand the recycling information, this paper constructs a three-level recycling network composed of several pick-up points, a recycling center and a remanufacturing factory. Each pick-up point is responsible for collecting waste electronic products in rural areas. And then, enterprise M uniformly arranges vehicles to transport the waste electronic products at each pick-up point to the recycling center. The recycling center will test and sort these waste electronic products, transport the completely scrapped products to the abandoned equipment center for recycling and landfill, transport some scrapped products to the remanufacturing factory for disassembly and maintenance, and transport the reusable finished products and parts to the manufacturing enterprise M. At the same time, by building O2O recycling platform, consumers, pick-up points, recycling centers, remanufacturing plants and manufacturing enterprise M are connected to make the whole recycling process transparent. The whole recycling network is shown in "Figure 1".

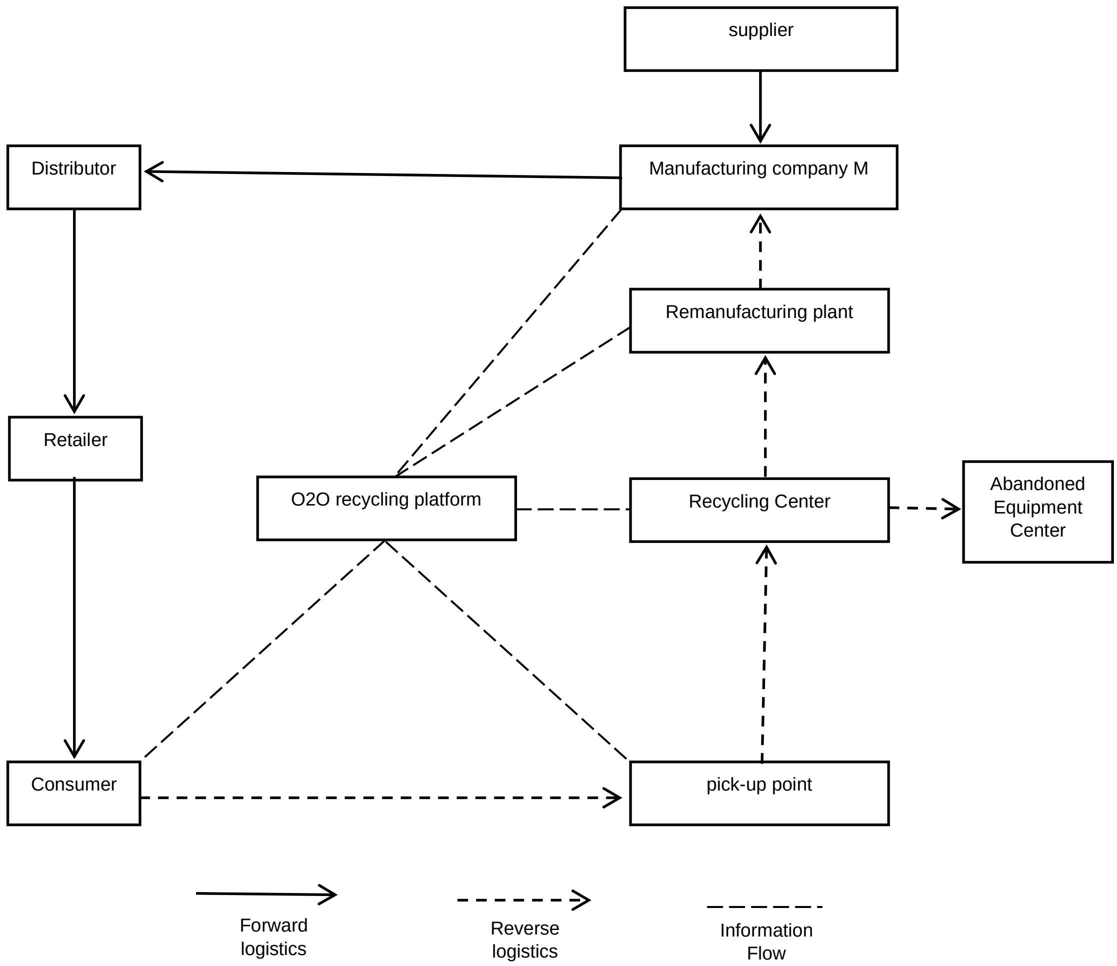

Figure 1 Structure diagram of recycling network based on O2O model.

It is assumed that the waste parts can be homogeneous with the new parts after recycling and treatment, but in general, the number of electronic products manufactured through recycling will not exceed the market demand, so it is unrealistic to supplement the saleable inventory only by recycling. Therefore, the parts inventory sources of manufacturing enterprises that implement recycling usually include new parts that rely on ordering and replenishment from upstream suppliers and waste parts that are recycled, that is, a dual source inventory structure is formed.

