MINING AND QUANTIFYING THE OPTIMAL DBH RANGE OF LOBLOLLY PINE WITH IMPROVED PARTICLE ALGORITHM

D. Qing,[*] *J. Li*,[*] *Q. Deng*,[†] *S. Liu*[*]

Abstract: In order to fully understand the objective law of height and DBH growth of loblolly pine trees and exploring the best DBH (Diameter at Breast Height) Range for loblolly pine tree height growth, 13 340 loblolly pines with initial DBH between 1 inch and 7 inch were selected from Alabama as research objects, and statistics on its growth from 2000 to 2015. Because particle swarm optimization (PSO) is suitable for solving non-linear problems, the optimal DBH of loblolly pine is transformed into the optimization problem of PSO, which quantifies the optimal DBH range of loblolly pine at different scales by mapping strategy. The experimental results show that the range of the breast diameter suitable for the high growth of the pine tree is concentrated between 3.7 inch and 7.3 inch. The height of the pine tree begins to enter a period of rapid growth from a breast diameter of 3.9 inch (±0.2 inch). The tree height growth rate reached a maximum at a breast diameter of 6.4 inch (±0.6 inch), and the tree height entered a slow growth period after the breast diameter of 11.92 inch (±0.3 inch). In general, when the breast diameter exceeds 15.26 inch (±0.3 inch), the height of the pine tree stops growing.

Key words: *loblolly pine, particle swarm optimization, quantification of DBH range, outlier point processing, forest management*

Received: July 30, 2020
Revised and accepted: April 30, 2022
DOI: 10.14311/NNW.2022.32.007

1. Introduction

Forest health management is conducive to the sustainable development of forests. While acquiring forest resources, human beings must follow the objective laws of forest tree growth and protect forest ecosystems to a great extent [1, 2]. Southeastern United States is one of the world's largest timber producing regions with more than 18 million hectares of pine forest [3]. As one of the most important

[*]Dongsheng Qing; Shuai Liu; Jianjun Li – Corresponding author; Central South University of Forestry and Technology, No. 498 Shaoshan South Road, Changsha City, Hunan Province, China, E-mail: 390033868@qq.com, xifang99@126.com

[†]Qiaoling Deng – Corresponding author; Dongsheng Qing; Hunan Applied Technology University, Shanjuan Road, Dingcheng District, Changde City, Hunan Province, China, E-mail: 1006308937@qq.com, 673390302@qq.com

commercial materials in the southeastern United States, loblolly pine is critical to the impact of the entire southeastern timber industry in the United States [4]. A reasonable forest harvesting strategy is beneficial to the sustainable management of forests [5].

The growth of forest trees is accompanied by the growth of tree height and DBH. The diameter of the breast and the height of the trees are the most direct manifestations of whether the growth of trees is healthy. In the study of the dynamics of some forest stands, the tree height and DBH of forest trees are also essential measurement factors [6, 7]. Scientifically and effectively quantify the relationship between DBH and tree height of loblolly pine can better grasp its growth status, in order to develop a more reasonable management strategy of loblolly pine. As far as I know, in the study of the growth law of loblolly pine, some researchers have explored the growth of loblolly pine from different angles. For example, Sharma M studied the effect of density on the growth of loblolly pine [8]; Farjat A E developed a model to study the effects of climate change on height growth of loblolly pine [9]; García O. constructed a biological consistency stand growth model of loblolly pine [10]; Trincado G constructed a mixed effect model of height and diameter for loblolly pine plantation in southeastern United States [11]. In addition, relevant researchers have studied the relationship between age and the growth of loblolly pine on the scale of time. For example, Harms W R studied the same initial spacing, age, and site index of loblolly pine growth and development in the southeastern United States [12]; Zhao D studied the growth of loblolly pine in the southeastern United States for 16 consecutive years [13]. From the research progress of loblolly pine, it is still scarce to formally discuss the quantitative relationship between DBH and tree height of loblolly pine.

The particle swarm algorithm was first proposed by American electrical engineer Eberhart and social psychologist Kennedy in 1995 based on the principle of bird foraging and the algorithm has been successfully applied in various fields so far. There are also examples of the application of this algorithm in forest management. For example, Izquierdo uses particle swarm optimization to solve the problem of forest fire-fighting drone assignment [14]; Bui D T uses the GIS neuro-fuzzy inference system to establish a forest fire model and uses particle swarm optimization (PSO) to optimize the model parameters [15]; Li Jianjun solved the spatial optimization problem of water conservation forest in Dongting Lake by particle swarm optimization [16] and Zheng Peng solved the problem of forest harvesting planning by particle swarm optimization [17]. From the research results, the particle swarm optimization algorithm has certain advantages for solving the nonlinear and multi-objective problems existing in forest management. In order to fill the gap in the quantitative problem of the relationship between the DBH and the height of the pine, we selected 13 340 initial species of loblolly pine with a breast diameter between 1 inch and 7 inch from Alabama as the research object, and statistics on their growth from 2000 to 2015. Then, using the group optimization algorithm to quantify the optimal DBH range of different scales of loblolly pine. To help relevant practitioners to understand more clearly the objective laws of DBH and tree height growth during the growth of loblolly pine, and to develop a scientific and sustainable development strategy of loblolly pine.

2. Method

2.1 Research area and data sources

Alabama is a state in the southeastern United States, with Tennessee to the north, Mississippi to the west, Florida to the south, and Georgia to the east. The state has a mild climate, hot and humid, and is a subtropical and rainy climate with an average annual temperature of about 17 °C. The annual average temperature in the northern mountains is about 16 °C, the annual average temperature in the south is about 19 °C, and the highest in the hot summer is 39 °C. In addition, the northern mountains of Alabama have snow in winter, with annual precipitation of 1 300-1 500 mm and sufficient precipitation in the south to reach 1 600 mm. In general, Alabama's four seasons are more evenly distributed. It may be subject to a tornado disaster every year from March to April, and sometimes it will be damaged by hurricanes in late summer. From the 49 counties of Autauga, Baldwin, Barbour, Bibb, etc. in Alabama, 13 340 randomly selected loblolly pine with an initial breast diameter between 1 inch and 7 inch was selected as the research object, continuous observation of its growth from 2000 to 2015, with a cycle of five years, each fire pine was investigated a total of four times. The growth information of loblolly pine is shown in Tab. I.

