Optimization of carton recycling site selection using particle swarm optimization algorithm considering residents' recycling willingness

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With the development of the express delivery industry, how to increase the recycling rate of waste cartons has become a problem that needs to be solved. Recycling enterprises began to provide the new recycling mode, door-to-door recycling services, to residents with waste cartons. In this paper, we constructed a site selection model for a carton recycling site with the aim of maximizing total profits. Considering the residents' recycling willingness and the government subsidy earned through the contribution to carbon emission reduction, this model achieves the task of site selection and unit price fixation for carton recycling. We used particle swarm optimization (PSO) algorithm to solve the model and compared it with genetic algorithm (GA) for validity testing. PSO algorithm was also used to carry out sensitivity analysis in this model. The proposed model and the results of the sensitivity analysis can be used for decision-making in recycling enterprises as well as for further research on waste recycling and reverse logistics.

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18 **Abstract**

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20 waste cartons has become a problem that needs to be solved. Recycling enterprises began to

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29 enterprises as well as for further research on waste recycling and reverse logistics.

31

33 **1 Introduction**

34   The rapid development of E-commerce and the express industry, has led to an increase in the

35 production and distribution of packaging cartons (Ma et al., 2022). Though recyclable, their

36   participation in recycling is still low resulting in adverse effects on the economy and the
37   environment (Tang, 2014). For the economy, the cost to paper mills of buying pulp raw materials
38   to produce new cartons is much higher than collecting waste cartons for remanufacturing (Shang
39   et al., 2021). For the environment, carelessly discarded cartons cause environmental damage, and
40   the excessive woodcutting for carton production poses great ecological harm, such as increasing
41   the global carbon dioxide content and leading to more extreme climate (Su et al., 2020). On the
42   contrary, recycling cartons can not only save production costs and bring better economic benefits,
43   but also promote carbon emission reduction (Tong et al., 2023, Cho et al., 2022). China's "Energy
44   Production and Consumption Revolution Strategy (2016–2030)" clearly states that the CO_2
45   emissions per unit of GDP in China are expected to decrease by 18% from 2015 levels by 2020
46   and decrease by 60–65% from 2005 levels by 2030 (NDRC and NEA, 2016). Therefore, it is
47   necessary to increase carton recycling in order to achieve this objective.

48   Raising the carton recycling rate requires an efficient recycling system. Therefore, in
49   February 2022, the National Development and Reform Commission and other departments issued
50   a "Guidelines on accelerating the construction of urban environmental infrastructure" (NDRC et
51   al., 2022), proposing to improve the regional recycling system of renewable waste resources to
52   help achieve the goal of carbon peaking and carbon neutrality. Now, the recycling of waste
53   resources, including carton recycling, is in a transitional period in China. Traditional carton
54   recycling is mainly carried out using urban floating recycling vendors, however the problem of
55   aging and low efficiency exists when using these mediums (Liu et al., 2015, Li, 2002), and the
56   method for determining the carton recycling unit price lacks transparency (Wang et al., 2008).
57   Today, the maturity of the Internet has paved the way for developments in the carton recycling
58   industry, allowing for the formation of a new recycling mode namely "Internet + waste recycling"
59   (Huang and Wei, 2012). In the new recycling mode, third-party recycling enterprises are born,
60   such as "Mr. Cat" and other enterprises. These recycling enterprises set up recycling sites in certain
61   areas of the city and provide recycling services to the residents who have the demand for recycling
62   waste cartons. After residents place orders online, the staff will come to their doors to collect the
63   cartons and pack them for delivery to the paper mills in the suburbs. Compared with the traditional
64   carton recycling mode, this new mode has the advantages of process institutionalization and price
65   transparency (Wang et al., 2018). The new recycling mode greatly improves the efficiency of
66   carton recycling, namely, decreases carbon emissions and increases the output value of the

67   recycling industry. However, due to their short history, the third-party recycling enterprises have
68   to deal with problems like the low recycling rate of cartons and insufficient economic benefits,
69   which are mostly likely the results of unsuitable site distribution and pricing strategies of carton
70   recycling. Therefore, it is necessary to conduct further research on the recycling site selection and
71   pricing amongst recycling enterprises.

72   The problem of recycling site selection is actually a facility location problem in reverse
73   logistics. From different backgrounds and perspectives, various scholars have proposed models
74   and designed a number of solutions for the facility location problem. Chauhan and Singh (Chauhan
75   and Singh, 2016) used hybrid multi-criteria decision making method to select a sustainable
76   location for a healthcare waste disposal facility. Zhao et al. (Zhao et al., 2016) minimized the total
77   cost and total risk, and solved the hazardous waste recycling site selection problem through multi-
78   objective optimization. Yadav et al. (Yadav et al., 2018) proposed the importance of urban waste
79   recycling and transportation, and established an interval value location model for urban waste
80   recycling and transfer stations under uncertain conditions. Aydemir-Karadag (Aydemir-Karadag,
81   2018) proposed a profit-oriented mixed integer mathematical model, which takes into account both
82   environmental impacts and economic benefits, for the site routing problem of hazardous wastes.
83   Liu et al. (Liu et al., 2019) constructed an optimization model of recycling plant location using
84   genetic algorithm, and conducted an empirical study with Panyu and Nansha districts in
85   Guangzhou as examples. Toutouh (Toutouh et al., 2020) proposed a series of applications for
86   single-objective and multi-objective heuristic algorithms based on PageRank method and two
87   multi-objective evolutionary algorithms to resolve urban garbage dump sites location problem.

88   In the research on facility location in the reverse logistics sphere, vast amounts of literature
89   studied the recycling and treatment of non-reusable wastes such as medical, construction and
90   hazardous waste. However, as the implementation of new waste recycling mode are in the early
91   stages, few studies have been conducted on recyclable waste resources such as cartons. There are
92   several new characteristics in the new carton recycling model that have not been discussed in the
93   previous studies. First, unlike other models that serves all nodes, the number of nodes in the new
94   carton recycling model depends on the carton price offered by the recycling enterprise to the
95   residents. That is to say, only when the recycling price is higher than residents' psychological
96   expectation, residents are willing to participate in recycling (Minli et al., 2018), otherwise,
97   residents would rather to dump the cartons. Moreover, for the purpose of environmental protection,

98   the contribution of recycled cartons to carbon emission reduction should be considered, and these

99   can act as a certain subsidy for enterprises by the government (Galinato and Yoder, 2010).

100 In addition, scholars have adopted different methods to solve the location model. Some

101 scholars used multi-criteria approaches such as Analytic Hierarchy Process (AHP) (Aragones-

102 Beltran et al., 2010), comprehensive network analysis and data envelopment analysis (Khadivi and

103 Ghomi, 2012) to conduct site selection research. Some scholars also use meta-heuristic algorithms

104 in the site selection research, such as genetic algorithm (Liu et al., 2019), simulated annealing

105 algorithm (Santosa and Kresna, 2015) and other meta-heuristic algorithms based on evolutionary

106 strategies. In fact, metaheuristic algorithms are designed to address a broad spectrum of

107 challenging optimization problems, including NP-hard problems like site selection problem,

108 without the need for extensive problem-specific adaptations. In the meantime, meta-heuristic

109 algorithms based on swarm intelligence, such as particle swarm optimization (PSO) algorithm also

110 have very good performance in site selection problems (Ezugwu et al., 2020, Pour and Nosraty,

111 2006, Boonmee et al., 2018). PSO has the advantages of fewer required parameters, easy particle

112 coding, fast convergence, and strong universality. Its optimization is mainly based on the fitness

113 function, which is very suitable for solving complex optimization problems (Wang et al., Yang et

114 al., 2022, Huang et al.), and it is an ideal method to solve NP-hard problems such as the carton

115 recycling site selection problem.

116 Based on the new characteristics of the new carton recycling mode and the advantages of

117 PSO algorithm, this paper focuses on site selection in carton recycling enterprises and constructs

118 a single objective model, including the carbon emission reduction subsidies to maximize the total

119 profit, and applies PSO algorithm to solve the problem. The model validity analysis and sensitivity

120 analysis are then conducted based on a case study to discuss the influence of relevant parameters

121 in the recycling process, so as to provide reference and suggestions for the decision-making of

122 recycling enterprises. In a research sense, reasonable recycling site selection and carton pricing for

123 recycling enterprises can fill the gap in the development of reverse logistics in the new waste

124 recycling mode.

125

126 **2 Methodology**

127 This study is completed from the perspective of a recycling enterprise. The carton recycling

128 site location model includes a single-layer reverse logistics network. See Fig. 1 for the specific

129   diagram. There are two types of nodes in the network. One is a set of resident nodes with certain

130   carton weight, and all their information are known. The other is the recycling site set up by the

131   enterprise for collecting and temporarily storing cartons. Its location and the unit carton recycling

132   price need to be determined.