2.2 Symbol Description

d: market demand rate; μ: recyclability of recycled waste electronic products;

A: the fixed cost of each purchase; B: fixed cost recovered by the enterprise each time;

L: recovery lead time; n: ordering times;

T_r: one recovery cycle; T_p: one procurement cycle;

Q_r : Recycling batch of waste electronic products within a recycling cycle; Q_p: purchase batch each time;

P_1: unit price of new parts; P_2: recovery price of waste parts per unit;

Q_s: out of stock quantity;

C_1 : unit parts inventory cost of enterprise warehouse;

C_2: unit parts inventory cost of the recovery center;

C_3 : unit processing cost of waste parts in remanufacturing factory;

C_4: stockout cost corresponding to unit stockout quantity;

TC: the total inventory cost of an enterprise in a recovery cycle;

2.3 Model Assumptions

In order to simplify the model, this section puts forward the following assumptions on the model:

(1) This paper only considers a single kind of parts, and these parts and recycled electronic products are assembled at the ratio of 1:1.

(2) After processing, the recycled waste parts have no quality difference from the new parts, which can be directly added to the parts inventory of manufacturing enterprises.

(3) The arrival process of waste electronic products is Poisson process, and the recovery quantity obeys the Poisson distribution with the parameter of λ, and λ is related to the recovery price and meets $\lambda = a + b * P_2$. a is the voluntary recovery amount of consumers when the recovery price is 0, and b is the sensitivity coefficient of the recovery amount to the recovery price [10].

(4) The market demand for such electronic products is stable at d.

(5) This paper allows the stockout and considers the loss cost caused by out of stock, but out of stock does not need to be supplemented in the next cycle.

(6) The research period is the time interval between two adjacent receipt of recycled parts.

(7) The recovery process includes six types of costs: the purchase cost of new parts, the inventory cost of enterprise parts, the inventory cost of parts in the recovery center, the recovery cost of waste parts, the processing cost of recovered parts and the stockout cost of the enterprise.

(8) The products recovered in $(T_r - L, T_r)$ treatment period shall be treated in the next cycle.

(9) The purchase process is instantaneous replenishment, and the recovery process has a processing period.

2.4 Model Derivation

It is necessary to set the time when the enterprise completes the last purchase and recycling as the starting time, and the enterprise's inventory includes newly purchased parts and recycled parts, and its inventory level $Q_p + \mu Q_r$. A safety inventory level s is preset. When the inventory level drops to s, the second purchase and replenishment is carried out. Subsequently, the safety inventory is not considered. When the enterprise inventory level drops to 0 at T_0, the recovery instruction is issued at $T_r - L$, the order instruction is issued at Tr, and the recovery replenishment and order replenishment at Tr are just right to complete a recovery cycle. "Figure 2" and "Figure 3" show the changes in enterprise inventory level and inventory level of recovery center respectively.

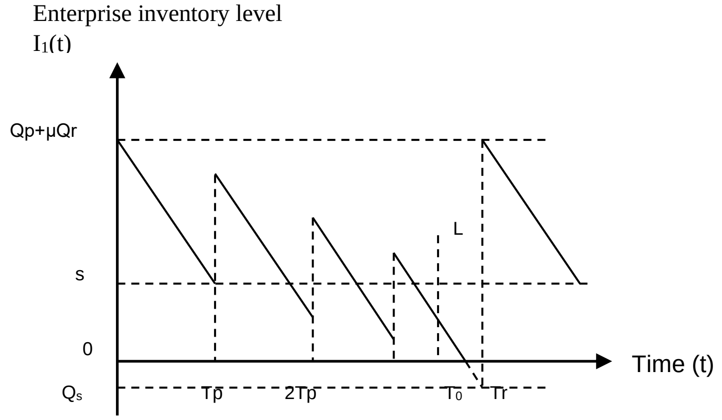

Figure 2 The change of enterprise inventory level.

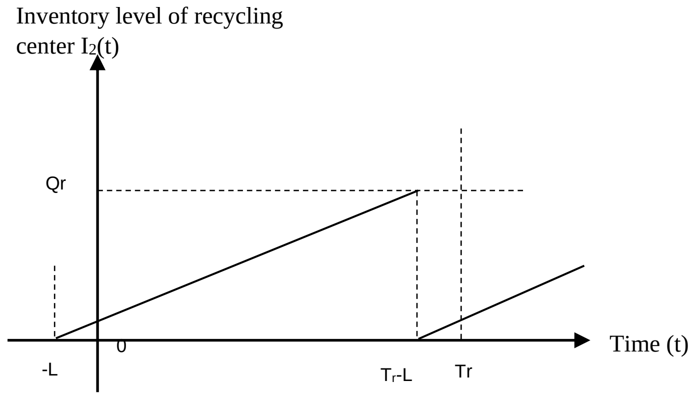

Figure 3 The change of inventory level of recycling center.