2.2 Data rationality testing and processing

The data is almost imperfect. In fact, most data causes errors, missing or inconsistent types of attribute values in the data due to uncontrollable factors. Therefore, a comprehensive quality analysis of the data is required before data modeling. The purpose of data quality analysis is to ensure the correctness and validity of the data. In general, the normal growth of the DBH and the tree height is basically a linear relationship, and the general linear models (GLM) are usually used to investigate the relationship between stand height and DBH [18]. According to the literature [19], the linear fitting correlation coefficient R^2 of tree height and DBH during pine growth is generally (0.58, 0.65). The tree height and DBH fitting of the initial loblolly pine in the paper are shown in Fig. 1. It can be seen from Fig. 1 that R^2 does not belong to 0.58-0.65, it may be due to record deviation during sampling or imperfect data due to various accidental factors (existing outliers). However, for whatever reason, outliers will directly affect the accuracy of the fit and even get some wrong results. Therefore, in order to correctly reflect the growth law of loblolly pine and ensure the correctness and validity of the experimental data, it is necessary to correct the initial experimental data.

This paper uses a statistical method based outlier diagnosis strategy [20], as showed in Eq. (1).

$$g_0 = \frac{|x_i - \bar{x}|}{s}. \tag{1}$$

To satisfy the requirement of $P(|x_i - \bar{x}| \geq g_0 s) = \alpha$.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \qquad s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}, \tag{2}$$

Year	2000		2005		2010		2015	
number	DBH [inch]	Tree height [foot]	DBH [inch]	Tree height [foot]	DBH [inch]	Tree height [foot]	DBH [inch]	Tree height [foot]
1	6.8	45	8.0	55	10.0	72	12.1	82
2	6.0	44	7.4	57	10.3	66	14.1	84
3	5.1	33	5.8	37	7.7	47	9.7	63
4	6.3	31	7.5	39	10.1	50	13.2	66
5	6.8	45	8.7	55	9.3	66	11.6	85
6	6.6	39	7.1	47	8.3	55	9.7	72
7	5.2	34	5.6	47	6.3	54	7.5	71
8	5.4	33	6.1	43	7.8	58	10.1	74
9	6.2	32	6.9	31	7.1	34	8.03	37
10	5.6	36	7.4	46	9.0	52	11.6	70
11	3.3	36	6.5	42	7.7	59	9.0	65
12	3.5	37	7.2	44	8.8	58	11.1	74
13	4.2	41	5.1	42	6.1	52	7.07	58
14	1.2	11	6.4	38	7.9	53	9.2	64
15	1.0	11	5.8	42	7.1	56	8.0	67
16	2.3	13	5.4	33	7.3	53	9.1	62
17	1.9	13	5.2	34	6.6	55	8.1	67
				....				
13440	5.2	27	6.3	48	7.0	55	8.5	70

Tab. I *The information table of loblolly pine growth from 2000 to 2015 in study samples.*

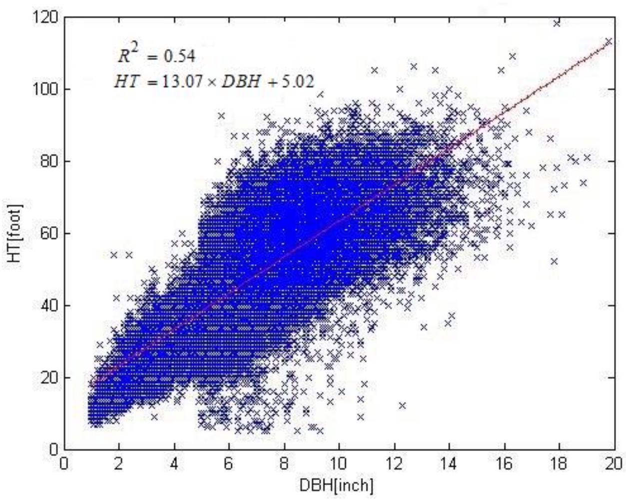

Fig. 1 *The relationship between height and DBH of loblolly pine with initial data.*

where x_i is a certain data to be tested, the value of g_0 can be found by looking up the table according to the given significance level parameter α and sample size n.

If $|x_i - \bar{x}| \geq g_0 s$, then think that x_i is an abnormal data and needs to be processed.

Due to record deviations in the survey process, these record deviations are mainly reflected in the record of the tree height. In order to ensure the integrity of the data, the outliers detected in the paper do not use the direct elimination strategy, but use the mean interpolation method to correct the data. In other words, if it is detected that the loblolly pine in the sample has an outlier at the corresponding tree height under a certain breast diameter, the average value of the tree height under the DBH is used to replace the outliers. The algorithm flow is as follows.

(1) Obtain all the tree heights (H_i) of the loblolly pine in the sample when the breast diameter is D_i, recorded as $H_i = \{H_{i1}, H_{i2}, \ldots, H_{ij}, \ldots, H_{im}\}$.

(2) Calculate the mean and standard deviation of H_i, recorded as $\bar{H}_i$ and s. According to the characteristics of the data in the text, the value of g_0 is 3.

(3) If $\left|H_{ik} - \bar{H}_i\right| \geq g_0 s$, $k = 1, 2, \ldots, m$, then think that H_{ik} is an outlier (abnormal point), Replace with $H_{ik} = \bar{H}_i + rand()$. Repeat steps (1) $\sim$ (3) until there is no abnormal data in the data.

The purpose of outlier processing is to correct the possible abnormal tree height of loblolly pine in the sample. Linear fitting between height and DBH of treated loblolly pine is shown in Fig. 2.

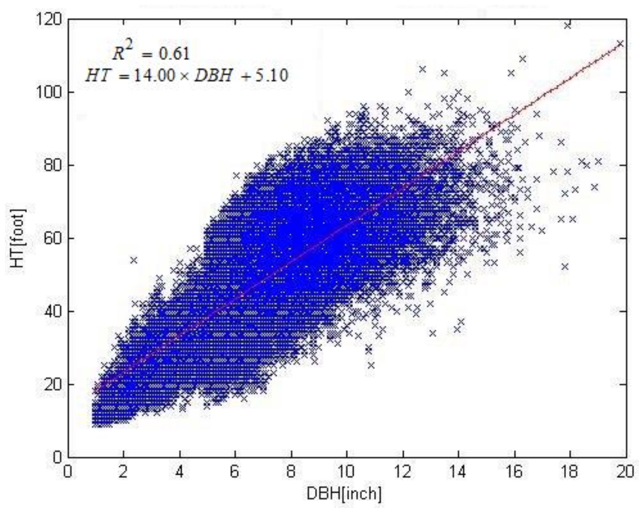

Fig. 2 *The relationship between height and DBH of torchlight pine after treatment.*

From Fig. 2, the correlation coefficient of linear fitting increased from 0.538 to 0.605, which accorded with the normal linear fitting range of height and DBH of pine trees.