133

134   Figure 1

135

136   2.1 Problem Description

137   In the carton recycling process, the enterprise needs to set up a carton recycling site in a

138   certain residential area, and post the unit carton recycling price to residents in the area on the

139   official website. Each resident has a psychological expectation about the unit carton recycling

140   price. Only when the recycling unit price offered by the enterprise is higher than his expectation

141   will he participate in the recycling. The enterprise provides door-to-door pickup service from the

142   site to residence for each resident. After serving all the residents, the enterprise takes all the

143   collected cartons to a suburban paper mill and resells them to the mill at the resale price offered

144   by the mill.

145   The enterprise's carton recycling cost consists of the cost of recycling cartons from residents

146   and the transportation cost of providing door-to-door services. Since the paper mill is usually far

147   away from the city center, its distance is hardly affected by the location of the recycling site in the

148   urban residential area. Therefore, the transportation cost of sending cartons from the site to the

149   paper mill can be considered as fixed and is not included in the model. The income of carton

150   recycling comes mainly from the resale of cartons to the paper mill. On this basis, considering the

151   contribution of recycled cartons to carbon emission reduction, the subsidies offered by the

152   government influenced by the total weight of recycling cartons are set as additional income for the

153   enterprise. In the end, the enterprise's profit is equal to its income minus its costs.

154   In order to help the enterprise to maximize the total profit including the carbon emission

155   reduction subsidies, the location of the carton recycling site and unit carton recycling price

156   considering residents' willingness need to be studied through decision making. In summary, the

157   carton recycling site location model is constructed on the basis of comprehensively considering

158   the interests of residents, the recycling enterprise and their contribution to carbon emission

159   reduction.

160

161   2.2 Model Assumptions

162   In order to better reveal the core of the problem and improve the generality of the model

163   proposed in this paper, this study is based on the following assumptions.

164   1. The proposed carton recycling site location model can be used as the basis for future path

165   optimization, but this model does not consider path optimization. The enterprise provides door-to-

166   door pickup service from site to residence.

167   2. The transportation cost between the site and the paper mill is not considered.

168   3. The quality of cartons of each resident in the area and his psychological expectation about the

169   unit carton recycling price is known, and cartons are assumed to be homogeneous, which means

170   we only care about the weight of the cartons and do not care about their capacity, soundness and

171   other characteristics. Residents who have the recycling willingness will hand over all their cartons.

172   At the same time, due to the characteristics of price transparency of the new recycling mode, the

173   unit carton recycling price offered by the enterprise for all residents is unified.

174   4. For environmental reasons, the enterprise uses electric cars, which consume no fuel and produce

175   no carbon emissions. The transportation cost by distance is known, which is irrelevant to loads.

176   The unit resale price offered by the paper mill is also known, and the carbon emission subsidy

177   based on the total weight of recycling cartons is certain, too.

178   5. The distance between the site and the resident is assumed to be Euclidean distance, regardless

179   of the fixed cost and capacity limitation of the vehicle for recycling and the influence of the street

180   on the distance.

181   6. We assume that the location of the site in the region is arbitrary, and only one is selected,

182   regardless of the opening cost of the site.

183

184   2.3 Description of Parameters

185   The model parameters are defined as follows.

G	Set of all the nodes in the reverse logistics network, $n = \{n \mid n = 0,1,2,...,N\}$, 0 is the recycling site.
K	Set of all the residents in the reverse logistics network, $i = \{i \mid i = 1,2,...,N\}$.

p	The unit carton recycling price offered by the enterprise (CNY/Kg).
p_i	The psychologically expected unit carton recycling price of Resident i (CNY/Kg).
p^r	The unit carton resale price offered by the paper mill (CNY/Kg).
d_i	The distance from resident i to the recycling site (Km).
w_i	The weight of the cartons owned by the resident i (Kg).
c_f	The unit transportation price per kilometer (CNY/Km).
λ	The carbon emission reduction subsidy coefficient (CNY/Kg).
x_i	The decision variable, $x_i = 1$ if the residents are willing to participate in carton recycling, otherwise, $x_i = 0$.

186

187   2.4 Mathematical Model Construction

188   It can be seen from the problem description that the ultimate goal of the recycling enterprise

189   is to maximize net profit. Therefore, the objective function of the model includes the cost and

190   profit of carton recycling, which is detailed as follows.

191   (1) The cost of recycling cartons from residents

192   This cost is equal to the sum product of the unit carton recycling price offered by the

193   enterprise and the weight of the carton owned by the residents, and only when residents are willing

194   to sell them. It can be expressed mathematically as:

$$Cost_1 = \sum_{i \in K} x_i w_i p \qquad (1)$$

195   (2) The transportation cost

196   The transportation cost is equal to the sum product of the round trip distance from the site to

197   the residence and the unit transportation price per kilometer, and only when residents are willing

198   to sell them. It can be expressed mathematically as:

$$Cost_2 = \sum_{i \in K} 2x_i d_i c_f \qquad (2)$$

199   (3) Income from reselling

200   This is the main source of income for the enterprise. Similar to Equation(1), the income from

201 reselling is equal to the unit carton resale price offered by the paper mill multiplied by the total

202 weight of the collected cartons. It can be expressed mathematically as:

$$Income_1 = \sum_{i \in K} x_i w_i p^r \qquad (3)$$

203 (4) Carbon emission reduction subsidies

204 Given the contribution to the reduction in carbon emissions, we assume that the government

205 sets a subsidy for the enterprise to recycle as many cartons as possible. Since the enterprise's main

206 source of income comes from carton resale, profits are significantly affected by fluctuations in unit

207 carton resale price and the enterprise will not be encouraged to increase carton collection if they

208 are not sufficiently subsidized. Therefore, we refer to Juan's literature and setting the subsidy as a

209 coefficient λ based on the total weight of recycling cartons (Juan et al., 2019). It can be expressed

210 mathematically as:

$$Income_2 = \sum_{i \in K} x_i w_i \lambda \qquad (4)$$

211 To sum up, the enterprise's final total profit is expressed as:

$$F = Income_1 + Income_2 - Cost_1 - Cost_2 \qquad (5)$$

212 Since the objective function in operations research is generally to find the minimum value,

213 the objective function of the model proposed in this research is expressed as:

$$Min(-F) = \sum_{i \in K} x_i w_i p + \sum_{i \in K} 2 x_i d_i c_f - \sum_{i \in K} x_i w_i p^r - \sum_{i \in K} x_i w_i \lambda \qquad (6)$$

214 Regarding the constraints of the model, we make the following considerations:

215 (1) The constraint is mainly the price constraint; we require the unit carton recycling price to

216 be a positive number. It can be expressed mathematically as:

$$p \geq 0 \qquad (7)$$

217 (2) Since the enterprise's main income comes from the resale of cartons, the unit carton

218 recycling price must be less than the unit carton resale price. It can be expressed mathematically

219 as:

$$p^r \geq p \qquad (8)$$

220 (3) As mentioned above, residents are willing to participate in carton recycling only when the

221 unit carton resale price offered by the enterprise is higher than their psychological expectation.

222 Therefore, the value of variable x_i is related to the comparison of p and p_i values. It can be

223   expressed mathematically as:

$$x_i = \begin{cases} 1 & p \geq p_i \\ 0 & p ＜ p_i \end{cases}, \forall i \in K \tag{9}$$

224

225   **3 Algorithm Design**

226   3.1 Characteristics and applications of PSO

227   PSO is inspired by the study of bird foraging behavior. Its basic idea is to find the optimal

228   solution through the cooperation and information sharing between individuals in the swarm. Each

229   particle separately searches for the optimal solution in the search space, then records and shares

230   the individual optimal value. All particles in a swarm adjust their speed and position based on the

231   current individual optimal value they find and the current global optimal value shared by the whole

232   swarm (Eberhart and Kennedy, 1995).

233   There are many applications of PSO in the logistics field. Yao et al. (Yao et al., 2013)

234   designed the location model of automobile spare part warehouse and solved it with particle swarm

235   optimization algorithm for automobile production and transportation. Shen et al. (Shen and Chen,

236   2017) proposed a multi-depot model and used PSO algorithm to solve its location and path

237   optimization problems. Yang et al. (Yang et al., 2022) improved the particle swarm optimization

238   algorithm by introducing diversity enhancement mechanism and neighborhood search mechanism,

239   and applied it in the optimization of urban wet waste recovery path optimization.

240   In view of the above carton recycling site location model, combined with previous application

241   experience, we applied PSO algorithm to solve the model.

242

243   3.2 PSO Principles and Calculation Procedures

244   The basic principles of PSO (Tchomte and Gourgand, 2009) are as follows.

245   In the feasible solution space of a D-dimension, there is a particle population P, in which there

246   are $Npop$ randomly distributed particles. Each of these particles has their own initial moving speed

247   and initial position, and those in the whole population are optimized iteratively $MaxIt$ times. With

248   each iteration, each particle keeps track of two extreme values ($Pbest, Gbest$) to update its speed.