In the whole recovery cycle Tr, the enterprise inventory level is:

$$I_1(t) = j * Q_p + \mu Q_r - d * t, (j-1) * T_p < t \leq j * T_p, j = 1,2,3 \dots n \tag{1}$$

The expected inventory level of enterprise parts in a recovery cycle is:

$$E(I_1(t)) = \frac{\sum_{j=1}^{n} \int_{(j-1)*T_p}^{j*T_p} (j * Q_p + \mu Q_r - d * t) dt}{n * T_p} = \frac{Q_p - (n-2) * \mu Q_r + ns}{2} \tag{2}$$

Therefore, the expected inventory cost of enterprise parts is:

$$\frac{Q_p - (n-2) * \mu Q_r + ns}{2} * C_1 \tag{3}$$

When $(n-1)T_p < T_0 \leq nT_p, I_1(T_0) = 0, T_0 = \frac{nQ_p + \mu Q_r}{d}$ (4)

$$Q_s = d * (T_r - T_0) = (n-1) * \mu Q_r - ns \tag{5}$$

the cost of stockout is

$$C_4 * [(n-1) * \mu Q_r - ns] \tag{6}$$

and $I_1((n-1)\ T_p) - Q_p > 0$, $I_1((n-1)\ T_p) - d * T_p \leq 0$.

If $d * T_p \leq Q_p$, there will be no stockout, but the inventory level will continue to accumulate over time, which is unrealistic for the sustainable development of enterprises. This paper does not consider this kind of situation.

When $d * T_p > Q_p$, $\frac{\mu Q_r}{\mu Q_r - s} \leq n < 1 + \frac{\mu Q_r}{\mu Q_r - s}$ (7)

the order cost in a recycling cycle is

$$n * (A + P_1 * Q_p) \tag{8}$$

If the time between arrivals of waste electronic products subject to Poisson distribution obeys to negative exponential distribution with λ as the parameter, $1/\lambda$ represents the average time between arrivals of the recycled waste electronic products, and the arrival time of the m-th waste electronic products is $T_m = m/\lambda$. In a recovery cycle T_r, the total time span from the time when the recovery instruction $T_r - L$ is issued in the previous cycle to the time when the recovery instruction $T_r - L$ is issued in this cycle is T_r, and the number of waste parts recovered in the T_r is $Q_r = \lambda * T_r$, the recovery cost is $P_2 * Q_r$ (9)

The expected inventory of the recycling center is:

$$E[(T_r - T_1) + (T_r - T_2) + \cdots + (T_r - T_{Q_r})] = \frac{Q_r - 1}{\lambda} + \frac{Q_r - 2}{\lambda} + \cdots + \frac{Q_r - Q_r}{\lambda} = \frac{(Q_r - 1)Q_r}{2\lambda} \quad (10)$$

Therefore, in the recycling cycle T_r, the expected inventory cost of recycled waste electronic product parts is:

$$\frac{(Q_r - 1)Q_r}{2\lambda} * C_2 \quad (11)$$

the processing cost of recovered parts is:

$$Q_r * C_3 + B \quad (12)$$

To sum up, the total inventory cost of the manufacturing enterprise in the whole recovery cycle T_r is:

$$TC = n * (A + P_1 * Q_p) + \frac{Q_p - (n-2) * \mu Q_r + ns}{2} * C_1 + \frac{(Q_r - 1)Q_r}{2\lambda} * C_2 + Q_r * C_3 + B + P_2 * Q_r + C_4 * [(n-1) * \mu Q_r - ns] \quad (13)$$

The inventory cost per unit time is:

$$\frac{TC}{T_r} = \frac{\left[n * (A + P_1 * Q_p) + \frac{Q_p - (n-2) * \mu Q_r + ns}{2} * C_1 + \frac{(Q_r - 1)Q_r}{2\lambda} * C_2 + Q_r * C_3 + B + P_2 * Q_r + C_4 * [(n-1) * \mu Q_r - ns]\right]}{Q_r / \lambda}$$

$$= \frac{(a + bP_2) * \left[n * (A + P_1 * Q_p) + \frac{Q_p - (n-2) * \mu Q_r + ns}{2} * C_1 + \frac{(Q_r - 1)Q_r}{2(a + bP_2)} * C_2 + Q_r * C_3 + B + P_2 * Q_r + C_4 * [(n-1) * \mu Q_r - ns]\right]}{Q_r} \quad (14)$$