2.3 Quantitative process of optimum dbh range of loblolly pine

2.3.1 Particle swarm optimization

Particle swarm optimization (PSO) was proposed by Kennedy and Eberhart in 1995. The algorithm modifies the model of the Hepper simulated bird population (fish school) so that the particles can "fly" toward the solution space and "fall" at the location of the optimal solution. Update the position of particle optimization according to Eq. (3) and Eq. (4) [21].

$$v_{id}^{k} = wv_{id}^{k-1} + c_1 r_1 \left(pbest_{id} - x_{id}^{k-1}\right) + c_2 r_2 \left(gbest_d - x_{id}^{k-1}\right), \tag{3}$$

$$x_{id}^{k} = x_{id}^{k-1} + v_{id}^{k-1}, \tag{4}$$

where v_{id}^{k} is the flight speed of particle i at the kth iteration; x_{id}^{k} is the position of particle i at the kth iteration; c_1 and c_2 are learning factors, which mainly used to adjust the maximum step size of algorithm learning; r_1 and r_2 are two random numbers; w is inertia weight; d is the dimension of the solution space; $pbest_{id}$ is the current optimal value of particle i, while $gbest_d$ is the overall historical optimal value.

2.3.2 General ideas

Forest growth includes breast diameter and tree height growth. In this paper, the range of optimal breast diameter is defined from the scale of forest growth as: At a certain scale, there is a breast diameter range DR_{k} in which the growth rate of tree height is greater than other breast diameter ranges at this scale.

$$DR_{\mathrm{k}} = \max\left(\frac{\Delta HT_{ki}}{\Delta DBH_{ki}}\right) \qquad i \in (1, 2, 3, \ldots, Z), \tag{5}$$

where ΔHT_{ki} is the average growth of tree height in a range of breast diameter; ΔDBH_{ki} is the size (scale) of a certain range of breast diameter; Z is the total number of breast diameter ranges at this scale.

In order to search for the optimal DBH range of loblolly pine, the DBH and tree height during the growth of all loblolly pine in the sample are mapped into a two-dimensional space, and it is used as the target space for particle swarm optimization. Each particle finds the optimal DBH range of loblolly pine by dynamically adjusting its upper and lower search limits. In this way, the problem of quantifying the optimal breast diameter range of loblolly pine is transformed into the optimization problem of particle swarm algorithm in the target space.

2.3.3 Algorithm execution process

(1) Fitness function and constraints According to the purpose of this paper, the setting of fitness function is shown in Eq. (6).

$$f(x) = \frac{\Delta \bar{h}_{\mathrm{X}}}{\Delta d_k} \tag{6}$$

$\Delta\bar{h}_{\mathrm{X}}$ is the average growth of tree height in a range of breast diameter; Δd_k is the size (scale) of a certain range of breast diameter. The goal of particle swarm optimization in the paper is to find the maximum value of the fitness function. All the constraints of the algorithm are set as follows.

$$\begin{cases} x_i = [x_i^f, x_i^l] \\ x_i^f, x_i^l \in [0.1 \quad 20] \\ x_i^f < x_i^l \\ \mathrm{x}_{\mathrm{particlesize}}{=}150 \\ 0 \leq v_i^k \leq 1.12 \\ 1 \leq k \leq \mathrm{maxnum} \\ t_w \geq 200 \\ r_1, r_2 \in [0 \quad 1] \\ c_1 = 2, c_2 = 1 \\ w = 0.5 \\ \mathrm{maxnum} = 60 \end{cases}, \tag{7}$$

where x_i is a particle; x_i^f is the lower limit of the range of the breast diameter during the optimization of particle x_i; x_i^l is the upper limit of the range of the breast diameter during the optimization of particle x_i; $x_{\mathrm{particlesize}}$ is the number of particles; v_i^k is the update speed of the particle x_i; t_w is the number of the pines corresponding to the particle x_i; c_1 and c_2 are learning factors, which mainly used to adjust the maximum step size of algorithm learning; r_1 and r_2 are two random numbers; w is inertia weight; maxnum is the maximum number of loops of the algorithm.

(2) Algorithm flow

Algorithm 1 The improved PSO algorithm.

Initialize the particle swarm algorithm, including the initial position $x_i^1 = [x_i^f, x_i^l]$ of the particle, the initial velocity v_i^1 of the particle, the particle population size $x_{\mathrm{particlesize}}$, the maximum number of cycles maxnum, and the DBH range *cd*, etc.

Repeat

Evaluation: If the number of torch pines corresponding to particle x_i is greater than t_w, calculate the fitness value of particle x_i according to the fitness function (Eq. 6). Otherwise, reinitialize x_i.

Find the $pbest_i$: Compare the current fitness value of each particle with its historical optimal fitness value ($f(pbest_i)$). If the current particle's fitness value is better than its historical optimal fitness value ($f(pbest_i^k) > f(pbest_i)$), if the current particle's fitness value is better than its historical optimal fitness value, replace the particle's historical best position with the particle's current position ($pbest_i = pbest_i^k$).

Find the $gbest$: Compare the current fitness value of each particle to the global best fitness value ($f(gbest)$). If the current particle's fitness value is better than the global optimal fitness value ($f(pbest_i^k) > f(gbest) \quad i = [1, 2, 3, \ldots, x_{\mathrm{particlesize}}]$), then replace the global best position with the current particle position ($gbest = pbest_i^k$).

Update the Velocity: The search speed and search position of each particle are updated according to Eq. (3) and Eq. (4).

until the stopping criterion is met

3. Result

3.1 Analysis of results

Fig. 3 is the optimal breast diameter range change situation and algorithm convergence situation of the particle swarm optimization algorithm at a scale with a diameter of 0.4 inch. In order to avoid accidental errors, 10 experiments were carried out (No. 1 ∼ No. 10). It can be seen from the graph that the number of cycles of convergence of the algorithm in each round of experiments is less than 25. The fast convergence rate shows that particle swarm optimization can solve the problem of optimum DBH of loblolly pine. The experimental results show when the DBH of loblolly pine ranged from 5.62 inch to 6.05 inch, the ratio of height growth to DBH growth was the largest, which indicated that the height of loblolly pine increased rapidly in this DBH range.