249   Each particle has a velocity and a position, and the initial particle is randomly generated as

250   follows:

$$x_i = rand(1, size).\times(x_{max} - x_{min}) + x_{min} \tag{10}$$

$$v_i = rand(1, size).\times(v_{max} - v_{min}) + v_{min} \tag{11}$$

251 Where *size* is the particle length, $[x_{min}, \ x_{max}]$ is the particle range, and $[v_{min}, \ v_{max}]$ is the

252 velocity range. Thus, the updated formula of the particle is:

$$v_{ij}(t+1) = w \cdot v_{ij}(t) + c_1 \cdot rand1_{ij} \cdot (Pbest_{ij}(t) - x_{ij}(t))$$
$$+c_2 \cdot rand2_{ij} \cdot (Gbest_j(t) - x_{ij}(t)) \tag{12}$$

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \tag{13}$$

253 In the formula, $i = 1, 2, ..., N$ is the number of the particle, $X_i = (x_{i1}, x_{i2}, ..., x_{iD})$ represents the

254 position of the i particle; $V_i = (v_{i1}, v_{i2}, ..., v_{iD})$ is the velocity of particle i;

255 $pbest_i = (pbest_{i1}, pbest_{i2}, ..., pbest_{iD})$ represents the position with the highest fitness value

256 reached by the i particle itself (that is, the position of the individual optimal solution in history);

257 $gbest = (gbest_1, gbest_2, ..., gbest_D)$ represents the position with the highest fitness value reached

258 by all particles in the population (that is, the position of the global historical optimal solution).

259 Parameter w is called the inertia factor, which is used to balance the global and local search ability

260 of particles. $rand1_{ij}$ and $rand2_{ij}$ are two independent uniform random numbers generated within

261 range $[0,1]$. c_1 and c_2 are two learning factors that control the influence of social and cognitive

262 components., $t = 1, 2, ...$ represents the number of iterations.

263 Shi (Shi, 1998) introduced a parameter w_t, called inertia weight, into the PSO. Since it

264 decreases linearly in the search process, it can affect the velocity and position of each particle,

265 which is used to balance exploration and utilization capabilities and control the convergence

266 behavior of PSO. Inertia weight is added into the algorithm so that the PSO will operate smoothly.

267 Inertial weights are calculated using the following equation:

$$w_t = w_{max} - \frac{(w_{max} - w_{min})}{T} \cdot t \tag{14}$$

268 In the formula, w_t decreases linearly as the number of iterations increases, and w_{max} and

269    $w_{\max}$ represent the maximum and minimum inertial weight values respectively.

270   Based on the principle of PSO, we now design the specific steps of using PSO in the carton

271   recycling site location model.

272   Step 1: read the x and y coordinates of residents in the data file, as well as the weight w_i of

273   the cartons owned by the resident i and the psychologically expected unit carton   recycling   price

274   p_i of carton recycling of Resident i.

275   Step 2: set parameter values in the PSO algorithm, including the maximum number of

276   iterations $MaxIt$, the number of populations $Npop$, the maximum inertia weight w_{max}, the

277   minimum inertia weight w_{min}, the particle learning factors c_1 and c_2, the velocity range

278   $[v_{min}, \ v_{max}]$ and the position range $[Varmin, Varmax]$.

279   Step 3: determine the particles encoding. In this research, the x and y coordinate location of

280   the recycling site and the unit carton recycling price are decision variables. Then $Npop$ 3D

281   particles are randomly generated as the initial particle swarm, their positions and velocities are

282   generated according to Equation(10) and (11). The first two dimensions of the particle represent

283   the x and y coordinates of the site, respectively, and the third dimension represents the unit carton

284   recycling price.

285   Step 4: calculate the Euclidean distance from the site to each resident, then the fitness of each

286   particle $particle(i).profit$ is calculated according to the objective function mentioned in the

287   previous model.

288   Step 5: set the position of particle i as $pbest_i$ in the initial particle swarm, and the position

289   of the particle with the largest fitness value as the initial global historical optimal solution $gbest$.

290   Step 6: the iteration begins, each particle in the population updates its position and velocity

291   according to Equation(12) , (13) and (14).

292   Step 7: after the iteration, the global optimal solution in the last generation is output as the

293   result of algorithm calculation.

294   Fig. 2 briefly describes the flow of the algorithm calculation process.

295

296   Figure 2

297

4 Computational experiments

4.1 Algorithm validity test

The Solomon benchmark is a widely recognized dataset that is commonly used to study issues related to Vehicle Routing Problems (VRP). In this section, a Solomon benchmark example set with adjusted parameters (Bent and Van Hentenryck, 2004) is used to verify the effectiveness of the PSO. We compare the PSO with the Genetic Algorithm (GA) by randomly selecting several examples from the original six types. The following experiments were executed 10 times with MatlabR2021a on a PC with Intel core i5 CPU operating at 1.60 GHz. The parameter settings of PSO are presented in Table 1, and the parameter settings of GA are presented in Table 2. The fitness function of these two algorithms is the objective function of the model. In addition, We refer to the price table of domestic waste paper recycling on December 14, 2022 (feipinzhan.com, 2022), and assume that the unit price of carton resale in the model is 2 CNY/Kg, and refer to the relevant parameters of several new energy waste recycling vehicles released by the Ministry of Industry and Information Technology (MIIT, 2022), assume that the energy consumption of vehicles per kilometer is 0.30 KWH, and multiply by the domestic electricity price of about 0.6 CNY per KWH, then set unit transportation cost is 0.2 CNY/Km, and the carbon emission reduction subsidy coefficient is temporarily set to zero. The average value is recorded as the optimal results. The results are shown in Table 3:

Table 1. The basic set of parameters of PSO

Table 2. The basic set of parameters of GA

Table 3. DNSPSO Test results

Figure 3(A)(B)(C)(D)(E)(F)

The comparison of examples used in our calculation are shown in Fig. 3. The line in the box represents the median fitness value calculated by PSO for each example, and the blue represents that of GA. It is evident that PSO produces continuous consistent results in small, medium or large-scale cases, while the GA's results are frequently inconsistent. In addition, the median fitness value

328 calculated by GA is lower than that calculated by PSO in each example.

329   Such comparison may be related to the coding methods of the solutions and the characteristics

330 of the two algorithms. Firstly, from the perspective of the coding method, when using PSO to solve

331 the recycling site location problem, only three digits are needed, and the calculation results of

332 Matlab are automatically accurate to four decimal places. GA coding generally adopts binary

333 coding, and uses a long array composed of only 0 and 1 to express the solution of the site location

334 problem (Kratica et al., 2001), which is much more complex than PSO on the premise of ensuring

335 the same accuracy. Secondly, from the perspective of algorithm characteristics, PSO based on

336 swarm intelligence strategy seeks the optimal solution by simulating the foraging of birds within

337 a certain range (Chen and Tan, 2018), which has certain similarity with the site location problem

338 in the kernel. However, when finding the optimal solution, GA based on evolution strategy has

339 lots of abstract operations such as chromosome crossover and mutation for site location problem

340 (Alp et al., 2003, Rybickova et al., 2019), which may affect the convergence of the algorithm. Fig.

341 4 shows the convergence of the two algorithms after we run the RC207 example and get the value

342 around average fitness value. In conclusion, we reasonably believe that PSO is effective and robust

343 in solving the proposed carton recycling site location model.

344

345   Figure 4 (A)(B)

346

347 4.2 Model validity analysis

348   The most important feature of this model is that the number of residents it serves depends on

349 the unit carton recycling price. When we validate the model, we compare it to a model that serves

350 all residents, which implies the unit carton recycling price is set as the highest to meet all residents

351 expectations. We assume that the unit transportation cost is 0.2 CNY/Km, and the carbon emission

352 reduction subsidy coefficient is still temporarily set to zero.

353   Fig. 5 shows the comparison of total profit as the unit carton resale price rises in two models.

354 It is not difficult to see that when the unit carton resale price is low, the model that considers

355 residents' willingness to participate in recycling can get more total profits. This is because when

356 the income from reselling cartons to the paper mill is not sufficient, serving residents with a high

357 price will lead to a loss of the enterprise. However, when the unit carton resale price rises, the gap

358 between the total profits calculated by the two models will narrow. That is to say, when the income

359   from reselling cartons is sufficient, the enterprise can still get profits by serving the residents with

360   high price. This comparison can prove the validity of our proposed model.

361

362   Figure 5

363

364   4.3 Sensitivity analysis

365   After verifying the effectiveness of PSO and the validity of our proposed model, we will

366   complete the analysis and discussion of the proposed carton recycling site location model, that is,

367   sensitivity analysis. Among them, the large-scale calculation example RC207 will be used as the

368   sensitivity analysis, specific data of RC207 example are in the supplementary material. Since the

369   model is built from the perspective of the recycling enterprise, and the ultimate goal of recycling

370   enterprises operation is to maximize their total profit, which involves the important decision of the

371   unit carton recycling price. Therefore, we mainly discuss the influence of the variable parameters

372   in the model on the unit carton recycling price offered by the enterprise and the final total profit.