Through the establishment of the above models, the research on dual source inventory control of manufacturing enterprise M is transformed into the optimization of the following function F. On the basis of meeting the corresponding constraints, the optimal value is solved to obtain the optimal inventory control strategy.

$$Min\ F = \frac{TC}{T_r}$$

$$\text{s.t.} \begin{cases} (a + bP_2)\, n(Q_p + \mu Q_r - s) - dQ_r = 0 \\ \mu Q_r / (\mu Q_r - s) \le n < 1 + \mu Q_r / (\mu Q_r - s) \\ \mu Q_r - s > 0 \\ T_p > L \\ Q_p, n, Q_r \in N^+; P_2 \ge 0 \end{cases}$$

3. MODEL SOLUTION

The model in this paper is about the multivariate nonlinear function of Q_p, Q_r, n, P_2. In order to better find the optimal solution of the function, this paper chooses genetic algorithm to solve it.

$$Min\ Fun = F(Q_p, Q_r, n, P_2)$$

$$\text{s.t.} \begin{cases} c < 0 \\ ceq = 0 \\ Q_p, n, Q_r \in N^+; P_2 \geq 0 \end{cases}$$

Q_p, Q_r, n, P_2 are positive integers, and genetic algorithm can not effectively solve the integer programming with nonlinear equality constraints. In order to facilitate the solution, the equality constraints in this paper are relaxed and transformed into unequal constraints. The specific steps are as follows:

(1) According to $ceq = 0$, $Q_r = f(Q_p, n, P_2)$ can be obtained. A relatively small positive number m is selected, and $|\ Q_r - f(Q_p, n, P_2)\ | \leq m$ is a new constraint

(2) The enumeration method (n = 2,3,4...) is used in ordering times, so as to determine the range of other variables under the corresponding n, and then matlab R2015b genetic algorithm optimization toolbox is used to find the approximate optimal value of the objective function under the corresponding constraints;

(3) It is required to compare the approximate optimal value of the objective function corresponding to each n, and determine the optimal ordering times n^*, so as to make the objective function value as small as possible;

(4) It is required to substitute n^* into the original objective function, run it many times with the toolbox to obtain multiple groups of data, and then filter out the minimum value of the objective function, and its corresponding solution is the approximate optimal solution of the model.

4. EXAMPLE SIMULATION

A manufacturing enterprise M is located in a county with relatively backward economy. The enterprise produces small electronic product d, and the assembly production is carried out according to the ratio of 1:1. In order to improve the utilization rate of product parts and reduce the pollution of waste electronic products to rural areas, the manufacturing enterprise carries out the recycling of waste electronic products in the countryside. It is assumed that the recycling rate μ of small electronic products is 50%, the purchase price of new parts is 40 yuan per piece, the unit inventory cost of enterprise parts is 2.5 yuan, the unit inventory cost of waste parts in the recycling center is 1.5 yuan, and the unit processing cost of used parts is 10 yuan [11]. The market demand for this electronic product is fixed at 333 pieces per day, the fixed cost of each start-up order is 300 yuan, and the fixed cost of each start-up recovery is 700 yuan [12]. In addition, it is assumed that the set safety stock is 600 pieces, the recovery lead time is 3 days, and the unit stockot cost is 30 yuan / piece. Moreover, according to the literature [10], when the recovery price is 0, the recovery amount is 100, and the sensitivity coefficient of the recovery amount to the recovery price is 5.

Table 1. Minimum value of unit inventory cost under different ordering times

n	*Q_p*	*Q_r*	*P_2*	*Min F*
2	*3400*	*2403*	*0*	*14415.940*
2	*3330*	*2555*	*1.233*	*14563.380*
2	*3340*	*2477*	*0.735*	*14493.907*
3	*1940*	*2305*	*0.532*	*14067.716*
3	*1950*	*2299*	*0.417*	*14057.593*
3	*1960*	*2311*	*0.393*	*14060.243*
4	*1180*	*1792*	*0.213*	*13743.829*
4	*1120*	*1714*	*0.723*	*13790.290*
4	*1150*	*1770*	*0.539*	*13767.874*
5	*820*	*1589*	*0.864*	*13704.051*
5	*831*	*1564*	*0.565*	*13704.534*
5	*847*	*1586*	*0.313*	*13673.139*