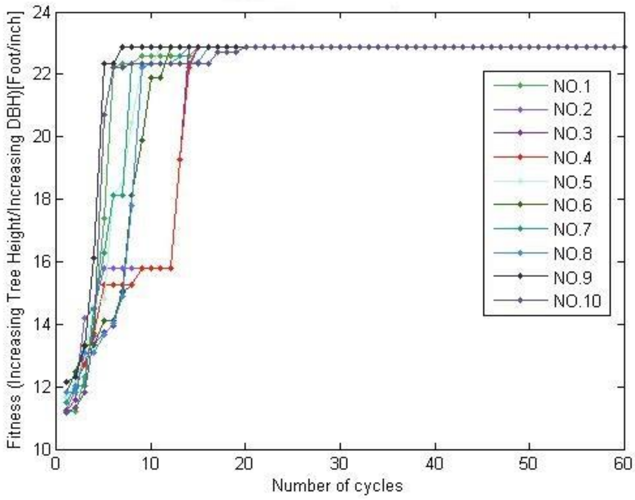

Fig. 3 *Iteration and convergence of the algorithm when the range is 0.4 (inch).*

According to this principle, we experimented the growth of loblolly pine at different DBH scales. It is found through experiments that the optimal breast diameter range of loblolly pine is concentrated between 3.9 inch and 7.1 inch. During the growth of loblolly pine, the high growth rate of the pine tree is the fastest in this DBH range. For example, when the range scale is 1 inch, the optimal breast diameter range of loblolly pine is 4.32 inch to 5.23 inch, the increase in tree height in this range is 14.95 foot; When the range scale is 2 inch, the optimal breast diameter range of loblolly pine is 3.84 inch to 6.13 inch, the increase in tree height in this range is 26.17 foot, etc. The optimum DBH range of loblolly pine at various scales is shown in Tab. II.

Optimal breast diameter range [inch]	Tree height increase [foot]	Scale [inch]
5.62 ∼ 6.05	9.12	0.4
6.23 ∼ 6.83	11.59	0.6
4.52 ∼ 5.32	13.87	0.8
4.32 ∼ 5.23	14.95	1.0
3.26 ∼ 4.46	18.97	1.2
3.27 ∼ 4.67	21.05	1.4
3.01 ∼ 4.61	22.41	1.6
4.01 ∼ 5.81	24.23	1.8
3.84 ∼ 5.84	26.17	2.0
3.60 ∼ 5.80	27.89	2.2
3.40 ∼ 5.80	29.74	2.4
3.22 ∼ 5.82	31.64	2.6
3.00 ∼ 5.80	33.43	2.8
2.80 ∼ 5.80	35.02	3.0
2.90 ∼ 6.10	36.67	3.2
2.74 ∼ 6.14	38.32	3.4
2.51 ∼ 6.11	39.90	3.6
2.32 ∼ 6.12	41.48	3.8
2.41 ∼ 6.41	43.07	4.0
2.20 ∼ 6.40	44.73	4.2
2.03 ∼ 6.43	46.27	4.4
1.91 ∼ 6.51	47.96	4.6
1.75 ∼ 6.55	49.53	4.8
1.53 ∼ 6.53	51.18	5.0
1.40 ∼ 7.00	55.83	5.6

Tab. II *The optimal breast diameter range of loblolly pine under different scales.*

3.2 Verification of results

In order to verify the correctness of the algorithm results, 20 pieces of loblolly pine were randomly selected from the samples, and analyze the relationship between tree height and DBH. Repeated 4 experiments using this method, As shown in Fig. 4 to 15. Fig. 4, Fig. 6, Fig. 8, and Fig. 10 are the growth status of 20 loblolly pine. Fig. 5, Fig. 7, Fig. 9 and Fig. 11 are fitting curves of DBH and tree height of loblolly pine in random samples. Fig. 12 to Fig. 15 show the growth rate of tree height of loblolly pine. Tab. III shows the average growth rate of loblolly pine tree height (foot) in four experiments.

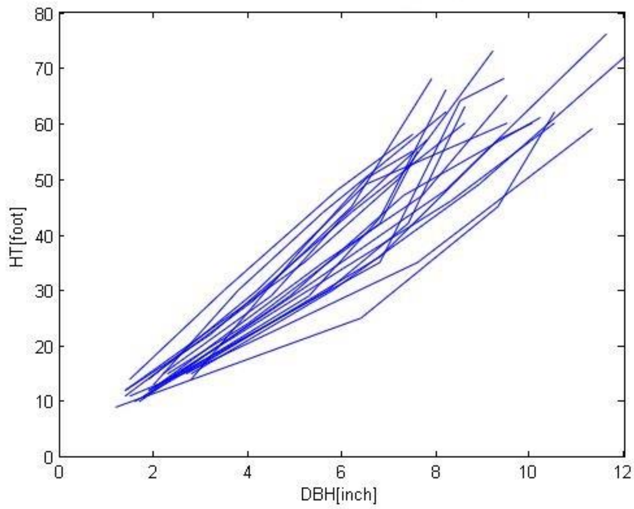

Fig. 4 *The first group of loblolly pine growth status.*

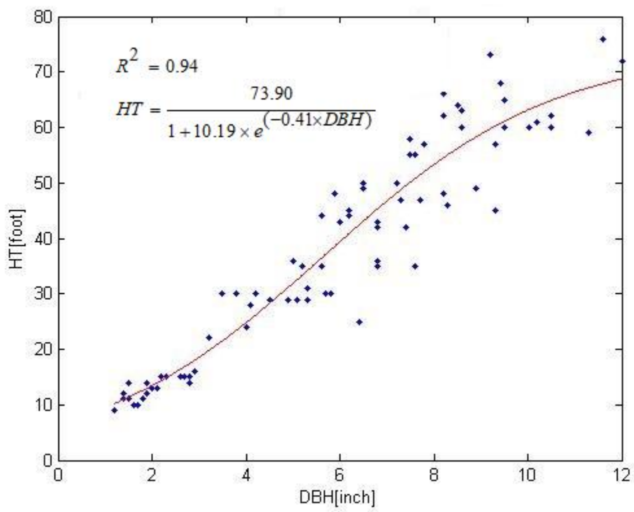

Fig. 5 *Fitting curves of height and DBH of the first group of loblolly pines.*

Tab. III shows that the average growth rate of the pine tree height is the fastest when the breast diameter is 6 inch, the average growth rate of tree height is 7.34 foot. Secondly, when the diameter of the torch is 5 inch, the average growth rate of the tree height is 7.16 foot under this DBH. Generally speaking, the DBH of loblolly pine is between 4 inch and 7 inch. In addition, Tab. III also shows that when the DBH of loblolly pine is greater than 12 inch, its growth rate slows down and its tree height tends to be stable. In summary, the optimal DBH range of loblolly pine in random sampling is basically consistent with the optimal DBH range explored