373   First, we explore the influence of the unit carton resale price and the unit price of

374   transportation per kilometer on the unit carton recycling price and the final total profit of the

375   enterprise, without considering the carbon emission reduction subsidy briefly. According to the

376   actual unit carton recycling price in China, it generally fluctuates between 2CNY/Kg and

377   3CNY/Kg, so the unit carton recycling price is set to fluctuate within the range. In addition, we

378   consider a 50% fluctuation in the unit transportation cost. The specific calculation results are

379   shown in Fig. 6. It can be observed from the total profit comparison that the total profit rises

380   steadily with the rise of the unit carton resale price. Fig. 6(A) shows several smooth curves with

381   even spacing. The scenario with lower unit transportation price per kilometer can obtain higher

382   total profit, and with the rise in unit carton resale price, the difference in total profit will gradually

383   increase. In the unit carton recycling price comparison (Fig. 6(B)), with the rise of the unit carton

384   resale price, price curves show plateaus and sharp increases, and overlap (but not cross) at many

385   nodes. By observing a single curve, it can be found that each curve has several plateaus, that is to

386   say, with the rise in unit carton resale price, the unit carton recycling price may remain stable for

387   a period of time. As the unit carton resale price continues to rise, the unit price of recycling may

388   jump by leaps.

389   The plateaus in the curve of the unit carton recycling price comparison reflect the precise

390   calculation of the proposed model and algorithm for the maximum benefits of the enterprise. To
391   specifically explain this point of view, through the observation of the example data, we can find
392   that the psychologically expected value of unit carton recycling price of some residents only
393   accounts for a small portion, and the marginal benefit of the enterprise to rise the unit price to serve
394   these residents may be less than the transportation cost, which is the reason for the plateaus in the
395   curve. With the rise of the unit carton resale price, when it reaches a certain value, the curve may
396   enter a new plateau. In addition, due to the large number of residents in the RC207 example, the
397   total profit curve remains steadily growing even though there are many plateaus and sharp
398   increases in the unit carton recycling price curve. That is to say, although the site selection and
399   pricing strategy of an enterprise are very sensitive to the influence of other factors, the huge
400   number of services determines that its total profit will not be greatly affected.

401

402   Figure 6(A)(B)

403

404   Figure 7(A)(B)

405

406   We choose a scenario where the unit transportation price per kilometer is 0.2CNY/Km, and
407   discuss the influence of the carbon emission reduction subsidy coefficient on the overall profit and
408   pricing strategy of the enterprise. See Fig. 7 for specific calculation results. The comparison of
409   total profit and unit carton recycling price are similar to Fig. 6. The results show that under the
410   same unit carton resale price, a higher carbon emission reduction subsidy coefficient may
411   encourage the enterprise to raise the unit recycling price and collect more cartons, but this is not
412   necessarily the case (the curves may overlap).
413   Since the sensitivity analysis considers all scenarios with varying parameter combinations,
414   we found that even the PSO algorithm, which is highly stable in the validity test, will repeatedly
415   calculate two results under some scenarios with parameter combinations. See Fig. 8 for details of
416   the two results (unit carton resale price is 2.3CNY/Kg, transportation cost is 0.2 CNY/Km, carbon
417   emission reduction subsidy coefficient is 0.3).
418   These results have some implications for our proposed model and algorithm. At the model
419   level, the two results show that although enterprises set different carton unit recycling price, the
420   final total profits are almost identical, which confirms a point: if the number of residents is large

421 enough, small fluctuations in unit carton recycling price considering the psychological

422 expectations of a small number of residents will not affect the enterprise's overall total profit. At

423 the algorithm level, although the total profit of the two results are similar, the solution with low

424 profit may still be suboptimal. In this case, the solution with the higher profit should be chosen.

425 this also tells us that the PSO algorithm needs to be strengthened.

426

427   Figure 8(A)(B)(C)(D)

428

429 4.4 Discussion

430   From the sensitivity analysis, we can know that a higher unit carton resale price and a lower

431 unit transportation price can promote the enterprise to raise the unit carton   recycling   price and

432 collect more cartons, thus achieving the two goals of contributing to carbon emission reduction

433 and profit maximization. In addition, we came to several important conclusions:

434   1. The carton pricing strategy is sensitive to cost variables, and higher carbon emission

435 reduction subsidy may encourage the enterprise to raise the unit recycling price and collect more

436 cartons.

437   2. Although the enterprise's pricing strategy is affected by other factors, the total profit

438 remains stable in the end because the number of residents is large enough. The different pricing

439 strategies made by considering the psychological expectations of a small number of residents

440 towards the carton recycling unit price will not affect the enterprise's overall total profit.

441   3. It can be concluded from the two points above that the overall decision of an enterprise is

442 influenced by many aspects. Therefore, it has important reference significance to set location

443 selection and pricing as decision variables simultaneously. Compared with first pricing and then

444 site selection or first site selection and then pricing, our approach in theory has more

445 comprehensive consideration and can help to find better solutions.

446   4. The deviation of the PSO algorithm in the sensitivity analysis on the one hand confirms

447 the second conclusion above, and on the other hand shows that the classical PSO algorithm adopted

448 in this paper still has instability in large-scale site selection research. The latest improved PSO

449 algorithm can be used or combined with the algorithm based on evolutionary strategy in future site

450 selection research.

451   5. While we utilized a calculation example in the sensitivity analysis, its application to real-

452   world data in the future can further unlock its practical value.

453   Overall, this model offers valuable insights for recycling enterprises. Operating costs for

454   such enterprises comprise multiple components, which at times can be mutually challenging. Our

455   study integrates site selection and carton pricing strategies to encourage enterprises to approach

456   cost-related issues from a comprehensive standpoint. Moreover, the matter of carton pricing and

457   subsidies involves a complex interplay between enterprises, government entities, and residents.

458   Although this paper did not delve deeply into the intricacies of this game, relying instead on

459   simplified assumptions, future research can explore the dynamics of this game within reverse

460   logistics in greater detail. By effectively combining this aspect with logistics optimization, a more

461   comprehensive theoretical framework can be established.

462

463   **5 Conclusion**

464   Waste cartons recycling is a huge benefit to the economy and the environment. The

465   development of the Internet has given birth to new carton recycling mode. Considering the

466   characteristics of this new carton recycling mode and the in-applicability of the previous location

467   research models for it, we reconstruct the carton recycling site location model from the perspective

468   of recycling enterprises. In the model, the unit carton recycling price and site selection are both

469   decision variables, residents' willingness to recycle considering their psychological expectations

470   regarding the unit carton recycling price and the subsidy income of carbon emission reduction are

471   fully considered. The following are the specific conclusions of our study.

472   (1) Main conclusions

473   Firstly, we have involved the application of PSO algorithm to the solution of the model. In

474   the algorithm validity test, the performance of PSO is more stable than that of GA, and better

475   solutions can be found. Secondly, we validate the model by comparing it to a model that serves all

476   residents, which shows the significant increase in total profit when setting location selection and

477   pricing as decision variables simultaneously. Finally, we did a sensitivity analysis which shows

478   that although the pricing strategy of an enterprise is sensitive, the total profit can remain stable

479   rather than change dramatically after undergoing a fluctuation in pricing strategy. This is because

480   the number of residents is large enough.

481   (2) Theoretical significance

482   Firstly, our research innovatively combines location selection and carton pricing decisions

483   together for collaborative optimization, which can avoid the sub-optimal solution when the two

484   decisions are optimized separately. Secondly, the model proposed by us has high universality and

485   can incorporate other decisions such as inventory optimization or route optimization for more

486   systematic and comprehensive optimization in the future.

487   (3) Management significance

488   The carton recycling site selection model proposed in our study fills the gap in the

489   development of reverse logistics in the new waste recycling mode and lays a good foundation for

490   the exploration of site selection in the field of waste recycling. At the same time it provides a great

491   reference value for decision-making in recycling enterprises: although enterprises have very

492   mature research and use experience on site location selection and pricing decision-making in

493   reality, these two decision-making tasks sometimes belong to two different departments, which

494   may lead to the generation of sub-optimal solutions, and thus increase the operating costs of

495   enterprises. In our proposed model, the idea of collaborative optimization between the two can

496   provide new thinking for the operation of enterprises.

497   (4) Limitations and future direction

498   Future studies can make some improvements in these ways: leaving the number of sites

499   unfixed to solve a multi-site location problem considering site opening costs, combining path

500   optimization and site location together to build a site location route optimization model.