Accordingly, μ=50%, d=333, λ=100+5P_2, A=300, B=700, P_1=40, L=3, s=600, C_1=2.5, C_2=1.5, C_3=10, C_4=30, C_4=30. Also, it is suggested to set m=0.5, substitute the above corresponding data into formula (14) and n=2, 3, 4... respectively. According to the constraint conditions, it is easy to known that when $n \geq 6$ is used, Q_p, Q_r, n, P_2 satisfying the constraint cannot be found to make

$|Q_r - f(Q_p, n, P_2)| \leq m$ true. Therefore, the desirable value of n is 2, 3, 4 and 5.Then, genetic algorithm toolbox is used to solve the problem, and the corresponding approximate minimum value can be obtained. (as shown in "Table 1")

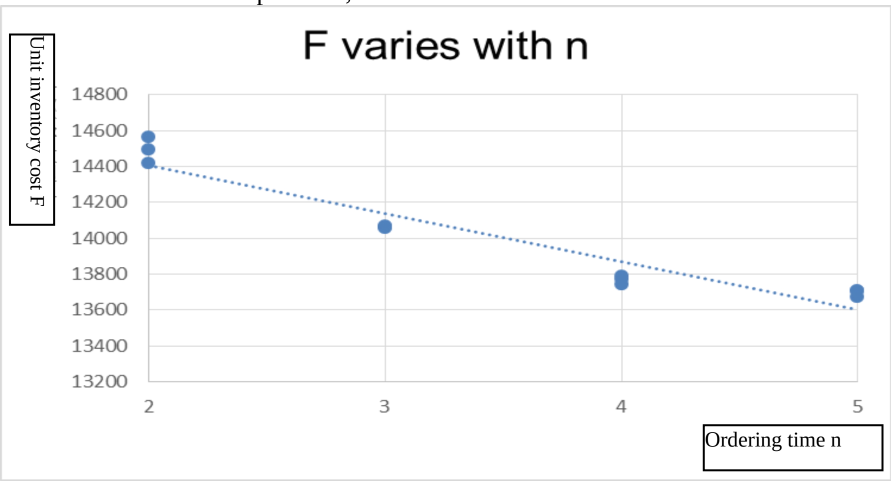

Figure 4 The change of unit inventory cost with ordering times.

According to "Figure 4", when other variables are uncertain, the unit inventory cost roughly decreases with the increase of ordering times. Therefore, the optimal ordering times are $n^* = 5$, it is required to run and solve the objective function under the condition of $n^* = 5$ for many times, and take ten times to obtain the data in "Table 2".

Table 2. Inventory strategy of manufacturing enterprise M

	Q_p	n	Q_r	P_2	Min F	T_p	T_r
1	820	5	1589	0.864	13704.501	3.047	15.235
2	851	5	1587	0.237	13667.341	3.137	15.685
3	831	5	1564	0.565	13704.534	3.042	15.210
4	853	5	1590	0.209	13664.599	3.147	15.735
5	840	5	1580	0.443	13691.836	3.093	15.465
6	847	5	1586	0.313	13673.139	3.123	15.615
7	830	5	1564	0.585	13705.536	3.039	15.195
8	830	5	1575	0.618	13699.077	3.056	15.280
9	822	5	1595	0.840	13697.976	3.062	15.310
10	820	5	1597	0.886	13698.884	3.059	15.295

It can be seen from "Table 2" that the optimal inventory strategy of manufacturing enterprise M is to recycle every 15.735 days and purchase every 3.147 days in a recycling cycle. There are five purchases in total. The purchase batch is 853 pieces, the recycling batch is 1590 pieces, the recycling price is 0.209 yuan per piece, and the unit inventory cost is 13664.599 yuan.

5. CONCLUSION

This paper studies the dual source inventory control model of manufacturing enterprises in rural areas considering recycling logistics. In the actual operation process, the dual source inventory control model can well control the recycled inventory and marketable inventory, and provide a reference for enterprises to determine the single purchase batch, recycling batch and recycling price. However, the model still has some shortcomings. For example, in order to reduce the complexity of the model, this paper only studies the inventory change of single product in a recovery cycle. In addition, the recycling cost of waste electronic products is relatively low. In the actual operation process, it is difficult to achieve the expected effect based on consumers' sensitivity to the recycling price. How to reduce assumptions, improve consumers' satisfaction with the recycling price and make the model have more extensive practical significance is one of the main directions to be considered in the future.

AUTHORS' CONTRIBUTIONS

Huijun Huang provided ideas for this paper, Bing Lai is responsible for writing the paper.

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