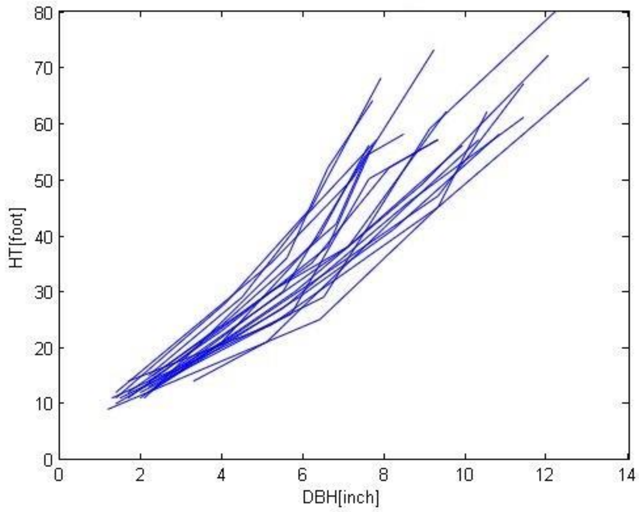

Fig. 6 *The second group of loblolly pine growth status.*

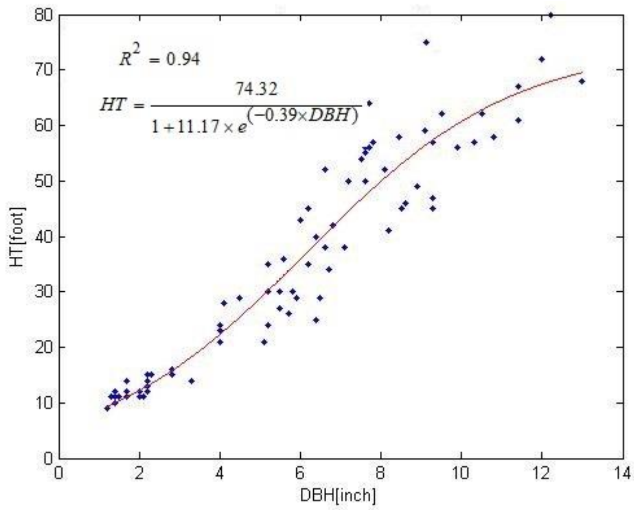

Fig. 7 *Fitting curves of height and DBH of the second group of loblolly pines.*

by the particle swarm algorithm, indicating the reliability of the algorithm and the optimal DBH range during the growth of loblolly pine.

4. Discussion

Now a lot of countries begin to pay attention to the management of artificial and natural forests. Researchers believe that appropriate artificial intervention can promote the sustainable development of forests. However, it is a pity that most

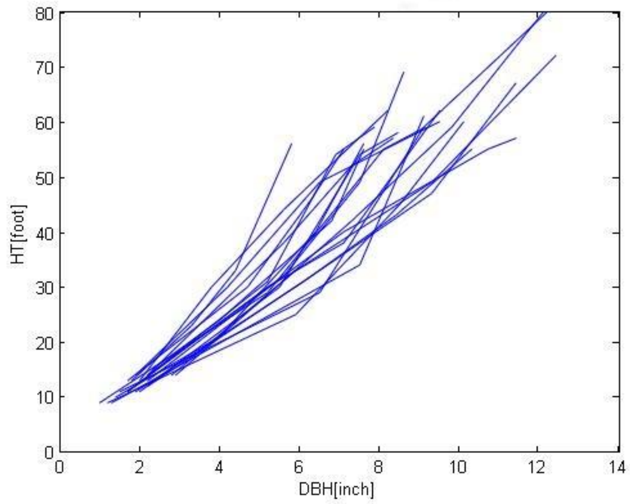

Fig. 8 *The third group of loblolly pine growth status.*

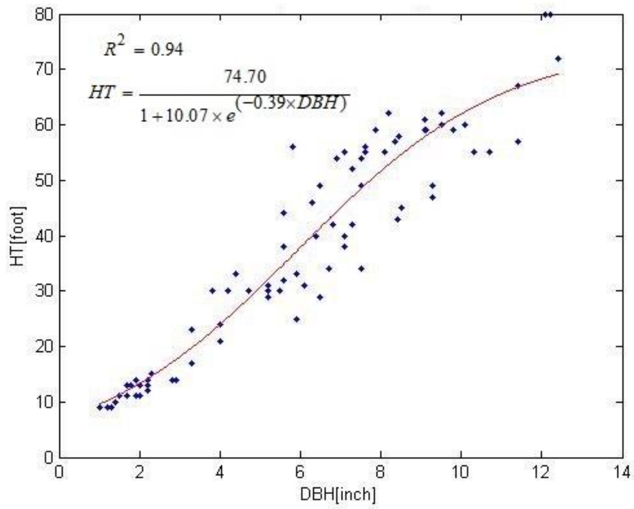

Fig. 9 *Fitting curves of height and DBH of the third group of loblolly pines.*

forest operators still rely on their own accumulated experience in dealing with this problem due to the lack of scientific and reliable management basis. Compared with other fields, the automation of forest shows low-level automation. It is hoped that more science and technology (such as AI technology) can be applied to forest management.