501

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509

510

511

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635

Figure 1

Diagram of carton recycling

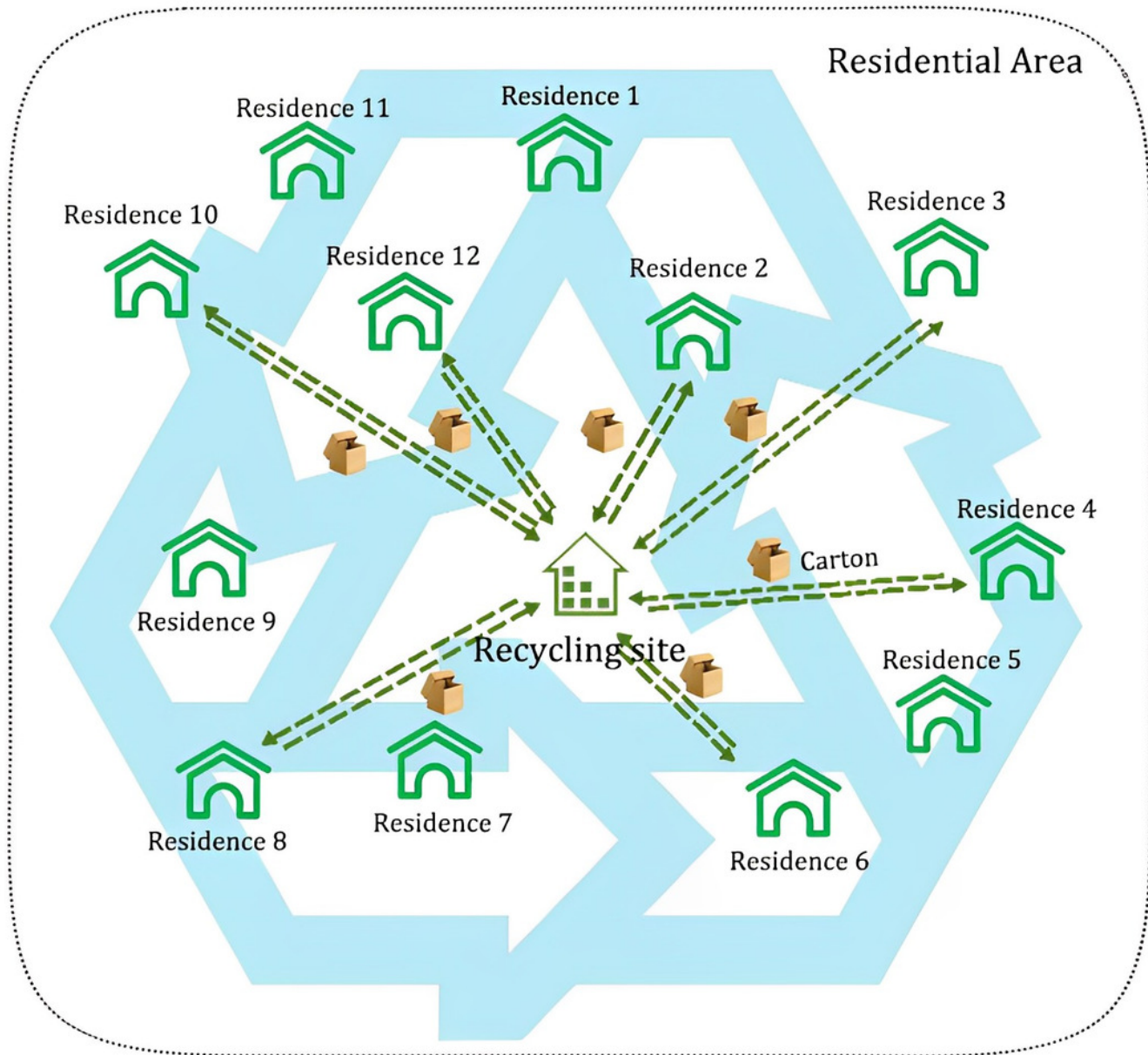



Figure 2

Flow chart of algorithm calculation process

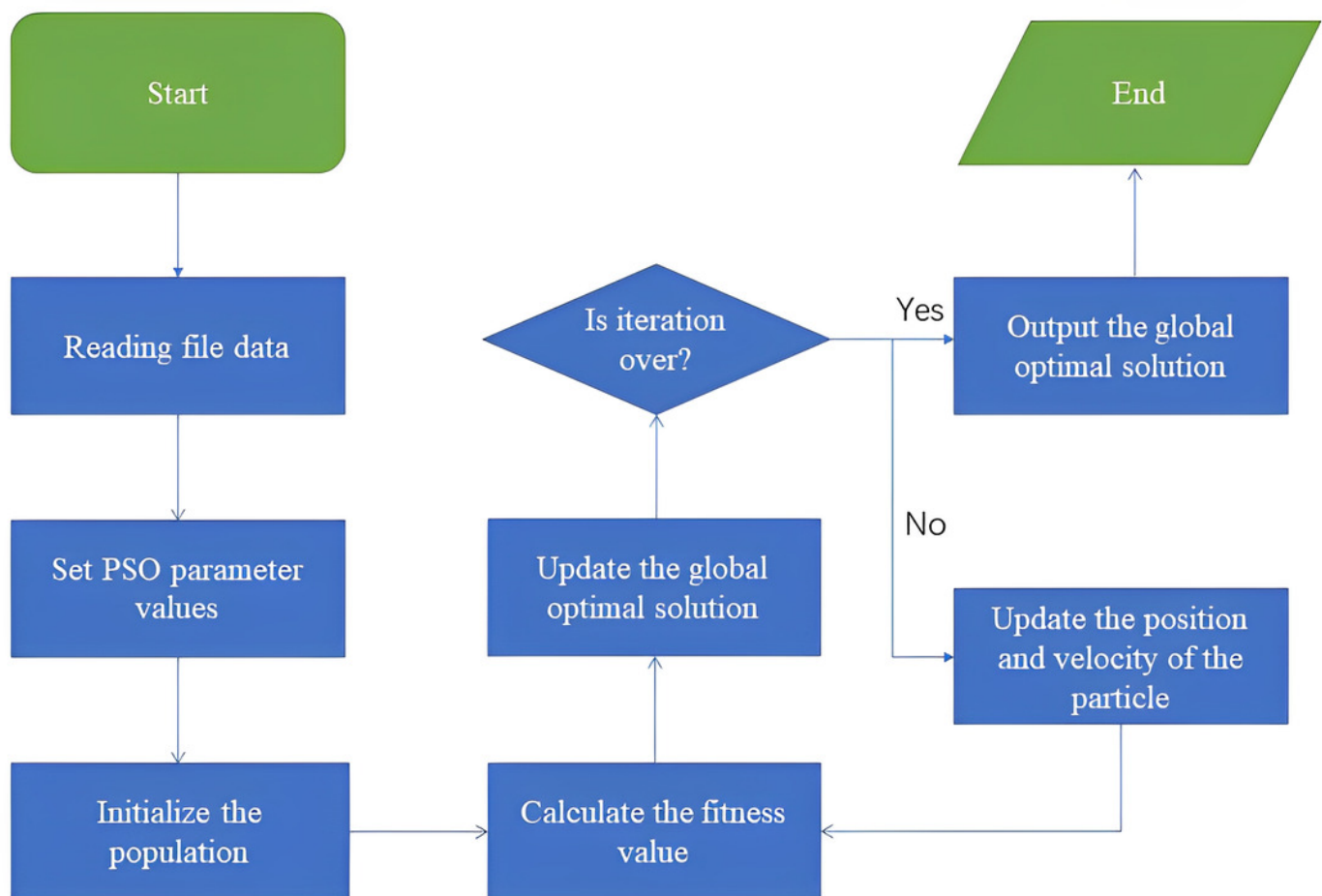



Figure 3

Results of comparison between PSO and GA