Loblolly pine is suitable for growing in humid climates, which is grown in southern New Jersey, Florida, and western Texas, et in the United State. In general, the growth status and wood yield of loblolly pine are better than other broad-leaved forests [22]. In natural forests, the maximum breast diameter of loblolly

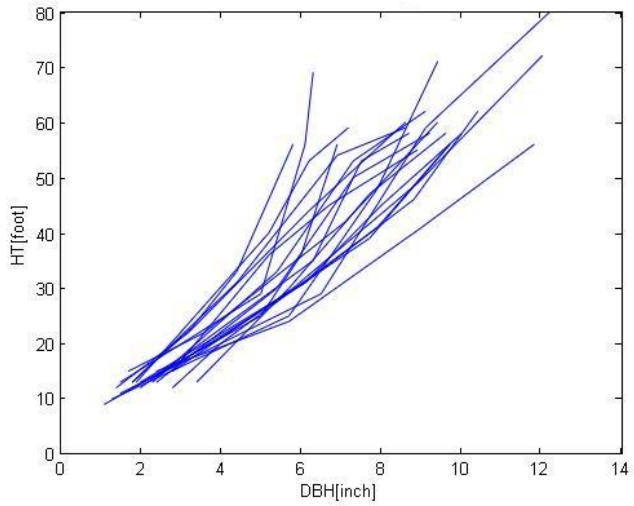

Fig. 10 *The fourth group of loblolly pine growth status.*

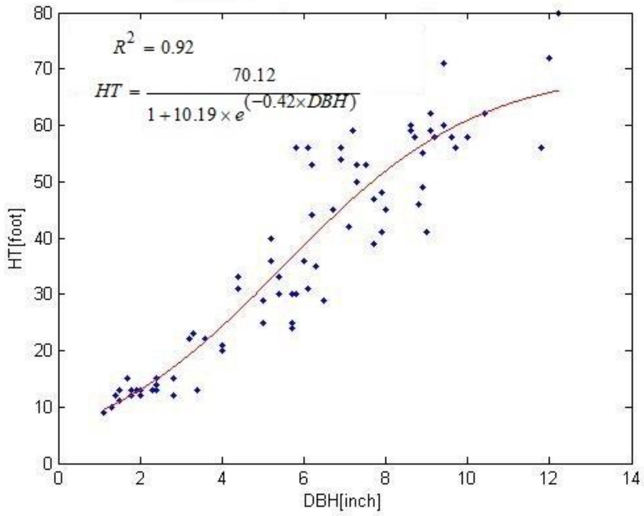

Fig. 11 *Fitting curves of height and DBH of the fourth group of loblolly pines.*

pine during growth is generally less than 20 inch, and the highest tree height is generally not more than 120 foot. Most of the loblolly pine has a breast diameter between 4.5 inch and 11 inch and a tree height between 25 foot and 72 foot. In order to fully understand the objective law of height and DBH growth of loblolly pine trees and exploring the best DBH range for loblolly pine tree height growth, the particle swarm optimization algorithm is used to quantify the optimal DBH range of loblolly pine in Alabama at different scales, The experimental results show that the range of the breast diameter suitable for the high growth of the pine tree

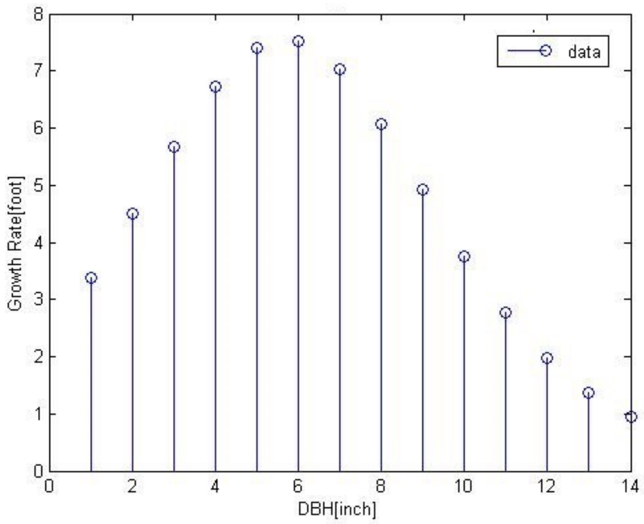

Fig. 12 *The average growth rate of the height of the first group of loblolly pines.*

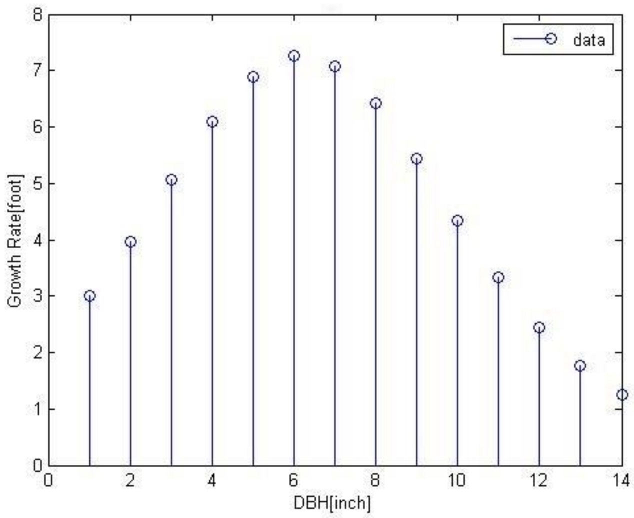

Fig. 13 *The average growth rate of the height of the second group of loblolly pines.*

is concentrated between 3.7 inch and 7.3 inch. The height of the pine tree begins to enter a period of rapid growth from a breast diameter of 3.9 inch (±0.2 inch). The tree height growth rate reached a maximum at a breast diameter of 6.4 inch (±0.6 inch), and the tree height entered a slow growth period after the breast diameter of 11.92 inch (±0.3 inch). In general, when the breast diameter exceeds 15.26 inch (±0.3 inch), the height of the pine tree stops growing. However it is not known whether the optimal DBH range of loblolly pine in other regions (such as Florida, Texas, Jilin, etc.) is consistent with it, further discussion and verification

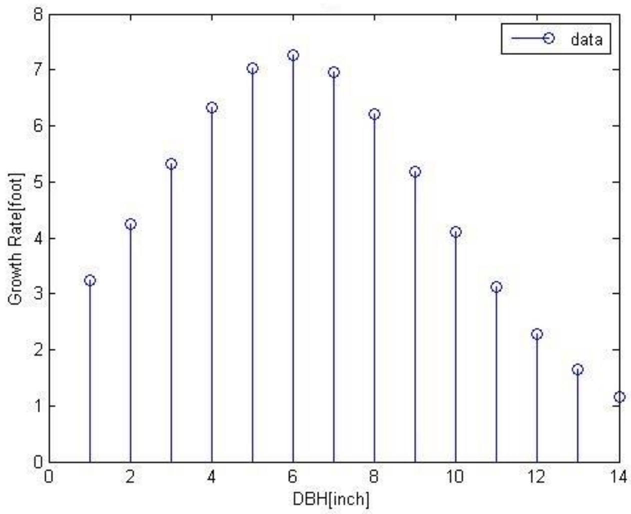

Fig. 14 *The average growth rate of the height of the third group of loblolly pines.*