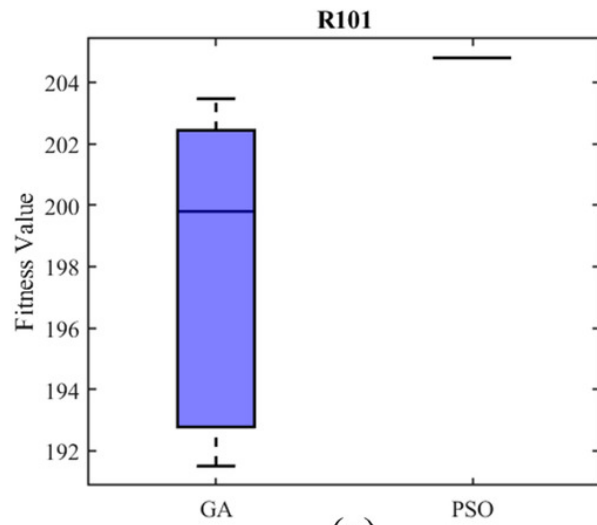
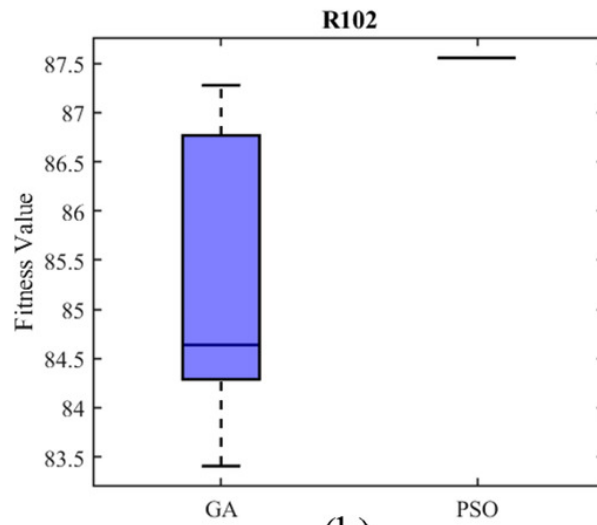
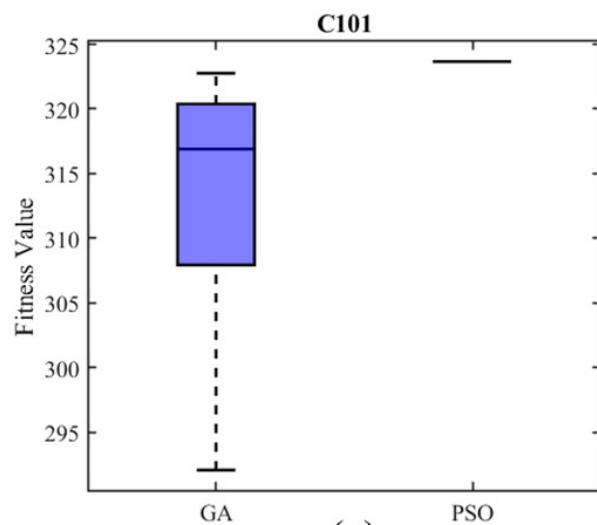
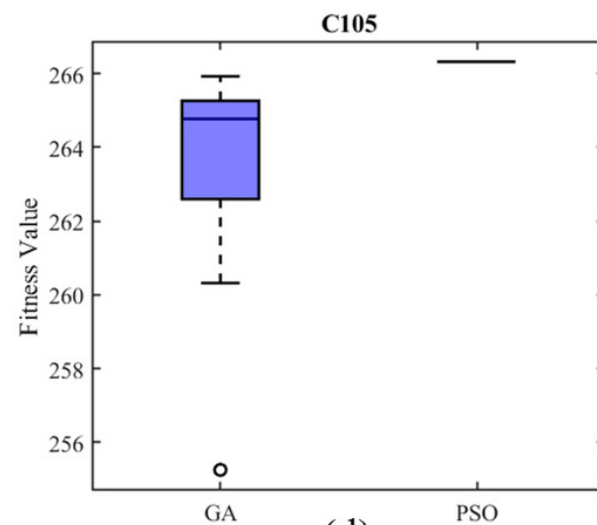
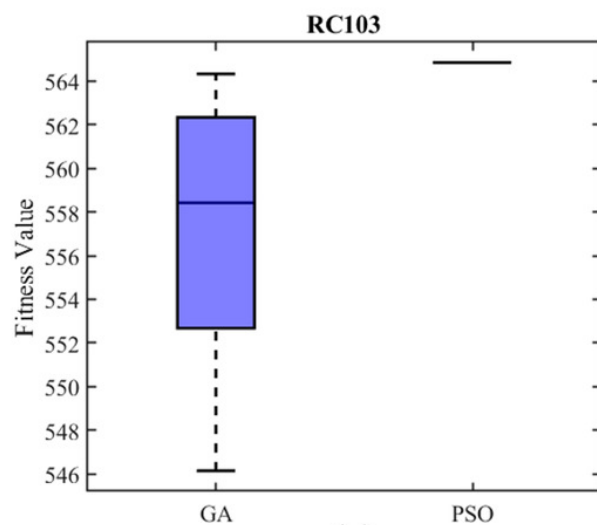
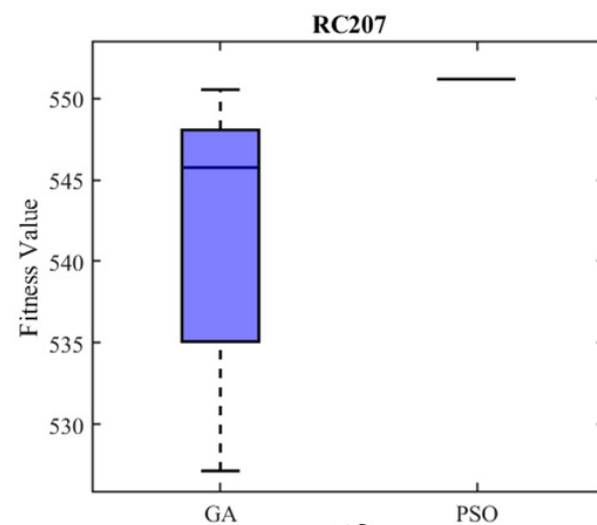



Figure 4

Comparison of algorithm convergence when obtaining values around the average (using RC207 example)