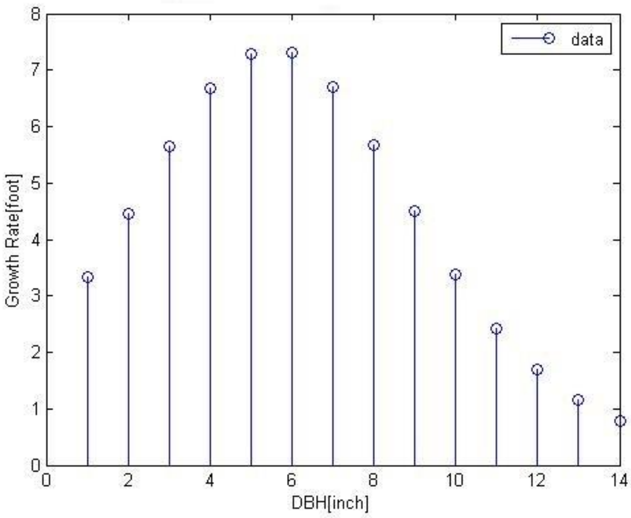

Fig. 15 *The average growth rate of the height of the fourth group of loblolly pines.*

is required. This manuscript is an attempt to combine intelligent algorithm with forest management. its results can solve the problem of quantifying the optimal DBH of Loblolly pine, provide forest managers with a more scientific reference range of DBH, and find the best time for tree cultivation and felling. On the other hand, this method can provide reference for the management of other tree species.

In addition, in order to make the research results reliable,In this paper, the initial data is processed by using the statistical-based outlier diagnosis method, and the data is corrected by the mean interpolation method. In fact, outlier diag-

Breast diameter [inch]	High average growth rate of pine trees in 4 experiments [foot]
1	3.24
2	4.29
3	5.43
4	6.46
5	7.16
6	7.34
7	6.94
8	6.09
9	5.01
10	3.90
11	2.91
12	2.10
13	1.49
14	1.03

Tab. III *The average growth rate of loblolly pine height (foot) in four groups of experiments.*

nosis methods include distance-based outlier diagnosis [23], density-based outlier diagnosis [24], cluster-based outlier diagnosis [25] and neural network based outlier diagnosis [26] and so on. Different diagnostic methods have their own scope of application. Besides the mean interpolation method, the method of correction of outlier data includes deletion method, regression interpolation method, median interpolation method, and maximum likelihood estimation method.

Particle swarm optimization greatly improves the efficiency of problem solving [27]. Experiments show that the algorithm converges faster (as shown in Fig. 3). Compared to traditional methods, intelligent algorithms do have an advantage when solving nonlinear problems. But the intelligent algorithm is not perfect, and it is easy to fall into the local optimum is one of the main problems of the intelligent algorithm, especially when the experimenter sets unreasonable parameters, the intelligent algorithm may fall into local optimum [28–31]. In this paper, when $w = 0.5, c1 = 2$, and $c2 = 1$, the probability of the algorithm falling into local optimum is 3.36 %. In general, the setting of each parameter in the particle swarm algorithm needs to be determined according to the actual situation of the problem. For most problems, when $w = [0.25, 1.75], c1 = c2 = [0.75, 3]$, the effect will be better. Related research shows that the global search ability and local search ability of particle swarm optimization algorithm are not determined by a certain parameter, but rely on the cooperation of $w, c1$ and $c2$ [32]. In addition, we also found that the initial particle position of the particle swarm algorithm also has an impact on the convergence of the algorithm. In the particle swarm optimization process, if the initial particle position is relatively "uniform", the probability of the algorithm falling into local optimum is small, and the algorithm converges faster.

Acknowledgement

Professor Li Jianjun's project (National Natural Science Foundation of China: 31570627) and Professor Dr. Liu Shuai's project (Hunan Science and Technology Project: 2015wk3017) provide support for this study. Thanks The Forest Inventory and Analysis Database in USA.

References

[1] SWAMY L., DRAZEN E., JOHNSON W.R., BUKOSKI J.J. The future of tropical forests under the United Nations Sustainable Development Goals[J]. Journal of sustainable forestry, 2018, 37(2), pp. 221–256, doi: 10.1080/10549811.2017.1416477.

[2] TORRES-ROJO J.M., MORENO-SÁNCHEZ R., MENDOZA-BRISEÑo M.A. Sustainable forest management in Mexico[J]. Current Forestry Reports, 2016, 2(2), pp. 93–105, doi: 10.1007/s40725-016-0033-0.

[3] USDA FOREST SERVICE. 2008. Forest Inventory and Analysis national program. Available online at www.?a.fs.fed.us/program-features/ rpa/; last accessed Nov. 23, 2010.

[4] DICUS C.A., DEAN T.J., Tree-soil interactions affect production of loblolly and slash pine. For. Sci., 54 2), 2008, pp. 134–139. doi: 10.1093/forestscience/54.2.134.

[5] BRANDT J.S., NOLTE C., AGRAWAL A. Deforestation and timber production in Congo after implementation of sustainable forest management policy[J]. Land Use Policy, 2016, 52, pp. 15–22, doi: 10.1016/j.landusepol.2015.11.028.

[6] MOLTO Q., HÉRAULT B., BOREUX J.J., DAULLET M., ROUSTEAU A., ROSSIP V. Predicting tree heights for biomass estimates in tropical forests-a test from French Guiana[J].Biogeosciences, 2014, 11(12), pp. 3121–3130, doi: 10.5194/bg-11-3121-2014.

[7] LEI X., YU L., HONG L. Climate-sensitive integrated stand growth model (CS-ISGM) of Changbai larch (Larix olgensis) plantations[J].Forest Ecology& Management, 2016, 376, pp. 265–275, doi: 10.1016/j.foreco.2016.06.024.

[8] SHARMA M., BURKHART H.E., AMATEIS R.L. Modeling the effect of density on the growth of loblolly pine trees[J]. Southern Journal of Applied Forestry, 2002, 26(3), pp. 124–133, doi: 10.1093/sjaf/26.3.124.