(a) PSO

(b) GA

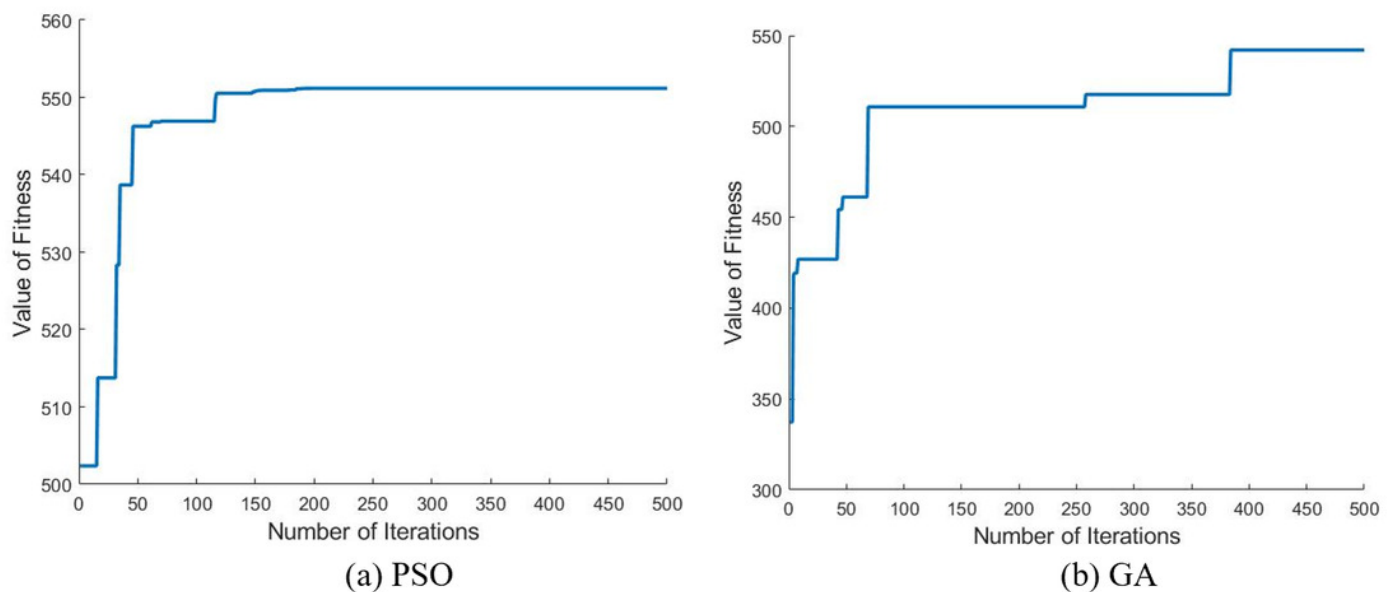



Figure 5

Comparison of total profit in two models

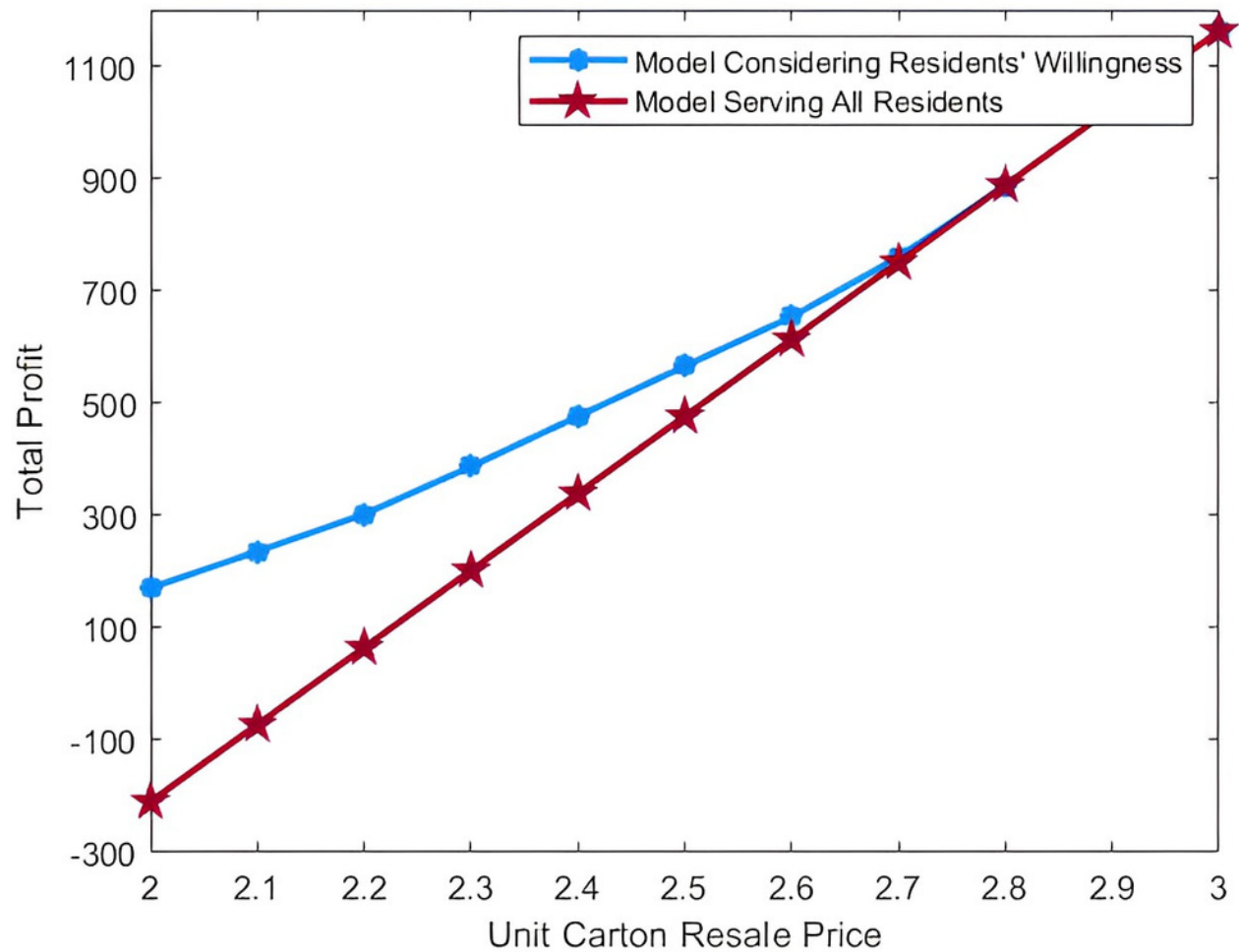



Figure 6

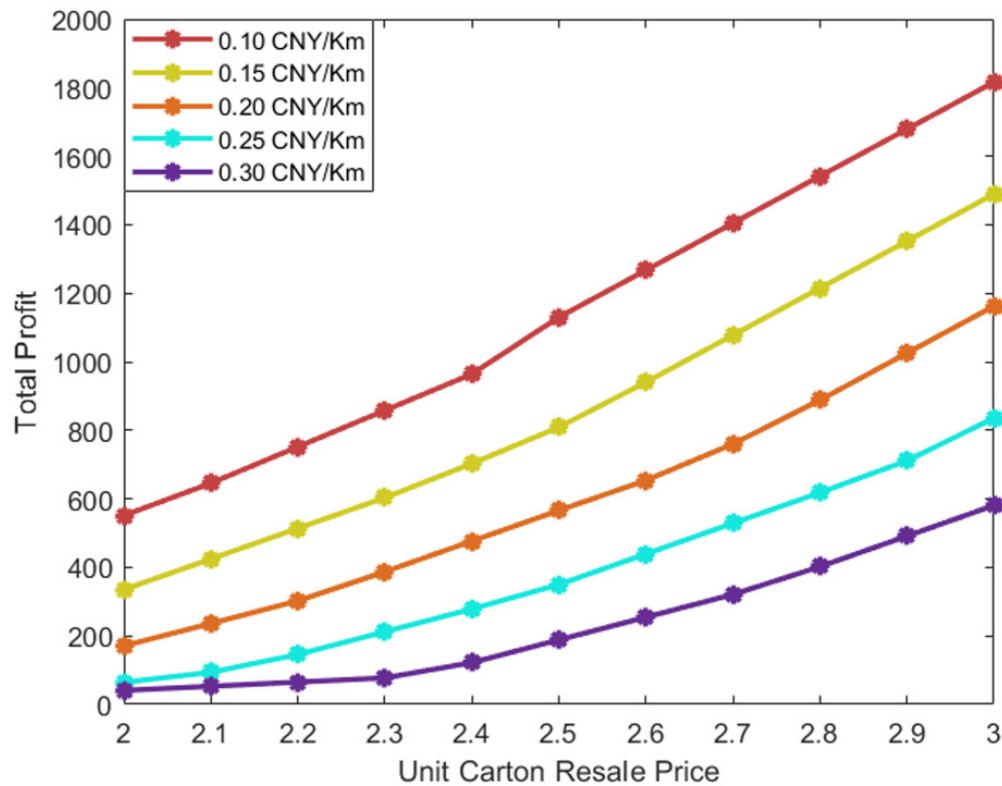
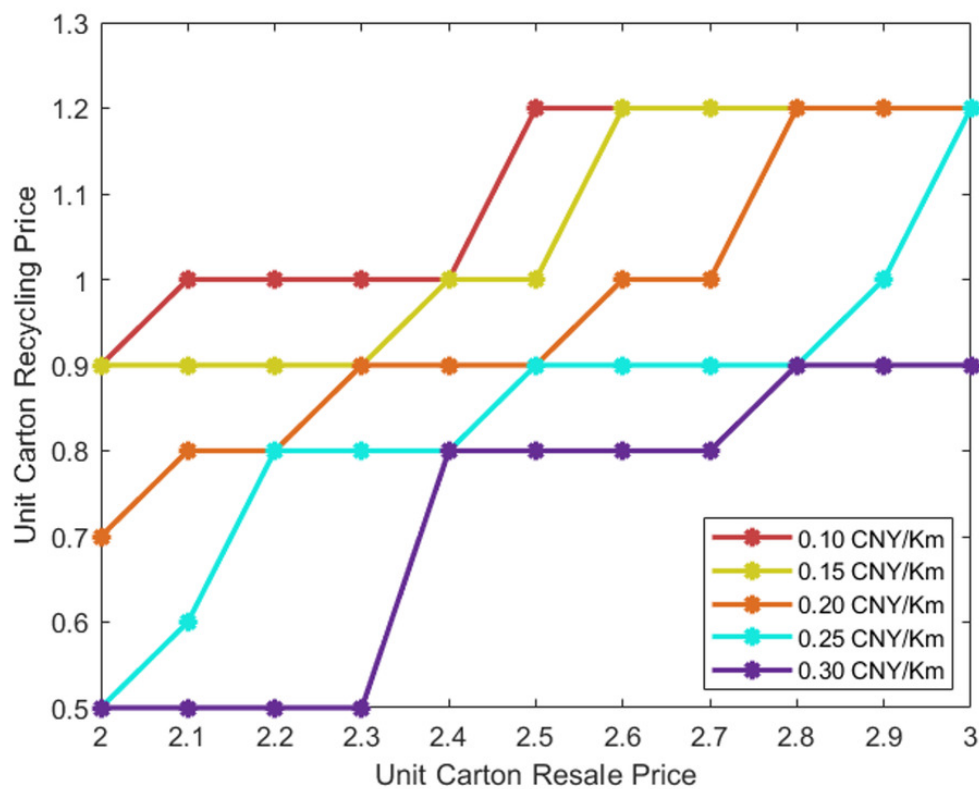
Comparison of total profit and unit carton recycling price

(a)

(b)