[9] FARJAT A.E., ISIK F., REICH B.J., WHETTEN R.W., MCKEAND S.E. Modeling climate change effects on the height growth of loblolly pine[J]. Forest Science, 2015, 61(4), pp. 703–715, doi: 10.5849/forsci.14-075.

[10] GARCÍA O., BURKHART H.E., AMATEIS R.L. A biologically-consistent stand growth model for loblolly pine in the Piedmont physiographic region, USA[J]. Forest Ecology and Management, 2011, 262(11), pp. 2035–2041, doi: 10.1016/j.foreco.2011.08.047.

[11] TRINCADO G., VANDERSCHAAF C.L., BURKHART H.E. Regional mixed-effects height–diameter models for loblolly pine (Pinus taeda L.) plantations[J]. European Journal of Forest Research, 2007, 126(2), pp. 253–262, doi: 10.1007/s10342-006-0141-7.

[12] HARMS W.R., WHITESELL C.D., DEBELL D.S. Growth and development of loblolly pine in a spacing trial planted in Hawaii[J]. Forest Ecology and Management, 2000, 126(1), pp. 13–24, doi: 10.1016/S0378-1127(99)00079-1.

[13] ZHAO D., KANE M. Differences in growth dynamics of loblolly and slash pine plantations in the southeastern United States[J]. Forest ecology and management, 2012, 281, pp. 84–92, doi: 10.1016/j.foreco.2012.06.027.

[14] IZQUIERDO J., MINCIARDI R., MONTALVO I., WHETTEN R.W., MCKEAND S.E. Particle Swarm Optimization for the biomass supply chain strategic planning[J], 2008.

[15] BUI D.T., BUI Q.T., NGUYEN Q.P., PRADHAN B., NAMPAK H., TRINH P.T. A hybrid artificial intelligence approach using GIS-based neural-fuzzy inference system and particle swarm optimization for forest fire susceptibility modeling at a tropical area[J]. Agricultural and forest meteorology, 2017, 233, pp. 32–44, doi: 10.1016/j.agrformet.2016.11.002.

[16] LI J., ZHANG H., LIU S., KUANG Z., WANG C., ZANG H., CAO X. Spatial optimization model of water conservation forest in Dongting Lake based on improved PSO[J].Acta Ecologica Sinica, 2013, 33(13), pp. 4031–4040, doi: 10.5846/stxb201207281072.

[17] ZHENG P. Research on application of harvesting planning based on improved particle swarm optimization algorithm [D]. Fujian Agriculture and Forestry University, 2008, doi: 0.7666/d.y1323065.

[18] LIU C., FANG W ., CAI QX., MA S., FANG J. Allometric Relationship between Tree Height and Diameter of Larch Forests in China[J]. Acta Scientiarum Naturalium Universitatis Pekinensis, 2017, 53(6), pp. 1081–1088, doi: 10.13209/j.0479-8023.2017.127.

[19] SHANYAO L.I. Analysis of Height-Diameter Relationship and Diameter Distribution of Pinus sylvestris var. mongolica Nature Forest[J]. Forestry Science & Technology, 2018, pp. 10–13, doi: 10.3969/j.issn.1001-9499.2018.02.004.

[20] ZHOU Y., ZHUO J. Big Data Mining–System Methods and Case Analysis [M]. Place of Publication: Mechanical Industry Press, 2016, pp. 240–241.

[21] KENNEDY J., EBERHART R. Particle swarm optimization (PSO)[C]//Proc. IEEE International Conference on Neural Networks, Perth, Australia. 1995, pp. 1942–1948, doi: 10.2514/2.2111.

[22] WAHLENBERG W.G. Longleaf pine: Its use, ecology, regeneration, protection, growth, and management[J]. Longleaf Pine: its use, ecology, regeneration, protection, growth, and management., 1946, 104, pp. 515–516, doi: 10.1126/science.104.2709.515.

[23] ANGIULLI F., BASTA S., PIZZUTI C. Distance-based detection and prediction of outliers[J]. IEEE transactions on knowledge and data engineering, 2005, 18(2), pp. 145–160, doi: 10.1109/TKDE.2006.29.

[24] LIN C.H., HSU K.C., JOHNSON K.R., LUBY M., FANN Y.C. Applying density-based outlier identifications using multiple datasets for validation of stroke clinical outcomes[J]. International journal of medical informatics, 2019, 132, pp. 103988, doi: 10.1016/j.ijmedinf.2019.103988.

[25] PAMULA R., DEKA J.K., NANDI S. An outlier detection method based on clustering[C]//2011 Second International Conference on Emerging Applications of Information Technology. IEEE, 2011, pp. 253–256, doi: 10.1109/EAIT.2011.25.

[26] HAWKINS S., HE H., WILLIAMS G., BAXTER R. Outlier detection using replicator neural networks[C]//International Conference on Data Warehousing and Knowledge Discovery. Springer, Berlin, Heidelberg, 2002, pp. 170–180, doi: 10.1007/3-540-46145-0_17.

[27] TANG D., DAI M., SALIDO M.A., GIRET A. Energy-efficient dynamic scheduling for a flexible flow shop using an improved particle swarm optimization[J]. Computers in Industry, 2016, 81, pp. 82–95, doi: 10.1016/j.compind.2015.10.001.

[28] KARABOGA D., AKAY B. A comparative study of artificial bee colony algorithm[J]. Applied mathematics and computation, 2009, 214(1), pp. 108–132, doi: 10.1016/j.amc.2009.03.090.

[29] REED M., YIANNAKOU A., EVERING R. An ant colony algorithm for the multi-compartment vehicle routing problem[J]. Applied Soft Computing, 2014, 15, pp. 169–176, doi: 10.1016/j.asoc.2013.10.017.

[30] MORADI M.H., ABEDINI M. A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems[J]. International Journal of Electrical Power & Energy Systems, 2012, 34(1), pp. 66–74, doi: 10.1109/IPECON.2010.5697086.

[31] DAI M., TANG D., GIRET A., SALID, M.A., LI W.D. Energy-efficient scheduling for a flexible flow shop using an improved genetic-simulated annealing algorithm[J]. Robotics and Computer-Integrated Manufacturing, 2013, 29(5), pp. 418–429, doi: 10.1016/j.rcim.2013.04.001.

[32] WANG D.F., MENG L. Performance Analysis and Parameter Selection of PSO Algorithms [J]. Acta Automatica Sinica, 2016, 42(10), pp. 1552–1561, doi: 10.16383/j.aas.2016.c150774