Figure 7

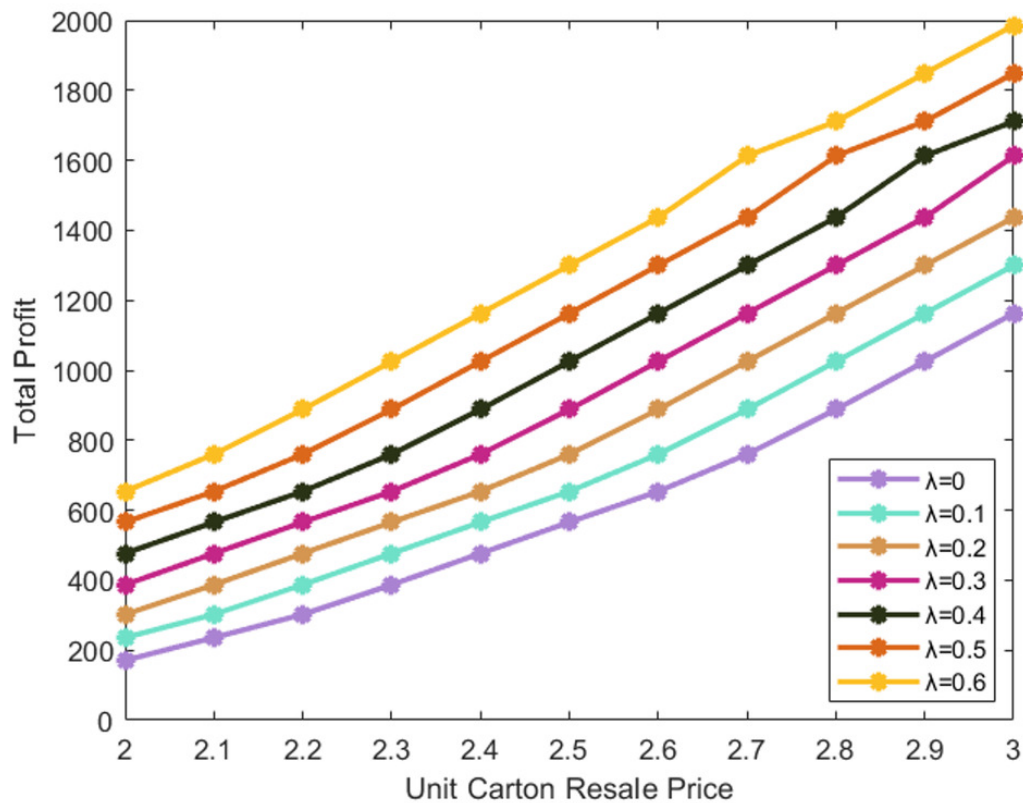
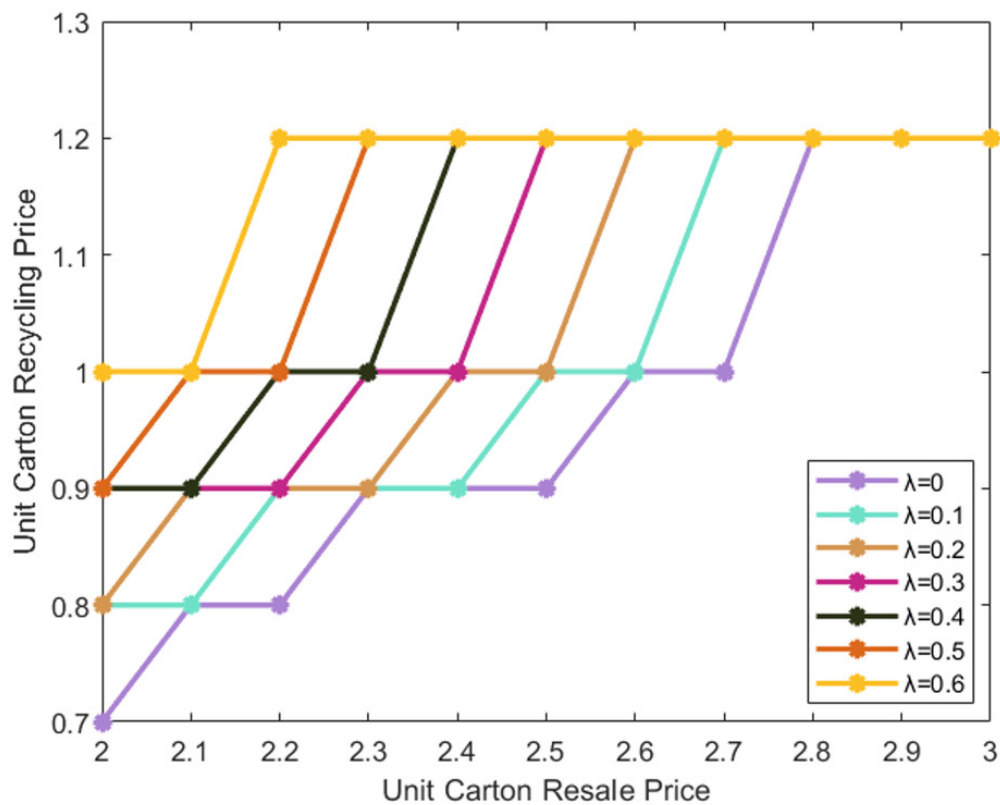
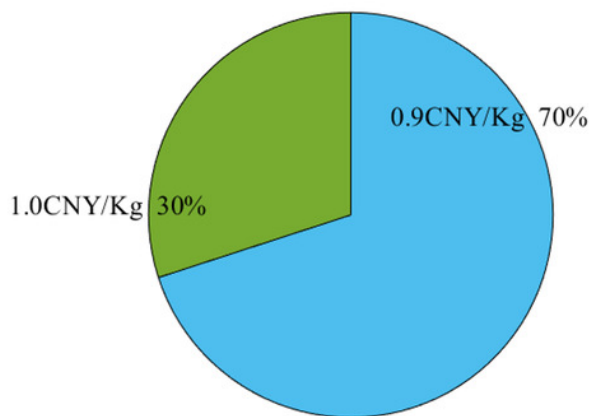
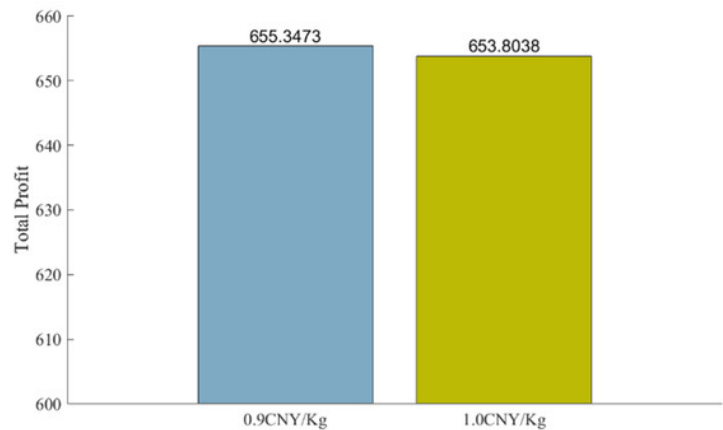
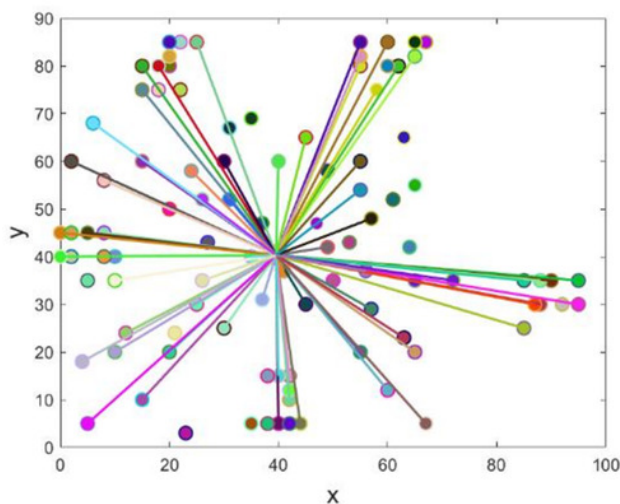
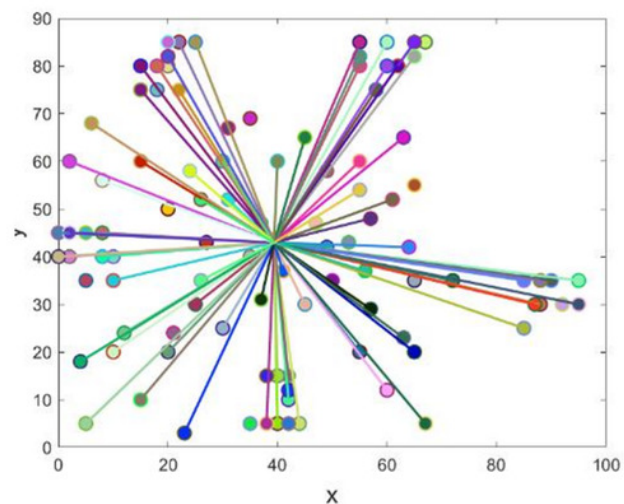
Comparison of total profit and unit carton recycling price (Considering subsidies)

(a)

(b)

Figure 8

PSO calculation results

(a) The number proportion of the two results

(b) The total profit of the two results

(c) Collection situation diagram (unit price is 0.9 CNY/Kg)

(d) Collection situation diagram (unit price is 1CNY/Kg)

The basic set of parameters of PSO

1 **Tables**

2   **Table 1.** The basic set of parameters of PSO

Parameter	Description	Value
$Npop$	Population Number	20
w_{max}	Maximum Inertia weight	0.9
w_{min}	Minimum Inertia weight	0.01
c_1	Personal learning factor	1.49618
c_2	Global learning factor	1.49618
$[v_{min},\ v_{max}]$	Velocity range	[-10,10]
$[Varmin, Varmax]$	Position range	[0,100]
$MaxIt$	Evolution terminate generation	500

The basic set of parameters of GA

1 **Tables**

3 **Table 2.** The basic set of parameters of GA

Parameter	Description	Value
$Npop$	Population Number	20
p_c	Chromosome crossover probability	0.6
p_m	Chromosome mutation probability	0.1
/	Chromosome selection method	Tournament
$MaxIt$	Evolution terminate generation	500

DNSPSO Test results

Table 3. DNSPSO Test results

Data set	Resident Amount	Total Profit (CNY)		Comparison Result (CNY)
		PSO	GA	
R101		204.80	198.27	+6.53
	25			
R102		87.56	85.28	+2.28
C101		323.65	313.03	+10.62
	50			
C105		266.32	263.28	+3.04
RC103		564.84	557.31	+7.53
	100			
RC207		551.17	541.95	+9.22